TOPS

Targeted Overlay Pavement Solutions

Open-Graded Friction Course

How-To Document

November 2022

U.S. Department of Transportation
Federal Highway Administration

Every Day Counts
Innovation for a Nation on the Move

NOTICE

NON-BINDING CONTENTS

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This document highlights Targeted Overlay Pavement Solutions (TOPS), an FHWA Every Day Counts initiative. TOPS integrates innovative overlay procedures into practices to improve performance, lessen traffic impacts, and reduce the cost of pavement ownership.
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16. Abstract
Open-graded friction courses (OGFC) can offer many benefits, such as reducing hydroplaning, surface reflectivity, and splash and spray, and improving wet pavement friction. These benefits can improve safety during wet-weather road conditions. This document describes practices used by Florida, South Carolina, and Georgia DOTs to improve OGFC durability and results from national research projects.

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LIST OF ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
DOT	Department of Transportation
FDOT	Florida Department of Transportation
FM	Florida test method
GDOT	Georgia Department of Transportation
GTR	Ground tire rubber
IC	Intelligent compaction
MPH	Miles per hour
NCHRP	National Cooperative Highway Research Program
NMAS	Nominal maximum aggregate size
OGFC	Open-graded friction course
PFC	Permeable or porous friction course
PMTP	Paver-mounted thermal profiling
SCDOT	South Carolina Department of Transportation
SMA	Stone matrix asphalt
TSR	Tensile strength ratio
WMA	Warm mix additive

INTRODUCTION

According to the National Center for Asphalt Technology (NCAT), open-graded friction courses (OGFC) offer many benefits, such as reducing hydroplaning, splash and spray, improving wet pavement friction, and reducing surface reflectivity. These benefits can improve driving safety during wet-weather conditions (Zie et al. 2019).

National Cooperative Highway Research Program (NCHRP) Research Report 887, Performance-Based Mix Design of Porous Friction Courses, states that OGFC can provide additional environmental benefits by reducing the pollutant load of stormwater runoff and traffic noise (Watson et al. 2018). According to the report, despite the safety and environmental benefits, the use of OGFC has diminished over the years due to durability and service life issues. Raveling is the main durability problem reported, and it can progress rapidly once it begins.

Many State departments of transportation (DOTs) have researched ways to improve the durability problems associated with OGFC. This how-to document combines information from Florida, South Carolina, and Georgia DOTs and national research projects.

Description and Terminology

OGFC is an open-graded asphalt mixture with a high percentage of coarse aggregates, almost uniform in size, resulting in a high percentage of air voids, usually 15 to 25 percent. The following terms may be synonyms for OGFC (FHWA 2022):

- Permeable European mix
- Porous asphalt
- Plant mix seal
- Popcorn mix
- Open-graded surface course
- Permeable friction course
- Porous friction course

State DOT specifications and definitions vary. For example, the Georgia Department of Transportation (GDOT) uses both OGFC and permeable European mix, and each product has unique properties and specifications (Hines 2021). For simplicity, this document will collectively refer to all of these mixtures as OGFC, regardless of the terminology used by State DOTs.

Benefits

OGFC mixtures are used only as a surface lift or as part of an entire porous pavement system. The main benefits of OGFC are improved safety by increasing the frictional properties of the pavement surface and allowing surface water to drain through the pavement. Removing water from the roadway surface improves contact between the tires and the pavement surface, thus reducing the potential for hydroplaning, crashes, and traffic fatalities during wet weather (Watson et al. 2018). Other safety improvements include the reduction of “splash and spray” and glare. Photos from NCHRP Research Report 877 (Figures 1 and 2) illustrate OGFC benefits compared to dense-graded mixtures.

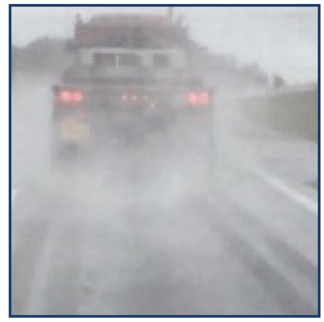

Figure 1. Backsplash and decreased visibility on a typical dense-graded mixture. (Source: Watson et al. 2018)

OGFC also can reduce pavement noise. While some highway noise comes from the vehicles themselves, a large part comes from the tire-pavement interaction, especially at speeds above 45 miles per hour (mph). Metropolitan areas often need noise reduction due to the proximity of businesses and homes to the highway. OGFC can reduce sound by three decibels dB(A) (Watson et al. 2018).

According to a state-of-practice article on porous friction course (PFC) in the United States, many State DOTs report initial noise reduction with new OGFC pavements and diminishing benefits as the pavement ages. Clogging and raveling of OGFC pavements reduce the permeability and noise reduction capabilities of OGFC, and the article reports that noise reduction benefits may only last 5 to 7 years. (Hernandez-Saenz et al. 2016). Research shows that OGFCs are initially quieter but can become louder than dense-graded mixtures due to raveling (West 2020).

Figure 2. Reduction of backsplash on an OGFC. (Source: Watson et al. 2018)

NCHRP Research Report 877 states that mixture properties, such as nominal maximum aggregate size (NMAS) and total air voids, also play a role in noise reduction. Smaller NMAS mixtures show reduced noise levels, even when clogged, while lower air voids correlate to increased noise levels.

PROJECT DESIGN AND PLANNING

Project Selection Criteria

OGFC mixtures typically use high-quality coarse aggregates and may have higher asphalt contents than dense-graded mixtures, making the mixtures more expensive. Therefore, State DOTs typically have criteria for when to use OGFC. According to GDOT, FDOT, and SCDOT specifications, OGFC is used as a surface course on most asphalt interstates, regardless of traffic volumes. For non-interstate roadways, selection criteria typically include traffic, speed, and wet-weather crash history. A summary of GDOT, FDOT, and SCDOT project selection criteria is shown in Table 1.

Table 1. OGFC asphalt surface course criteria.

Agency	Mixture Name	Remarks	Speed (mph)	Traffic (two-way ADT[1])
GDOT	12.5 mm OGFC	• All interstate routes. • For high ADT State routes with speed limits greater than or equal to 55 mph only when recommended by the Office of Materials and Testing.	≥ 55	> 25,000
FDOT	FC-5[2]	• Multilane flush shoulder roadways that meet the speed criteria. • Multilane curbed roadways with a history of wet weather crashes that meet speed criteria.	> 50	N/A
SCDOT	OGFC	• Most interstate routes – dependent on safety data and safety office decision-making.	N/A	N/A

FDOT does not use OGFC mixtures in the following conditions:

- Median crossovers.
- Turnouts.
- Gore areas of multi-lane, high-speed facilities.
- Flexible pavements within proposed toll facilities with electronic data collection that have saw cuts and loop installation in the pavement surface.

Existing Pavement Condition

The existing pavement should be in good or new condition before applying OGFC. Some State DOTs, such as FDOT, allow OGFC placement directly on a milled surface if the pavement is in good condition with no structural deficiencies (FDOT 2022). However, FDOT and GDOT report that an intermediate lift is usually placed just before the OGFC surface (Moseley 2021; Hines 2021).

Intermediate lifts are generally constructed from commonly used mixtures. For example, GDOT typically uses a 12.5 mm stone matrix asphalt (SMA) directly beneath the OGFC surface on interstates. On State routes, 12.5 mm polymer-modified Superpave™ dense-graded mixtures can be used, but most projects use SMA mixtures (Hines 2021).

Thickness Criteria

OGFC is typically applied in a thin lift. The thicknesses or spread rates for GDOT, SCDOT, and FDOT 12.5 mm OGFC mixtures are shown in Table 2. GDOT and SCDOT also have specifications for a 9.5 mm OGFC mixture (GDOT 2019, SCDOT 2019). However, DOT representatives mentioned during interviews that 9.5 mm OGFC mixtures are rarely used (Hines 2021; Selkinghaus 2021). The 9.5 mm mixture was recently added to SCDOT specifications (Selkinghaus 2021). According to Tran et al. 2021, 9.5 mm, mixtures may be more durable than

[1] Average daily traffic

[2] Friction course-5

12.5 mm mixtures while maintaining good permeability. Four State DOTs currently specify a 9.5 mm NMAS mixture, and one DOT uses a 4.75 mm NMAS mixture (West 2020).

GDOT also has a 12.5 mm permeable European mix specification, which is slightly coarser than the 12.5 mm OGFC and has higher air voids. Over the years, GDOT maintenance personnel noticed permeable European mixtures only lasted 6 to 8 years before raveling, underperforming OGFC mixtures. Since 2018, GDOT has primarily used a 12.5 mm OGFC mixture (Hines 2021).

Table 2. Specified spread rate or thickness for 12.5 mm OGFC.

Agency	Specified Spread Rate or Thickness	Tolerances
GDOT	100 lb/yd2 (approximately 1 inch)	±7 lb/yd2
FDOT	3/4 inches	±5% of the target spread rate
SCDOT	125 lb/yd2 (approximately 1.25 inches)	Not specified

OGFC lifts are not typically considered structural pavement layers. According to the 2022 FDOT *Flexible Pavement Manual*, OGFC (FC-5) has no structural value.

MIXTURES AND MATERIALS

Some State DOTs modify OGFC mixtures to improve durability and service life. This section highlights OGFC practices used by GDOT, FDOT, and SCDOT. All three of these State DOTs specify high-quality aggregates and asphalt binders.

Aggregates

Aggregate gradations should be balanced for functionality (e.g., friction and permeability) and durability. Research by Watson et al. (2018) suggests aggregate gradation be based on the following:

- For permeability and rutting resistance, design a coarse gradation within agency ranges.
- For noise reduction, design a fine gradation within agency ranges.
- For durability, design with higher binder content and higher fines content.

GDOT and FDOT recently updated OGFC design gradation bands based on NCHRP research (Hines 2021; Moseley 2021). According to the report, increasing the fines content or the percent passing the number 200 (75 µm) mesh (P-200) showed a marked improvement in OGFC mixture design durability and cohesiveness. The increased dust creates a mastic and provides a more durable mixture, based on laboratory Cantabro test results. The report suggests OGFC specifications should allow 2 to 6 percent P-200. According to the report, this is helpful where raveling is the primary form of distress, so long as the desired drainage can be attained. GDOT and FDOT recently updated specifications to allow more P-200.

Many SCDOT contractors do not have separate mineral filler silos to introduce extra fines into the mixture and increase the P-200. Therefore, instead of increasing the P-200 in the mixture, SCDOT modified its gradations to allow more aggregates to pass the number 4 (4.76 mm) and the number 8 (2.38 mm) sieves (Selkinghaus 2021). This change allows for the addition of common quarry screenings, which are generally readily available to contractors (Selkinghaus 2021). According to research, the quarry screenings could positively affect mixture durability while maintaining adequate permeability for drainage (Putnam et al. 2021). The current design gradation limits for all three State DOTs and the recommended gradation band from the draft AASHTO specification[3] are illustrated in Figure 3 and summarized in Table 3.

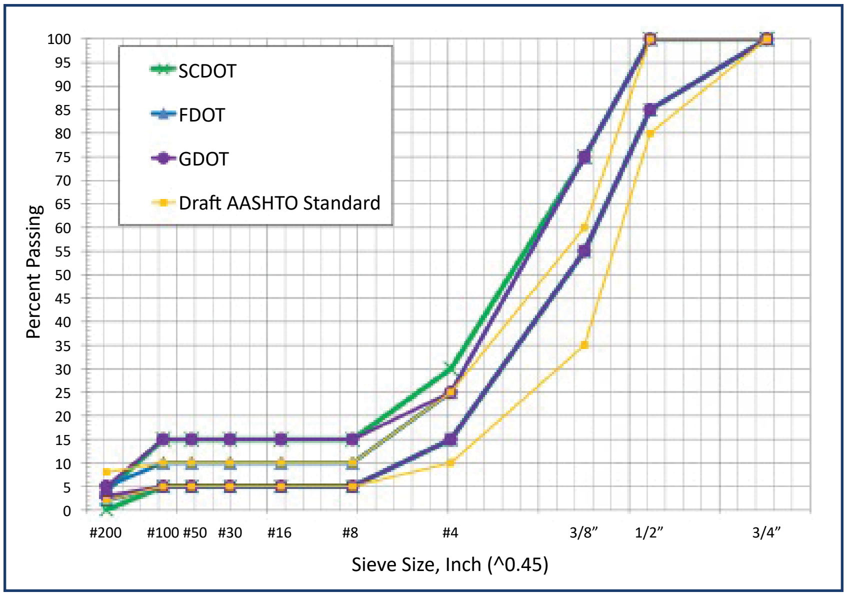

Figure 3. Illustration of 12.5 mm OGFC design gradation, percent passing. (Source: Watson et al. 2018)

Table 3. 12.5 mm OGFC mixture design gradation broadbands (percent passing).

Sieve Size Std. (Metric)	GDOT Broadband Specification	FDOT Broadband Specification	SCDOT Broadband Specification	Draft AASHTO Broadband Specification[4]
¾" (19.0 mm)	100.0	100	100.0	100
½" (12.5 mm)	85-100	85-100	85.0-100.0	80-100
3/8" (9.5 mm)	55-75	55-75	55.0-75.0	35-60
#4 (4.75 mm)	15-25	15-25	15.0-30.0	10-25
#8 (2.36 mm)	5-15	5-10	5.0-15.0	5-10
#16 (1.18 mm)	-	-	-	-
#30 (0.600 mm)	-	-	-	-
#50 (0.300 mm)	-	-	-	-
#100 (0.150 mm)	-	-	-	-
#200 (0.075 mm)	3-5	2-5	0.00-4.00	2-8

GDOT specifies a "Class A" stone for OGFC mixtures. Aggregates are classified as Class A if they meet AASHTO T 96 Los Angeles abrasion percent wear specifications in Table 4.

3 Use of this draft or specification is not a Federal requirement.

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Table 4. AASHTO T 96 percent wear specifications for Class A aggregate used in GDOT OGFC.

Aggregate Group	Class A Requirement (percent wear)	Notes
Group I	0 to 40	Group I is described as limestone, dolomite, marble, or any combination thereof.
Group II	0 to 50	Group II is described as slag, gravel, granitic and gneissic rocks, quartzite, synthetic aggregate, or any combination thereof.

GDOT's additional requirements for OGFC aggregates are the State's standard tests required for bituminous surface treatments.

FDOT OGFC aggregate requirements are similar to other asphalt mixtures but have additional requirements to prohibit aggregate blending. According to FDOT's 2022 Standard Specification Section 337, OGFC mixtures should be 100 percent crushed granite, granitic gneiss, or 100 percent crushed limestone or shell. Blending granite or granitic gneiss-classified rock with limestone or shell-classified rock is prohibited by FDOT for OGFC. According to FDOT, aggregates must be from sources approved for friction courses.

SCDOT 2021 standard specifications for aggregate in OGFC mixtures are summarized in Table 5.

Table 5. SCDOT OGFC aggregate specifications.

Aggregate Test	Requirement (percent)	Notes
LA Abrasion Loss AASHTO T 96	0 to 52	Using C grading.
Micro-Deval Abrasion Loss AASHTO T 327	15	Only required when LA abrasion loss is 42 to 52 percent.
Sulfate Soundness Loss AASHTO T 104	15	Five alterations.
Fracture Count AASHTO T 61	90	Two or more mechanically fractured faces.

While not a Federal requirement, transportation agencies might find it helpful to refer to AASHTO R 113-22 *Standard Practice for Materials Selection and Mixture Design of Porous Friction Courses* for recommended coarse and fine aggregate properties. These are summarized in Tables 6 and 7.

Table 6. AASHTO R 113-22 coarse aggregate quality specifications.

Aggregate Test	Specification Minimum (percent)	Specification Maximum (percent)
LA Abrasion Loss AASHTO T 96	-	30
Flat or Elongated (5 to 1) ASTM D 4791	-	10
Sulfate Soundness Loss AASHTO T 104	-	10 (Sodium sulfate), 15 (Magnesium sulfate)
Uncompacted Voids AASHTO T 326 Method A	45	-

Table 7. AASHTO R 113-22 fine aggregate quality specifications.[5]

Aggregate Test	Specification Minimum	Specification Maximum
Sulfate Soundness Loss AASHTO T 104	-	10 (Sodium sulfate), 15 (Magnesium sulfate)
Uncompacted Voids AASHTO T 326 Method A	45	-
Sand Equivalency AASHTO T 176	50	-

Asphalt Binders

Modified asphalt binders in OGFC mixtures are standard practice for most State DOTs. Ground tire rubber, styrene-butadiene, styrene-butadiene-styrene, and styrene-butadiene-rubber used as asphalt modifiers have increased the durability of OGFC mixtures. The increased stiffness promotes increased film thicknesses while preventing the draindown of the asphalt binder during production, transport, and construction (Watson et al. 2018).

Watson et al. (2018) suggest selecting a binder with a high temperature of two grades "stiffer" or higher than what is typically used for the geographic location. For example, a geographic location specifying PG 64-XX would use a PG 76-XX. According to the report, stiff asphalt binders are needed for enhanced durability. Some agencies have successful experience with OGFC mixtures even by using a PG binder, one grade stiffer than typically required for that geographic location. GDOT, FDOT, and SCDOT specify PG 76-22 binders for OGFC mixtures. GDOT, FDOT, and SCDOT OGFC binder specifications are summarized in Table 8.

Table 8. GDOT, FDOT, and SCDOT OGFC binder specifications.

Agency	Binder Grade (Design Asphalt Content, percent)	Notes
GDOT	PG 76-22 (6.00 to 7.25)	• Comply with GDOT Section 820.
FDOT	PG 76-22 or high polymer binder (5.5 to 7.5 for Granite or Granitic Gneiss, 6.0 to 8.0 for crushed limestone or shell rock)	• Comply with AASHTO M 332-20. • Comply with the additional requirements of FDOT Section 916. • High polymer binder may be substituted in a mixture with PG 76-22 at no additional cost to the department.
SCDOT	PG 76-22 (5.50 to 7.00)	• Comply with AASHTO M 320 with the addition of a maximum phase angle of 75 degrees (unaged).

Recycled Materials

GDOT, FDOT, and SCDOT specifications do not allow recycled materials in OGFC mixtures.

Other Materials

Other materials commonly used in OGFC mixtures are described below.

[5] Use of this draft or specification is not a Federal requirement.

Hydrated Lime

Many agencies use hydrated lime as a filler material, which doubles as an anti-strip agent to prevent moisture damage to the mixture (Watson et al. 2018). FDOT and GDOT OGFC mixtures can provide 12 or more years of pavement life, and the report attributes part of that success to hydrated lime. Both agencies indicate that hydrated lime performs better than liquid anti-strip additives in OGFC mixtures. GDOT and SCDOT require hydrated lime in OGFC mixtures. FDOT requires hydrated lime for OGFC mixtures containing granite or granitic gneiss aggregates. According to specifications, FDOT adds hydrated lime at a rate of 1.0 to 1.5 percent of total dry aggregate, depending on the aggregate source. GDOT and SCDOT specify a dosage rate of 1.0 percent of the total dry aggregate weight for OGFC mixtures.

Stabilizing Agent

Stabilizing agents are used in OGFC mixtures to minimize the draindown of the binder and increase the mixture's tensile strength. Draindown is an issue in open-graded mixtures because, typically, there is little material passing the number 4 (4.76 mm) sieve and a relatively low P-200 compared to conventional dense-graded mixtures. Stabilizing additives include cellulose fiber, mineral fiber, crumb rubber, polymers, and warm mix additive (WMA).

Fibers

Cellulose and mineral fibers are common stabilizing agents (Watson et al. 2018). GDOT allows cellulose and mineral fibers as stabilizing agents. FDOT requires either be used in all OGFC mixtures. SCDOT requires WMA instead of fibers.

GDOT requires all fibers to meet specifications and be procured through approved sources. Cellulose fibers can be fibers or pellets. Cellulose fibers have a dosage rate between 0.2 and 0.4 percent by weight of the total mixture, while cellulose pellets have a dosage rate between 0.4 and 0.8 percent by weight of the total mixture, as approved by the Engineer. Mineral fibers have a dosage rate between 0.2 and 0.5 percent by weight of the total mixture, as approved by the Engineer (GDOT).

FDOT has similar specifications to GDOT, including fiber lengths, sieve requirements, and thresholds for ash content, pH, oil absorption, and moisture content. FDOT does not permit the use of cellulose pellets. Fiber dosage rates for mineral and cellulose fibers are 0.3 and 0.4 percent, respectively (FDOT 2022).

Warm Mix Additive

SCDOT specifies WMA and does not require stabilizing fibers. The WMA should be included in SCDOT's Qualified Products List No. 77 and terminally blended with the asphalt binder. Clemson University researchers found that using WMA instead of fibers did not significantly affect laboratory draindown results. Laboratory results also indicated increased permeability and improved abrasion resistance based on Cantabro abrasion testing. Using WMA in place of fibers is preferred by SCDOT since it does not require additional metering equipment at the asphalt plant and reduces build-up in haul vehicles (Selkinghaus 2021). SCDOT specifies a dosage rate of 0.5 percent of asphalt binder weight and typically batches the OGFC between 265 and 290 degrees Fahrenheit (Ingevity 2018; Wurst 2011). SCDOT has seen OGFC quality improvements since implementing WMA and eliminating fibers (Selkinghaus 2021).

Ground Tire Rubber

Researchers found that ground tire rubber (GTR) can be used in OGFC for draindown resistance and as a binder modifier (NCAT 2014). GTR modification increases the viscosity of the binder and allows for slightly higher binder contents. The increased viscosity reduces draindown, and the higher binder contents lead to increased film thickness and mixture durability. Two sections at NCAT's test track constructed in 2012 used GTR-modified binders with no fibers. Both mixtures met recommended draindown requirements during construction, and after eight million equivalent single axle loads, both sections showed excellent rutting and durability performance (NCAT 2014).

MIXTURE DESIGN AND PERFORMANCE TESTING

State DOTs use agency-specific mix design procedures for OGFC mixtures. The mix design specifications for GDOT, FDOT, and SCDOT and the recommendations based on the NCHRP Research Report 877 are shown in Table 9.

GDOT and SCDOT use contractor mixture designs, while FDOT determines the optimum asphalt content from contractor-supplied materials and job mix formulas (Moseley 2021; Hines 2021; Selkinghaus 2021).

Table 9. OGFC mixture properties.

Mixture Property	GDOT (OGFC 12.5 mm)	FDOT (FC-5)	SCDOT (OGFC 12.5 mm)	NCHRP Draft AASHTO Standard[6]
Asphalt Content, percent	6.00 to 7.25 (test method not specified)	Granite/Gneiss: 5.5 to 7.5 Limestone/ Shell: 6.0 to 8.0 (FM 5-588)[7]	5.50 to 7.00 (SC-T-91)[8]	5.0 to 7.0 (most virgin and polymer binder), 6.0 to 8.0 (GTR modified)
Air Voids, percent	15-20	Not specified	Not specified	15 to 20 (CoreLok method), 17-20 (Dimensional)
Unaged Cantabro Loss, percent	Report only (AASHTO TP 108)[9]	20 max. during mix design	15 max.	20 max.
Tensile Strength Ratio	Not specified	Not specified	Not specified	0.70 min. (AASHTO T 283)[10]
Stripping Resistance	Not specified	Not specified	20 percent max (SC-T-69)[11]	Not specified

[6] Use of this draft or specification is not a Federal requirement.

[7] FM 5-588: Florida Method of Test for Determining the Optimum Asphalt Binder Content of an Open-Graded Friction Course Mixture Using the Pie Plate Method.

[8] SC-T-91: Method of Determining the Optimum Binder Content in an Uncompacted Bituminous Mixture.

[9] Recently updated to AASHTO T 401-22.

[10] With modifications as listed in the draft AASHTO standard.

[11] Method of Determining the Effectiveness of Anti-Stripping Additives in Asphalt Mixtures (20 percent compared to the control sample that was not boiled).

Mixture Property	GDOT (OGFC 12.5 mm)	FDOT (FC-5)	SCDOT (OGFC 12.5 mm)	NCHRP Draft AASHTO Standard[6]
Draindown at Production Temperatures, percent	Less than 0.3 (AASHTO T 305)	Not specified	Less than 0.5 (Min. retention coating 99.5%) (SC-T-90)[12]	Less than 0.3 (AASHTO T 305)[13]
Permeability (m/day)	Not specified	Not specified	Not specified	Meet agency criteria (50 min. recommended)
Porosity, percent	Not specified	Not specified	13.0 min. (SC-T-128)[14]	Not specified
Shear strength, (Optional) psi	Not specified	Not specified	Not specified	125 (AASHTO T 283)
Conditioned Tensile Strength, psi	Not specified	Not specified	Not specified	50 min. (AASHTO T 283)
Hamburg Wheel Tracker (Optional)	Not specified	Not specified	Not specified	PG 64 or higher, ≥10,000 passes; PG 70, ≥15,000 passes; PG 76 or higher, ≥20,000 passes (AASHTO T 324)
Cracking, I-FIT FI (Optional)	Not specified	Not specified	Not specified	25 min. (ILTest Procedure 405[15])

Performance Tests

Draindown

OGFC mixtures are susceptible to draindown due to the high void structure. State DOTs may find it helpful to refer to AASHTO T 305 Standard Test Method for the Determination of Draindown Characteristics in Uncompacted Asphalt Mixtures, not required by Federal statute or regulation, to determine draindown characteristics in uncompacted asphalt mixtures.

AASHTO T 305 considers draindown as the portion of material that separates itself from the sample after being heated to production temperatures in a wire basket for approximately one hour. Watson et al. (2018) suggest testing for draindown at a temperature 27 degrees Fahrenheit higher than anticipated production temperatures.

Permeability

The permeability of OGFC mixtures can be estimated using a falling head permeability test apparatus. According to the Florida test method (FM), 5-565, the falling head permeability test uses laboratory compacted samples or field cores. A falling head permeability test apparatus (Figure 4) is used to determine the water

[12] SC-T-90: Determining Drain-Down Characteristics in an Uncompacted Asphalt Mixture.

[13] Except use a 2.36 mm wire basket. Conduct the draindown testing at a temperate 15 degrees C (27 degrees F) higher than the anticipated construction temperature.

[14] SC-T-128: Porosity of Compacted Open Graded Friction Course Mixture Specimens.

[15] I-Fit Flexibility Index Test Illinois Test Procedure 405: Determining the Fracture Potential of Asphalt Mixtures Using the Illinois Flexibility Index Test (I-FIT).

flow rate through the specimen. Water in a graduated cylinder flows through a saturated asphalt sample, and the time it takes to reach a known change in the head is recorded.

According to FM 5-565, water flow may not be one-dimensional and laminar when used to test OGFC mixtures, which can affect accuracy. FM 5-565 suggests using the method for comparison against other OGFC mixtures and not to obtain absolute permeability values.

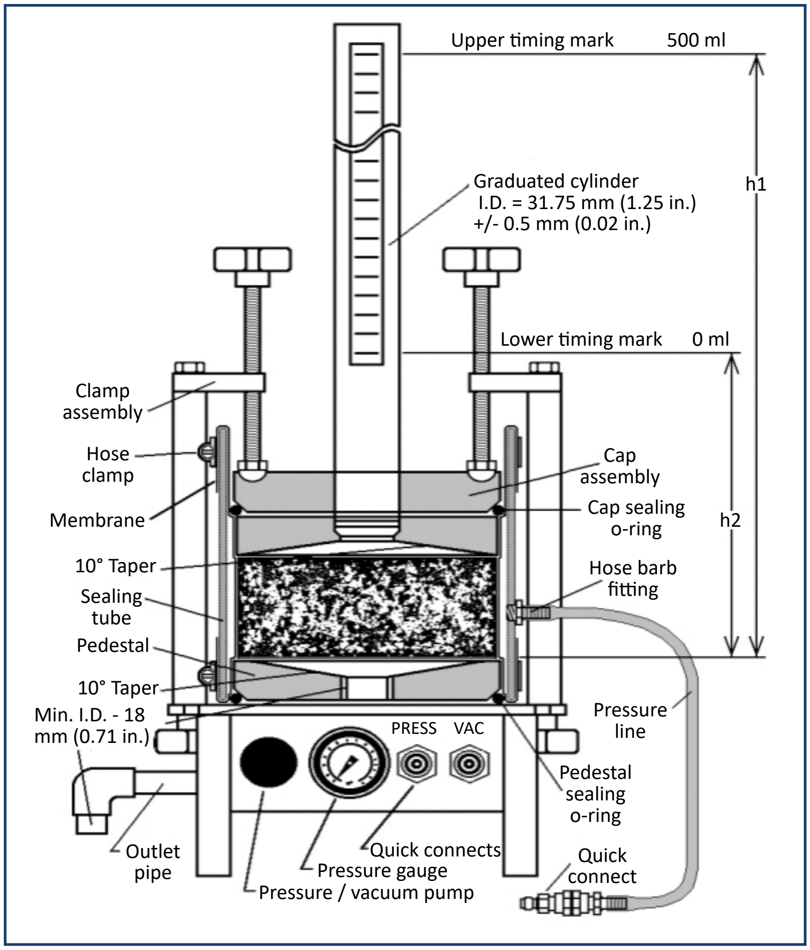

Figure 4. Falling head permeability apparatus (FM 5-565). (Source: FDOT FM 5-565)

Resistance to Wear

According to AASHTO T 401 (formerly AASHTO TP 108), the Standard Test Method for Cantabro Abrasion Loss of Asphalt Mixture Specimens (not required by Federal statute or regulation), a single specimen of compacted asphalt mixture is placed within the drum of a Los Angeles abrasion machine without the charge of steel spheres. The specimen is subject to a total of 300 drum revolutions. The percent material loss at the end of the test, referred to as the Cantabro loss, is determined based on the original specimen mass.

Watson et al. (2018) refer to the Cantabro test as an indicator of OGFC mixture durability and resistance to raveling. According to validation results of performance-based mix designs for OGFC mixtures, a maximum Cantabro loss of 15 percent is achievable for both lab-mixed and plant-produced specimens (Tran et al. 2021). AASHTO T 401, not required by Federal statute or regulation, includes field aging simulation protocols consisting of oxidation, moisture, and freeze-thaw cycle combinations.

Moisture Susceptibility

Because OGFC mixtures are permeable, they can be susceptible to moisture damage. Several test methods are used to evaluate moisture susceptibility and stripping resistance, such as the tensile strength ratio (TSR), boil, and wheel-tracking tests.

Tensile Strength Ratio Test

AASHTO T 283, Standard Test Method for the Resistance of Compacted Asphalt Mixtures to Moisture-Induced Damage, not required by Federal statute or regulation, uses indirect tensile strength to calculate TSR. Specimens are saturated with water and undergo freeze-thaw cycles. Samples are soaked in warm water before testing. The TSR from the moisture-conditioned sample is compared to a control sample.

Boil Test

A boil test consists of placing uncompacted asphalt in a beaker and boiling it for a specified time. For example, ASTM D 3625, Standard Practice for Effect of Water on Bituminous-Coated Aggregate Using Boiling Water, not required by Federal statute or regulation, suggests boiling for 10 minutes. After the boil period, the sample is observed to see if any stripping occurred.

Wheel-Tracking Test

Wheel-tracking devices such as the Asphalt Pavement Analyzer or Hamburg Wheel Tracking Test can be used to evaluate moisture susceptibility. Asphalt samples are moisture conditioned and subjected to a set amount of wheel tracking cycles.

Other Performance Tests

Other performance tests may help evaluate the durability of OGFC mixtures. Researchers suggest using rut and crack resistance tests during OGFC mix design (Watson et al. 2018). Report test methods and criteria are summarized in Table 9, along with the criteria used by GDOT, FDOT, and SCDOT. Many State DOTs do not plan to include rutting and cracking resistance tests since rutting and cracking are not primary distresses for OGFC mixtures (Tran et al. 2021).

CONSTRUCTION SPECIFICATIONS AND PRACTICES

Production, Storage, and Transportation

Special production, storage, and transportation considerations for OGFC mixtures are included in the following sections.

Mixture Production and Productivity

OGFC mixtures often contain fibers and hydrated lime, which require metering systems at the asphalt plant. General considerations for fiber and hydrated lime systems based on FDOT and GDOT specifications include:

- A separate feed system to store and proportion the required quantity and provide uniform distribution.
- Fibers or hydrated lime should be introduced before asphalt injection into the plant to ensure they are not entrained in the drier or plant exhaust system.
- A proportioning device meeting the following specifications:
  - Accurate to within ± 10 percent of the amount needed. Automatically adjusts the feed rate to maintain this tolerance at all times.
  - Provides in-process monitoring, either a digital display or printout of the feed rate in pounds per minute for verification.
  - Interlocks with the aggregate feed system to maintain correct proportions for all production rates and batch sizes.
- Flow indicators or sensing devices interlocked with plant controls to interrupt mixture production if the introduction of fiber or hydrated lime fails or does not meet the correct proportion.

Other OGFC-specific considerations during production include the following:

- GDOT requires mix temperature determination at least once per hour during OGFC production.
- SCDOT does not permit the production of other SCDOT mixtures during OGFC production to avoid cross-contamination.
- SCDOT performs draindown testing according to SC-T-90 at least once during the first day's production, then at least once every seven production days. If a draindown test produces a retention coating of less than 95 percent, draindown testing is conducted at least once every three production days afterward. Production is ceased if a draindown test produces less than 90 percent retention coating.

Storage and Transportation

Since OGFC mixtures are susceptible to draindown, FDOT restricts the storage of mixtures containing mineral fibers to one hour in a surge or storage bin and 1.5 hours for those containing cellulose fibers (FDOT 2022). GDOT allows OGFC storage for up to 12 hours but allows for the rejection of mixture if segregation, draindown, or stiffness of stored mixture is observed (GDOT).

In a validation project on performance-based OGFC mixtures, researchers found that extended silo storage and haul time significantly influenced Cantabro loss, adversely affecting mixture durability in the field (Tran et al. 2021). The report suggests using Cantabro testing as an acceptance test for plant mix as it is sensitive to changes in binder content and a minimum air void content requirement to minimize the air void effects on Cantabro results and provide adequate permeability.

Surface Preparation

A tack coat is recommended for bonding before OGFC placement. OGFC mixtures have a higher macrotexture depth, reducing the contact area between the layers and potentially reducing the bond strength (Putman et al. 2021). Therefore, specific application rates and tack materials may be specified for OGFC mixtures to improve bonding. GDOT, FDOT, and SCDOT tack specifications are summarized in Table 10.

Table 10. Summary of tack products and application rates.

Agency	Tack Product (Application Rate)	Notes
GDOT	• Bituminous tack (0.06 to 0.08 gal/sy). • Non-tracking hot-applied polymer modified tack (NTHAPT) (0.12 to 0.18 gal/sy). • CQS-Special Modified Asphalt Emulsion (0.22 to 0.28 gal/sy).	• Distribution rates are generally higher for OGFC compared to other mixtures. • Do not use anionic emulsified asphalt or cationic emulsified asphalt other than CQS-Special Modified Asphalt Emulsion in conjunction with a spray paver under OGFC or permeable European mix.
FDOT	• Approved undiluted emulsion from the FDOT-approved products list. Note that all FDOT-approved tack coats are non-tracking. • PG52-28 (0.06±0.01 gal/sy for newly constructed asphalt layers, 0.09±0.01 gal/sy for milled surfaces). PG52-28 binders are rarely used for tack coats (Moseley 2021).	• Target application rates greater than those specified may be used upon approval from the Engineer. • Distribution rates are the same for a base course, structural coarse, dense-graded friction course, and OGFC.
SCDOT	• Less tracking hot-applied bond coat (0.08 gal/sy minimum). • PG64-22 binder (0.08 gal/sy minimum).	• Use products listed on the SCDOT Qualified Products List. • Adjust distributors accordingly to apply hot-applied products uniformly.

PLACEMENT AND COMPACTION

Unless the Engineer waives the requirement, GDOT specifies a material transfer vehicle for OGFC regardless of the average daily traffic, project length, or mixture tonnage (GDOT SP400).

SCDOT requires a hauling plan that shows how many trucks will be used for each milepost of the project to ensure continuous paving and eliminate excessive loaded hauling truck idle time. The paving plan must also include the desired optimum paving speed in feet per minute. Unless the Engineer approves otherwise, the hauling time may not exceed 90 minutes.

SCDOT specifications include a requirement for pre-heating the paving equipment (including a material transfer vehicle and paver) with a half truckload of OGFC mixture. The half load to pre-heat the equipment is discarded but paid for by the DOT. SCDOT implemented this requirement based on research that showed 55 percent of localized roughness occurred at transverse joints (Putman et al. 2021). This requirement aims to reduce cooler asphalt temperatures at the start of paving, which may negatively impact compaction efforts and cause premature raveling.

FDOT, GDOT, and SCDOT do not permit pneumatic rollers. FDOT requires two static steel-wheeled rollers with an effective compaction weight of 135 to 200 pounds per linear inch determined by the total weight of the roller divided by the total drum width. FDOT describes an effective rolling pattern as seating the mixture without crushing the aggregate. Liquid detergent is recommended in the rolling water to minimize adhesion to the roller drums (FDOT 2022). SCDOT requires prompt rolling with an 8 to 10-ton tandem steel wheel roller.

SCDOT limits rolling to three passes, which should cease when the OGFC is properly seated. SCDOT research suggests increasing the number of passes to four at transverse joints (Putman et al. 2021).

Weather Limitations

FDOT permits OGFC placement at 65 degrees Fahrenheit, or 60 degrees Fahrenheit, when approved by the Engineer based on the contractor,'s demonstrated ability to achieve a satisfactory surface texture and finished surface appearance. The minimum ambient temperature may be further reduced to 55 degrees Fahrenheit when using a warm mix technology in OGFC mixtures containing PG 76-22 binder when agreed to by both the Engineer and Contractor. GDOT permits OGFC placement at 60 degrees Fahrenheit, or 55 degrees Fahrenheit when approved by the Engineer (GDOT). SCDOT allows OGFC placement at 55 degrees Fahrenheit when measured in the shade away from artificial heat sources (SCDOT 2021). SCDOT does not permit OGFC placement if temperatures were freezing the previous day to ensure a proper bond to the existing pavement surface.

Quality Assurance

Acceptance of the Mixture

Density testing and in-place air voids are typically not performed on OGFC mixtures. FDOT, GDOT, and SCDOT use loose mix samples to test asphalt content and gradation. Other acceptance requirements for these States include verifying spread rates and cross slope and smoothness requirements.

Intelligent Construction Technologies

Intelligent compaction (IC) and paver-mounted thermal profiling (PMTP) allow contractors to measure real-time temperature and compaction operations during paving, track progress visually, and digitally record measurement data and machine settings. According to Chang et al. (2022), these tools promote successful practices and allow for efficient troubleshooting if paving issues arise.

SCDOT research shows that approximately 55 percent of localized raveling on OGFC pavements occurs at transverse joints (Putman et al. 2021). SCDOT research reports state that lower compaction temperatures and, therefore, lower density at transverse joints may contribute to localized raveling. Using IC and PMTP technology allows contractors and agencies to view paving and compaction temperatures in real-time and creates records that can troubleshoot low temperatures and promote successful practices. An example of viewing IC and PMTP temperatures at the transverse joint is shown in Figure 5 (Chang et al. 2022).

Balanced Paving Applications

According to SCDOT research, balancing production and paving speeds can help reduce localized raveling caused by lower compaction temperatures. Tools such as phone applications can track plant production, the number and capacity of trucks, haul times, paver speed, roller parameters, and other variables. SCDOT requires paver speeds, haul routes, and production rates to be included in contractor paving plans (SCDOT 2021). Paver stops can also be monitored using PMTP equipment.

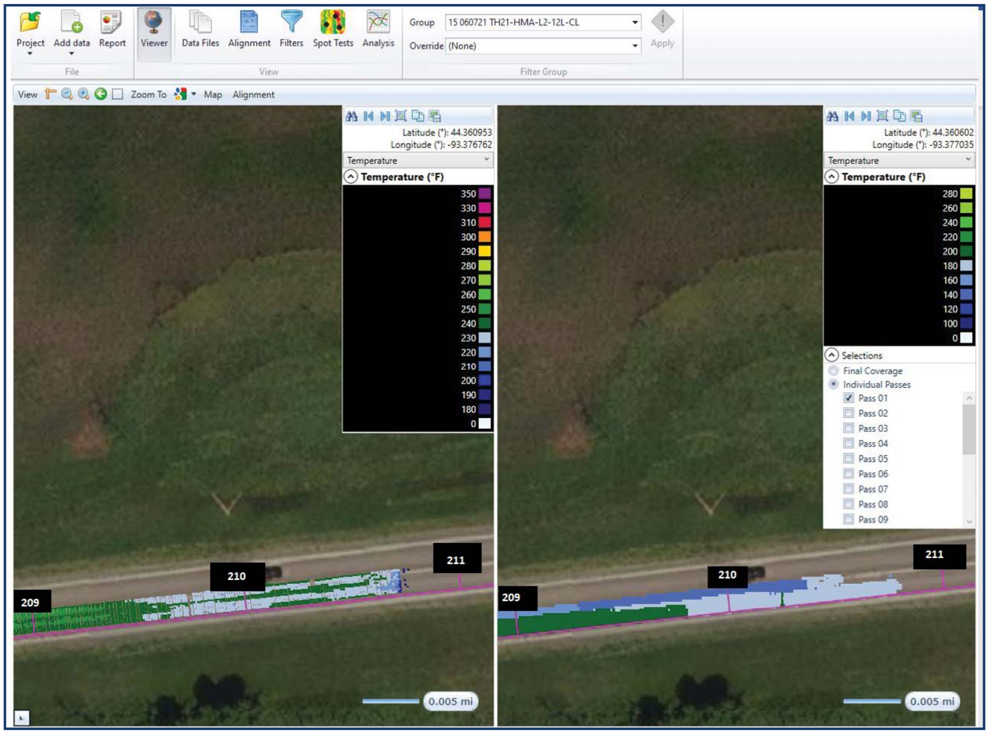

Figure 5. PMTP (left) and IC (right) data show low paving and compaction temperatures at transverse joints. (Source: Chang et al. 2022)

MAINTAINING AND REHABILITATING OGFC COURSES

According to NCHRP Research Report 877, OGFC pavements can become clogged with dust, silt, and other debris. This debris reduces the pavement permeability, and the OGFC may lose some associated benefits. Some research suggests using vacuum sweepers with high-pressure water systems throughout the year to clean the pavement and prevent clogging. However, these maintenance processes can be costly, and few State DOTs report such maintenance practices (Watson et al. 2018).

Winter Maintenance

Many northern State DOTs do not use OGFCs. Surveys from 2015 (West 2020) and 2016 (Hernandez-Saenz et al. 2016) show that most OGFC mixtures are used in southern States. According to a study conducted in 2014 by the University of Tennessee, northern states do not use OGFC mainly because of high winter maintenance costs and clogging when sand is used as a winter maintenance treatment. Due to the structure of the mix, OGFC layers are known to freeze more rapidly and thaw more slowly than conventional dense-graded mixtures. In rapid freezing conditions, moisture can get trapped in the open pores and cause black ice. OGFC is susceptible to snow plow damage and tire stud rutting (Onyango et al., 2022). Since OGFC layers behave differently from dense-graded mixtures, they may need unique winter maintenance plans.

Based on national survey results, Tennessee DOT concluded the following successful practices for OGFC winter maintenance:

- Sand is not recommended since it leads to the clogging of voids and decreased permeability (except for emergencies where surface friction is required).
- Snow plowing should be done carefully because OGFC has less resistance to snowplow blades.

- De-icing chemicals can be used at higher rates than dense-graded mixtures since the chemicals will drain through the OGFC.
- Salting can be used, but small salt rock pieces should be used for quick dissolution and minimized pore clogging. If too much salt is used, conditions can become slippery due to the excess salt.
- Pre-wetted (addition of brine or other liquids to granular materials) salt clings to the surface of OGFC and remains effective much longer than dry salt, which tends to collect at the bottom of the OGFC when applied in the dry form. Salt brine tends to run through the porous layer.
- Anti-icing (application of liquid chemicals before a winter storm to prevent ice bonding to the pavement) can be very effective but is sensitive to timing as it needs to be applied before the storm.
- OGFC may require 25-50 percent more salt or 30 percent more anti-icing materials. Although the need for salt is generally higher on OGFCs, research shows that traffic volumes play a role. As long as traffic volumes are high, the salt solution will be pumped in and out of the structure by the traffic, diminishing the need for extra salt.
- Proper training for operators on snow maintenance equipment is critical to ensure the proper application of treatments.

SUMMARY

OGFC surface courses can improve safety by increasing the frictional properties of the pavement surface and allowing surface water to drain through the pavement. Other benefits may include pavement-tire noise reduction and environmental benefits by reducing stormwater runoff.

Raveling is the primary durability issue with OGFC. Performance testing evaluates mixture properties for draindown, permeability, resistance to wear, moisture susceptibility, rutting, and cracking resistance. The performance testing results may be used to balance functional and durability characteristics.

OGFC mixtures are susceptible to draindown. Adding fibers or GTR and using WMA are ways to mitigate draindown. Draindown can be monitored by testing and avoiding long storage periods in the silo. The asphalt plant should carefully control and monitor the addition of fibers and hydrated lime other additives.

There are construction considerations specific to OGFC. Avoid over-compaction since OGFC has relatively high air voids compared to dense-graded mixtures. Also, note that the under-compaction of OGFC lifts may exacerbate durability issues like raveling. Compaction efforts are generally completed using static steel wheel rollers.

OGFC mixtures are thin lifts, so construction considerations should include temperatures and balanced paving operations. Consistent temperatures and paving speeds minimize the potential for under-compacting OGFC. Intelligent construction technologies can monitor and record paving temperatures. Proper tack application ensures bonding between the OGFC and the underlying lift.

The benefits of OGFC (permeability, noise reduction) may be reduced with pavement aging due to clogging and raveling. Although few State DOTs report regular maintenance to clean and unclog OGFC, some processes are available. OGFC may require unique winter maintenance procedures compared to dense-graded mixes.

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TOPS

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