Open-Graded Friction Courses: Florida's Experience

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The Florida Department of Transportation began its development of open-graded mixes in 1970 to provide improved wet-weather vehicular safety. Florida's FC-2 open-graded friction course is currently required for all multilane primary and Interstate highways of which the design speed is greater than 72 km/hr (45 mph). This mix uses locally available aggregates and is produced at a reasonable cost. Changes and additions to specification criteria have been made over the years to address undesirable results. Maintenance, rehabilitation techniques, and improved performance are being studied. Asphalt additives show promise to increase the design life of open-graded mixes.

Plant-mix seal, open-graded friction course, and popcorn mix are all terms used to describe the same coarse-graded, high-void surface mix used to improve tire-pavement interaction, especially during wet weather on high-speed, high-traffic-volume roadways.

Tire-pavement interaction is complex and depends on five factors (*1*):

- Driver reaction,
- Tires and tread,
- Weather,
- Vehicles and their brakes, and
- Pavement surface.

Of these factors, only one, pavement surface, can be controlled to any extent by highway agencies.

Florida is a state dependent on vehicular travel for its economy, both for the commercial movement of goods and the supply of services, and the movement of tourists who come for the climate as well as to visit natural and manmade attractions. Therefore, safe pavement surfaces are a must.

Providing a safe pavement surface is complicated by Florida's climate, which is subject to intense rainfall, and by the fact that most available aggregates are limestone, which history indicates are subject to polishing under traffic (*1*).

Florida Department of Transportation (DOT) officials have long been concerned about providing safe pavement surfaces. This concern is evidenced by early efforts in skid testing beginning in 1958 using a full-scale automobile. In 1965, Florida constructed a skid test trailer and hosted the Second Skid Test Correlation sponsored by ASTM, AASHTO, and FHWA, which resulted in the development of the current ASTM and AASHTO standard test methods.

Although no direct correlation has been shown between accidents and friction number (FN_{40}) measured at 64 km/hr (40 mph), when examining the range of FN_{40} between 20 and 30 for a typical highway, experts would agree that 30 is acceptable and 20 is potentially slippery (*1,2*). Measured and desirable friction characteristics also depend on speed.

In 1970, due to the inconsistency of friction numbers for the surface course mix then being used, Florida constructed test projects to evaluate the frictional and other performance characteristics of 26 different mix designs using many different aggregate types. These projects resulted in the standard specifications for wearing course (WC) mixes implemented in 1973. Four of those mixes, having the same gradation, but differing by type of aggregate, were the forerunners of Florida's FC-2 open-graded mix, which was implemented in 1976 after additional test projects, field experience, and performance measurements (*3*).

Part of the basis of Florida's development of open-graded type mixes was the plant-mix seal coats developed in a number of the western states and the information and encouragement provided by FHWA.

SPECIFICATIONS

Florida DOT maintains a highway system of more than 56,300 lane km (35,000 lane mi), the majority of which are Interstate and high-speed primary highways. Since 1973, it has been the policy of Florida DOT to require open-graded friction courses on all multilane facilities with a posted speed greater than 72 km/hr (45 mph). This mix is also optional for two-lane roads and low-speed multilane facilities (*4*).

The gradation requirements for Florida's open-graded friction course mix are shown in Table 1.

Florida DOT permits the use of a crushed granite, gravel, slag, or oolitic limestone as the coarse aggregate component for the FC-2 mix. It should be noted that crushed gravel must have 85 percent, 3 crushed faces [material retained on the 425 μm (No. 4 sieve)], and that Florida has a procedure for evaluating other sources of aggregates for use in FC-2 mixes based on in-place friction testing. It has been found that a fine-graded ASTM 89 stone works well to meet the gradation criteria. Most of the time, a small amount of sand or screenings are necessary to meet the 2.00 mm (No. 10) and 75 μm (No. 200) gradation requirements.

About 90 percent of the FC-2 mix designs use crushed oolitic limestone aggregate. This aggregate is native to southeastern Florida and has been described as calcium carbonate formed around a sand grain. Under traffic, the calcium carbonate wears down, exposing the grains of silica. Test sections and continuous monitoring of in-place pavements through

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TABLE 1 Gradation Requirements

Sieve Size	1973 WC	1976 FC-2	Typical FC-2
19.0mm (3/4 in.)	100		
12.5mm (1/2 in.)	90-100	100	100
9.5mm (3/8 in.)	70-100	85-100	96
4.75mm (No. 4)	25-50	10-40	40
2.00mm (No. 10)	7-17	4-12	11
425μm (No. 40)	-	-	10
180μm (No. 80)	-	-	5
75μm (No. 200)	0-5	2-5	2.1

friction testing have demonstrated the nonpolish characteristics of the aggregate. In addition to geological definition, a test on material retained on the 2.00 mm (No. 10) sieve of the acid insoluble [minimum 12 percent retained on the 75 μm (No. 200 sieve)], is used to distinguish this material.

Florida DOT uses the FHWA Design Procedure to determine the asphalt content (AC-30) of its FC-2 open-graded friction course (*5*). This is the only mix designed by Florida DOT. All other mixes are designed by the contractor under Florida's Quality Assurance/Quality Control Specification. Typical asphalt cement contents by weight are 6.3 percent for oolitic limestone, 5.5 percent for granite, and 12.5 percent for lightweight aggregate. It should be noted that the effective asphalt content by volume for the different aggregates is about the same.

Some additional specification requirements are unique to Florida's FC-2 open-graded friction course:

- Mix temperature target is fixed at 115°C (240°F). The mix must be produced within ±14°C (25°F) of the target. This limits possible drain down of the binder. For simplicity the temperature was specified because the asphalt cement viscosity at this temperature for asphalt cements in Florida does not vary significantly.
- Only one pass of a steel wheel roller is required. In addition, the roller weight is limited to 2411 kg/m [135 pounds/lineal in. (pli)] of drum width. This will prevent crushing of the aggregate, which in Florida is predominantly native oolitic limestone.
- A minimum ambient air temperature of 16°C (60°F) is required before laydown. This is necessary for workability and texture.
- FC-2 is always purchased by unit area (square yard) instead of weight, but a minimum spread rate is specified to make sure that it is not placed too thin.
- To prevent drainage of the binder during storage, a maximum of 1 hr is allowed in storage or surge bins.

PERFORMANCE

There are long lists of the benefits and limitations in the use of open-graded friction courses. The following is a listing of positive performance characteristics identified by others (*6,7*) that have been verified subjectively or objectively by Florida DOT.

- Hydroplaning potential is reduced. Before Florida started using opened-graded friction course, when it rained, drivers slowed down or pulled off the Interstate. Now this rarely happens. Reduction in hydroplaning potential with open-graded friction courses has been verified from friction measurements using the blank and rib tire by Florida and other states.
- Friction characteristics at high speed are maintained, especially in wet weather. This has been verified in Florida by friction measurements both at the standard 64 km/hr (40 mph) and at 97 km/hr (60 mph). The friction characteristics of dense-graded mixes including portland cement concrete pavement drop significantly with increase in speed. With the open-graded friction course only a small change in friction characteristics is measured within this speed interval.
- The ride is smooth and quiet. Tests in Florida using the Mays Ride Meter indicate a smoother ride for pavements with an open-graded friction course.
- There has been some indication of improved night visibility of traffic markings.

Limitations identified in Florida in using the open-graded friction course include the following:

- Service life appears to be less than the remainder of the pavement structure. Service life of Florida's FC-2 mix on Interstate pavements appears to be 10 to 12 years, whereas the rest of the pavement structure is generally more than 15 years (*8*). It should be noted that the original FHWA estimate for design life of open-graded friction course was 5 to 7 years.
- Care must be taken during production and laydown. The margin of safety in obtaining a quality performing product is tighter for open-graded friction courses, but it is a simple, fast operation.
- Maintenance is difficult. Patching and fog seals have not been effective in Florida. Researchers are investigating the use of milling to remove only the FC-2, leaving a smooth surface that may be repaved with a new FC-2 mix. This technique appears to have potential.

FRICTION DATA

The question most often asked is, what is the friction number (FN_{40})?

Florida DOT has a Friction Test and Action Program consistent with that recommended by the FHWA Technical Advisory on Skid Accident Reduction Program (*9*). Florida has three levels of friction testing:

1. All newly constructed pavement surfaces,
2. Periodic testing of segments of the entire system (about a 3-year cycle), and
3. Spot hazard requests to identify rapid changes.

On the basis of this data, using typical Interstate projects that have had 10 to 30 million vehicle coverages, the following statements regarding friction number (FN_{40}) can be made:

1. FC-2 with oolitic limestone will have initial FN_{40} of 35 to 40 and with accumulated traffic will stabilize at 30 to 35.
2. FC-2 with granite and slag will have an initial FN_{40} of between 35 and 40 and appears to stay in that range with a slow reduction of friction number with traffic.

3. FC-2 with gravel appears to have an initial FN_{40} of around 45 and drops to 40 after 15 million vehicle coverages.
4. FC-2 with lightweight aggregates has had an initial FN_{40} of about 50 and appears to maintain that value with traffic.

Florida was one of two states that guaranteed a minimum FN_{40} for all new or rehabilitated pavement surfaces to the FHWA for their participation. This has changed somewhat under the new Friction Test and Action Program, which, in addition to testing and monitoring the FN_{40}, has actions associated with low FN_{40} values.

PROBLEMS AND SOLUTIONS

As with most new processes, this process must be adapted to the specific circumstances, materials, and so forth, during which time changes are made or the process is abandoned. Florida DOT did run into problems, but was convinced of the potential benefits. Solutions to problems were identified and changes made to lessen or eliminate reccurrence. Discussions of some of these problems and solutions follow.

- Periodic "fat spots" or flushing. Open-graded friction courses are sensitive mixes. They are a combination of coarse aggregate and asphalt cement with some fines to give the asphalt some body to provide a thick film. The solutions to this problem were to place tight controls on the temperature of the mix, keeping it within the tolerances for the 115°C (240°F) target during production, and retaining Florida DOT control of the mix design to have tighter gradation control, especially on the 2.00 mm (No. 10) and 75μm (No. 200) sieves.
- Rich and lean areas occurred even when temperature, asphalt content, and gradation were proper. This was found to be due to storage of the mix in a silo early in the day to keep up with production. This resulted in drainage of the asphalt cement. Storage in silos or surge bins of FC-2 is now limited to 1 hr.
- Texture closing up with traffic. This problem was due to excessive fines in the mix along with placing the mix too thick. The maximum aggregate size governs the thickness. With a mix having the proper gradation and temperature, the paver itself can be used to determine the proper thickness. The mix should be placed as thin as possible while flowing smoothly under the screed with no pulling or tearing. This is about 13 mm (.5 in.) for typical FC-2 mixes. To obtain the correct thickness, the mix is purchased by unit area (square yard) with minimum spread rate, maximum thickness, and texture requirements specified.
- Inconsistent results. This is a matter of training and experience. Sometimes it takes a little assistance to make the contractor a believer that the specification requirements will result in a good job. The mix does not lend itself to hand work. If pulling or tearing occurs, the paver or the mix may need correction. Continual "throwing back" will result in poor appearance.
- Low friction numbers. The frictional characteristics of the FC-2 mix come from the aggregate. However, those characteristics may be affected by construction techniques, especially with Florida's oolitic limestone. Overrolling may crack the sharp edges of the aggregate and cause a low FN_{40}. Therefore, only one pass of the roller is required. Florida DOT specifications also limit the weight of the roller to 2411 kg/m (135 pli) for FC-2 mixes.
- Moisture damage. Although reported to be a problem in other areas of the country, Florida has not experienced stripping in the FC-2 layer or the underlying asphalt layers. This may be because of the type of aggregates available in Florida, which are predominantly limestone. Instances of moisture damage have occurred in the pavement structure where the original FC-2 was overlayed and water was able to enter and move in the overlayed FC-2 layer. Florida and many other states no longer allow the overlay of open-graded friction courses. They must be removed by milling. This does not appear to have a negative impact on the cost of rehabilitation because a leveling course is then eliminated.
- Premature ravelling has resulted where the FC-2 mix was not opened to traffic for some time (months). This can happen in stage or multiproject construction. It is theorized that the ravelling is the result of aging or structuring of the asphalt film during this dormant period. Contracts are now set up so that FC-2 is in place so that it may be opened to traffic as soon as possible.
- Imbedment of the FC-2 in underlying layers. This can appear as flushing or low frictions numbers. FC-2 must be placed on high stability structural mixes. It is not to be placed directly on fine-graded leveling course mixes.
- Premature ravelling. A recent review of this problem has identified the common factor to be the use of crushed gravel. Although some mixes with crushed gravel are performing well, many are not. Use of crushed gravel in FC-2 has been discontinued (*8*).

COST

Florida DOT's average bid price for FC-2 is $1.25/yd^2 for the specified 16 mm (5/8 in.) maximum thickness. At an average spread rate of 26.7 kg/m^3 (5 lb/yd^2), calculations indicate the cost to be $60.64/metric ton ($55.00/ton).

For an economic analysis, the important item to examine is the additional cost per square yard to provide a surface with desirable friction characteristics. Open-graded friction course is the only means to reduce high-speed hydroplaning potential.

IMPROVEMENT

Open-graded friction course consists mainly of coarse aggregate and asphalt cement. There is potential for improvement in the aggregate to determine the best grading and to be able to accurately predict frictional characteristics of the aggregate by some laboratory test, but the greatest potential for improvement appears to be in the asphalt cement binder. It is important that the asphalt have good adhesion to the aggregate in a thick film for durability without draining and that it be resistant to aging.

It appears that asphalt additives or admixtures are the answer. The problem appears to be identification of the correct additive or combination to do the job in the most economical fashion.

A number of states, including Florida, are specifying latex (styrene-butadiene) at 3 percent solids by weight of the asphalt cement in open-graded mixes. It stiffens the asphalt, permits additional asphalt to be added for improved durability and increased life (*6*), and appears to adhere better to the aggregate. A negative aspect appears to be the need for an increased target mix temperature of 143°C (290°F) to obtain workability, and even then workability appears to be decreased.

Florida is investigating the use of finely ground tire rubber "prereacted" or "preblended" at 12 percent by weight of the asphalt cement for open-graded mixes (*10*). This appears to produce results similar to the latex additive with the additional benefit of using waste tires, and the workability of the mix does not appear to be as sensitive. Other states are looking at other schemes of using ground tire rubber in these mixes.

In addition, numerous other additives are being promoted for this use. Styrelf, Novophalt, and Kraton are just some of the additive processes that have been examined by Florida and other states.

CONCLUSION

Open-graded friction courses have proven to be an improvement for safe travel, especially in wet weather, for high-speed roadways in Florida.

Florida has experienced some problems in using open-graded friction courses, but those problems have been overcome without extraordinary effort.

Improvements in the properties of the asphalt binder by use of additives appear to hold some promise to increase the performance of open-graded friction courses.

Two documents are recommended for further information on this subject:

- *NCHRP Synthesis 180: Performance Characteristics of Open-Graded Friction Courses* (*7*) provides an overview of the use of this material. It also contains FHWA Technical Advisory T5040.31 on Open Graded Friction Courses, which presents guidelines for use and the FHWA mix design procedure.
- *NCHRP Synthesis 104: Criteria for Use of Asphalt Friction Surfaces* (*1*) presents information on friction number, tire-pavement interaction, and skid-resistant surfaces.

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