Open-Graded Friction Courses

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COURSE OBJECTIVES

This course is an introduction to the subject of open-graded friction courses (OGFC) for roadway paving. The contents of this document are intended to serve as guidance and not as an absolute standard or rule.

The objectives of this course are to:

- **Provide technical information on open-graded friction courses (OGFC)**
- **Present their advantages and limitations**
- **Recommend factors to be considered when choosing an OGFC.**

Some of the topics for consideration include: *the benefits of using open-graded courses; safety advantages; noise reduction features; economic issues; service life; limitations or past problems; current OGFC mix designs usage;* and *real world examples.* The course research data will be used to provide material for generating any conclusions and recommendations for open-graded friction courses.

Upon course completion, the participant should be familiar with the fundamentals of open-graded friction courses. The course will present various aspects to be considered when selecting and designing OGFCs.

INTRODUCTION

An "**open-graded friction course**" is defined as a thin, permeable layer of asphalt that consists of uniform aggregate grading with a minimum of fines. The percentage of fine aggregate produces a large number of air voids in the compacted mix. The pavement consists primarily of single size coarse aggregate with a high asphalt content. The aggregate skeleton is responsible for the pavement's ability to carry traffic loads without undergoing permanent deformation. The load is carried by the stone while the asphalt keeps everything in place.

Open-Graded Friction Course

(Steve Muench; hawaiiasphalt.org)

The development of open graded hot mixes was a possible solution to the problems associated with chip seal construction. These pavements have been shown to reduce hydroplaning and poor visibility from splash and spray.

HISTORY

Oregon began experimenting with open-graded friction courses (OGFC) in the 1930's to improve the surface frictional resistance of asphalt pavements. In 1974, the Federal Highway Administration (FHWA) developed an OGFC mix design procedure to be used by state departments of transportation (DOTs). At first, many DOTs reported good performance using OGFC but others stopped using these mixes due to unacceptable performance. Since then, many significant improvements have been made in the areas of OGFC gradation and binder type.

Although DOTs experiences with open graded mixes has been varied, half of the states surveyed in a recent National Center for Asphalt Technology (NCAT) study indicated good performances with OGFC. Over 70 percent of the states reported an OGFC service life of eight or more years - plus approximately 80% of the states have standard specifications for open-graded mix design and construction.

MATERIALS

Recent open-graded friction-course pavements built in the U.S. and Europe have considerably higher air void contents than before (17 to 22%). The void content for hot mix asphalt (HMA) paving used in Tennessee is normally 4 to 7 percent. Newer OGFC mixes are much more open with more voids.

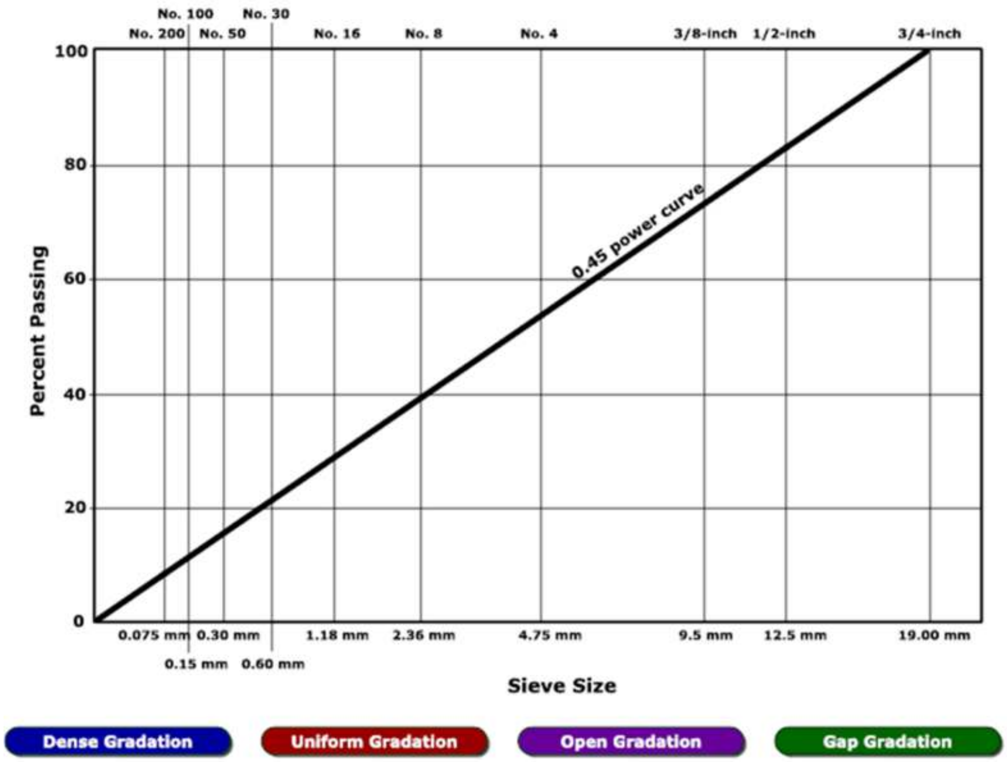
Job Mix Formulas and Design Limits for Open-Graded Friction Course (OGFC) and Porous European Mix (PEM)

Mix Control Typical Tolerance	Asphaltic Concrete	FHWA Guidelines	Georgia OGFC	PEM	12.5 mm Paving
	Gradation Requirements				
±0.0	% Passing 19 mm Sieve	-	100	100	100
±6.1	% Passing 12.5 mm Sieve	100	85-100	90-100	95-100
±5.6	% Passing 9.5 mm Sieve	95-100	55-75	35-60	80-93
±5.7	% Passing 4.75 mm Sieve	30-50	15-25	10-25	54-76
±4.6	% Passing 2.36 mm Sieve	5-15	5-10	5-10	35-57
±2.0	% Passing 75 μm Sieve	2-5	2-4	1-4	0-7
	Design Requirements				
±0.4	Range for % AC	-	-	5.5-7.0	5.3-7.0

(FHWA, Georgia DOT & Tennessee DOT)

Today's OGFCs are polymer-modified and include spun mineral or cellulose fibers. Polymer modifiers and fibers complement each other in the liquid asphalt. The polymer stiffens the asphalt binder and adds flexibility in order to resist raveling. The fibers disperse, overlap and form a mat, which keeps the liquid asphalt from draining to the bottom of the layer before cooling.

Typical Gradations



Open graded. Refers to a gradation that contains only a small percentage of aggregate particles in the small range. This results in more air voids because there are not enough small particles to fill in the voids between the larger particles. The curve is near-horizontal and near-zero in the small-size range.

(Steve Muench; hawaiiasphalt.org)

OVERVIEW

POSSIBLE APPLICATIONS

Open-graded courses are suitable for use in new construction, major rehabilitation, and overlay projects. OGFCs are best utilized when tailored to specific project areas with any of the following characteristics:

Hydroplaning

Locations with a high level of wet crashes

Good tire-pavement contact can be maintained in the presence of water

Wet/Nighttime Visibility

Sites with high number of wet/nighttime accidents

OGFC channels will minimize splash and spray due to rain

Skid Resistance

Locations needing higher friction for high speed wet weather driving

OGFC structure allows slower decrease in friction values

Location

OGFC should be used if adjacent to an existing OGFC project

Allows for continuity of pavement cross section and slope

Cross Slope

Sites with cross slopes less than 2% with 2 or more lanes in one direction

Effectively removes water from roadway surface

Roadway Smoothness

Alternative to chip seals and slurry seals to correct small surface irregularities

Rutting & depressions must be leveled with typical paving prior to OGFC overlay

Flushing and Bleeding

Temporary mitigation maintenance overlay

Open void structure increases pavement friction and allows absorption of free surface asphalt

OGFCs should be used where the benefits represent a priority – and adverse conditions that pose a threat are not present. These mixes produce the best results in warm southern climates since they can help mitigate heavy rainfall without being impacted by snow or ice.

BENEFITS

Open graded voids and its stone-on-stone skeleton give this type of mix many positive attributes. The porous nature allows immediate drainage of water from the pavement surface. Much like the recent European stone matrix asphalt (SMA) mixes, the stone-on-stone structure can hold up better to heavy traffic than other mixes. The texture of the larger aggregate without fines provides better traction (i.e. 1970s "popcorn" and porous asphalt mixes). The voids also absorb sound energy as tires roll over the pavement to reduce surface noise.

Advantages of using open graded friction courses include the following:

- **Mitigating noise, often providing a 3 to 5 decibel reduction in tire noise**
- **Increasing pavement life and decreasing long term costs**
- **Providing and maintaining good high speed and friction qualities**
- **Reducing potential hydroplaning**
- **Decreasing splash and spray**
- **Improving the visibility of painted pavement markings**

The most important OGFC benefit is its increase in roadway safety during wet weather from maximum tire-surface contact and pavement marking contrast. The open void structure drains any water to below the tire and pavement contact point to reduce any potential for skids or hydroplaning.

Since water is the greatest enemy of pavements, roadways benefit from the quick drainage of water that OGFC mixes allow. Their “open” aggregate structure allows runoff to drain right through the driving or friction course to an impervious intermediate course below, and out into roadside ditches. This eliminates tire spray and hydroplaning, improves wet pavement friction, increases surface reflectivity, and reduces traffic noise which produces a safer pavement.

OGFCs offer state DOTs a better-performing, driver-friendly pavement - but at a 30 to 40% cost premium over conventional asphalt mixes. However, open-graded paving is lighter in weight than conventional mixes, and is able to cover more pavement surface area. This OGFC cost disadvantage is outweighed when long-term life-cycle costing is used, both in terms of reducing maintenance and delay costs to highway users during maintenance operations.

SAFETY

Open-graded mixes are very safe due to their rapid drainage surfaces and excellent skid resistance. Chances of hydroplaning after heavy rainfalls are greatly reduced by the OGFC’s void structure. The aggregate structure creates a higher degree of friction and permeability for the pavement surface. This permeability improves friction during inclement weather and reduces splash/spray or hydroplaning due to increased surface drainage. Water can quickly enter and drain through the structure due to its 15 to 25 percent void range.

NOISE REDUCTION

Tire pavement noise is only one source of vehicle noise. Engines, exhaust noise, and wind shear can also contribute to the overall roadside noise. For roadways with high speed vehicles, **tire noise** is the dominant noise source.

Open-graded friction courses are typically quieter than regular paving. Research has shown that OGFCs reduce road noise levels for drivers as well as those who live or work near the roadway. The void structure within the open graded mix dissipates tire noise and causes the riding surface to absorb other noises instead of deflecting them.

In their paper, *Comparative Field Measurements of Tire Pavement Noise of Selected Texas Pavements*, McNerney, Landsbeger, Turen, and Pandelides presented field test data that showed open graded friction courses as the quietest surfaces tested. The top five quietest pavement types were HMA-based - as were seven of the top nine.

The quietest roadways were the result of road surfaces used in conjunction with noise structures, effective buffers and speed control. The perception of the reduction of noise, and its measurement in decibels (dBA), is a subjective matter. Each dBA represents a tenfold increase in energy from the unit below it. A 10 dBA increase basically is a doubling of loudness in human response in which a listener can say that it was twice as loud as the preceding sound. Three dBA is recognized as the threshold of perception of change and has a significant impact on most people.

Any noise reduction that a pavement can make will pay off for local governments and road agencies since noise barrier costs can be very expensive. Sound walls that were once considered an extravagance are now a standard operating procedure for new projects. Using open graded mixes to mitigate noise may prove to be a viable alternative versus the construction of noise structures. Barriers generally reduce noise levels by 3 to 5 decibels and cost $15 to $20 per linear foot. **Therefore, a considerable cost saving may be achieved by using OGFCs rather than barriers.**

Research has shown that OGFCs provide instant noise reduction by as much as 5 decibels. This immediate reduction is due to the diminishing effect that the open-graded structure of the asphalt layer has on the sound energy generated at the road surface. New research from the Nordic Road & Transport Research journal indicates immediate noise reductions of 3 to 5 dBA when an optimum drainage asphalt with air voids of 22 to 23 percent is employed. This is comparable to a traffic reduction of 50 percent, or a 100 percent increase in the protective distance from the road.

Open graded pavements produce noise at different frequencies versus those produced by conventional dense HMA mixes - this causes bystanders to assume that noise levels have dropped, even if instruments do not indicate a relative noise reduction. OGFC mixes help eliminate the more aggravating, high-pitched frequencies.

On the other hand, instruments can measure a decline in noise and humans may not perceive it. Human perception of noise versus dBA levels is a continuing challenge to acoustic researchers. In general, the clogging of the porous drainage structure will lead to a reduction in its drainage ability and in its ability to reduce noise.

ECONOMICS & LONGEVITY

Pavement longevity or service life is crucial for determining if a new method is economically viable. OGFC costs typically run 30 to 35 percent higher than those of conventional mixes but the mix in-place is lower which helps to offset the higher cost. This additional cost is due to extra mix components plus the equipment needed for mix production - increased production temperatures and slower production rates also contribute to these costs. The higher initial open-graded costs are balanced by long-term lower costs and maintenance savings. By considering user costs and traffic delays, it will be much cheaper to use OGFC when considering the whole life-cycle costs. Based on annualized costs, open-graded mixes are a cost-effective alternative by lasting a minimum of **19 months** longer than a conventional mix. The use of modified asphalt binders also tends to increase its life expectancy. Therefore, OGFCs are an attractive, cost-effective alternative over conventional pavements.

Typical OGFC Performance Factors

Quality of construction

Mix design

Regional climate

An important advantage of open-graded mixes is their resistance to rutting and deformation. OGFCs are less susceptible due to the interlock between the larger aggregates and the use of highly fractured aggregates. Open-graded pavement durability has been a problem in some areas although several OGFCs have provided 10 to 15 year service life. The pavement may age over time, oxidize and eventually begin to ravel. But most open-graded mixes are now designed and constructed using polymer modified asphalt cements. These polymer-modified asphalts also provide thicker films on the aggregate particles which minimize potential oxidation and reduces the tendency for raveling.

OGFCs have satisfactory service lives as long as proper care is taken in the mix design and usage. Today's open-graded mixes provide excellent durability and wear resistance to the full range of climatic and traffic conditions. The California Department of Transportation (CALTRANS) is currently using open-graded mixes to correct asphalt bleeding problems. The high voids in these mixes provide a reservoir for any excess asphalt bleeding from the underlying lift. In the past, open-graded friction courses were built with void contents as low as 12 percent and as high as 15 to 16 percent. Today's

OGFCs and European OGFC pavements have considerably higher air void contents, in the 17 to 22 percent range which prevents asphalt cement from flushing to the surface.

LIMITATIONS

The use of open-graded friction courses should be avoided in the following cases:

Unsound Paving

Never use OGFC directly over inadequate pavement without proper preparation of the existing pavement

Snow/Ice Areas

OGFC may tend to ravel in areas using tire chains, snowplows or tire studs

Modified binders can help mitigate this condition

Severe Turning Movements

Short radius turns (parking lots, intersections, truck stops, ramp termini, etc.) are not suitable for OGFC placement

Muddy/Sandy Areas

Fine material from sand or mud can clog the voids and reduce the drainage capacity

Oil and Fuel Discharge

Vehicle leakage can cause OGFC surface to soften and deteriorate rapidly

Areas to be Removed

Dense paving should be used as replacement material before overlaying with OGFC – prevents bathtub effect

Cold Climate

Avoid using OGFC in cold weather under 45 degrees F

Mixes with polymer modified binders are to be used where the temperature is between 45 and 55 degrees F

Special Pavement Patching

(www.fhwa.dot.gov)

PAST PROBLEMS

Past disappointment with the performance of OGFC led to a movement away from the mixes. During the 1960s, the FHWA pushed open-graded mixes to the state agencies. The extremely hot summer of 1980 accentuated the pavement distresses which caused many DOTs reason to reconsider using open graded mixes. A task force conducted a comprehensive pavement damage survey which showed significant cases of rutting, shoving, texture loss, blisters, slippage and stripping were found in most OGFC mixes - the most critical was the delamination of the mix immediately beneath the OGFC. These problems forced many of the states to place a moratorium on the use of OGFC by the early 1980s.

Raveling was also a major problem due to the presence of moisture and air which accelerated the oxidation process. OFGC mixes got a bad reputation because of a very rapid loss of paving material. Within the course of one year, a pavement with very little distress could rapidly deteriorate. During summer, the liquid asphalt cement would flow if exposed to heat for a long period of time. The resulting liquid asphalt without refinements would flow downward in the OGFC while the upper layer would become starved for asphalt and start to separate.

A recent survey showed vast improvements in open-graded pavements since their introduction in the 1950s. These improvements have been achieved with the help of good design and construction practices. OFGC mixes are more sensitive to temperature control. They require a lower and narrower placement temperature to prevent the thick asphalt film from draining off the aggregate. The ambient temperature should also be higher than normal during OFGC installation which can reduce its construction season. Hydrated lime is now used as an anti-stripping agent in OGFCs. The addition of fibers eliminates any drain-down of asphalt cement. **The secret to longer-life success is polymer modification of the asphalt binder.**

Survey Results

Agencies	Experience
50%	Good experience with OGFCs
70%	Service life of 8 or more years
80%	Standard OGFC specifications

CURRENT USAGE

State DOTs that have had success with OGFCs typically use different additives for performance enhancement, including:

Mineral fibers to increase the asphalt's ability to coat the aggregate

Polymer additives are used by most states for OGFC mixes

Hydrated lime is suitable for dry areas that can reach freezing temperatures

Rubberized asphalt allows higher binder content and improves durability

Any existing pavement structure deficiencies should be corrected. The base pavement layer needs to be dense graded to prevent possible structural failure.

Currently, many states require open-graded friction courses to be used on interstate projects. An ongoing, multi-year, pooled-fund study by 13 states is expanding interest in OGFC across the country. Georgia, Florida, South Carolina, Texas, Arizona, Colorado, Utah, Michigan, New Jersey, Rhode Island, and Vermont are among those participating in the study. In the past, northern states were reluctant to look at OGFCs because of the snow/ice removal issues plus the amount of water draining through the pavement. Due to improved safety benefits and performance of newer mixes, open-graded pavements are being re-examined.

Washington, Oregon and California use open-graded asphalt surface mixes to provide environmental benefits, skid resistance and added durability to new overlays. Washington State DOT (WSDOT) has placed over 386,000 tons of open-graded mix throughout their state. Open-graded surface mixes are also being used extensively for both new construction and rehabilitation overlays in northern California. Much of their popularity is due to the numerous environmental benefits they provide plus their proven durability.

The safety characteristics of OGFC mixes include good skid resistance and a quick draining surface. Open-graded mixes are designed and constructed with 15 to 25 percent voids, a range that allows surface water to drain through the mix to the edge of pavement. Standing water causes hydroplaning but when the water has drained through the pavement, no risk remains.

Georgia Department of Transportation

GEORGIA

After declaring its own moratorium on OGFC usage in 1981, the state of Georgia continued their research into open-graded mixes. Their investigation into moisture intrusion during the early 1980s resulted in revisions to the mix design plus changes in quality control and placement specifications. Georgia now uses open-graded mixes on all of its interstate hot-mix asphalt (HMA) pavements. Depth of placement is less than that of conventional mixes and depends on the condition of the existing pavement.

In 1992, Georgia specifications were changed to require a coarser gradation in order to enhance permeability and resist rutting. Georgia DOT primarily uses two polymers to modify asphalt cements used in open-graded mixes.

GDOT's has used a 0.5-inch standard mix composed of aggregate, polymer-modified asphalt cement, stabilizing fibers, and hydrated lime since 1993. The stiffer polymer-modified asphalt cement provides a greater film thickness and safeguards against the weathering problems experienced by earlier asphalt cements. Mineral fiber (typically

0.4%) has also been added to the total mix. The hydrated lime is used as an anti-stripping agent.

The conventional OGFC was placed at very low temperatures (230 to 248 degrees F) because of excessive asphalt cement drain-down during production and hauling. By adding polymers and fibers, the modified open-graded asphalt can be produced at much higher temperatures (320 to 338 degrees F) than conventional OGFC without drain-down problems.

Although standard open-grade friction course have typical service lives of eight years, the average life for Georgia's modified OGFC is 10 to 12 years. Based on annualized costs, this modified pavement would become a cost-effective alternative if it lasted just **19 months** longer than conventional mixes.

OREGON

Oregon continues to be a leader in use of OGFC in the United States. Over the past five years, the Oregon Department of Transportation (ODOT) has placed more than 3,600 lane miles of open-graded surface mix.

In the 1930's, Oregon started using open graded surface courses to improve skid resistance. The initial surface adopted as the standard contained a one-half inch maximum aggregate and installed at a minimum thickness of three-quarter-inch on a dense impermeable base. ODOT used the popcorn mix in the 1970s, half-inch minus aggregate size placed one-and-a-half-inches thick or thinner, as a friction course. Due to problems associated with durability, draindown and rich spots, Oregon was forced to slow its usage. However, Oregon accelerated the use of OFGCs during the 1980's and perfected their use.

Oregon's Type F mix is similar to the European porous asphalts, which typically use three-quarter-inch minus aggregate placed in thicker lifts. The Type F mix is two inches thick (as opposed to the thinner popcorn mixes) and uses a three-quarter-inch aggregate (instead of the half-inch or three-eighths-inch) with void ranges from 14 to 18 percent.

This mix performs much better than the old popcorn mix due to its coarseness, larger aggregate, and thickness. The resulting interlock provides more durability, stability and better drainage characteristics than thinner OGFCs. The Type F mix can handle more rain, reduce splash/spray, and have the same kind of frictional characteristics.

ARIZONA

The Arizona Department of Transportation (ADOT) began experimenting with open graded friction courses as early as 1954. They wanted a roadway surface with good skid resistance, good rideability and appearance. Over the years the gradation has changed slightly with more emphasis placed on using a single size aggregate.

In 1988, ADOT started to use crumb rubber mixed with hot asphalt (commonly referred to as asphalt rubber - AR) as a binder in hot mix asphalt (HMA) to reduce reflective cracking. Open-graded mixes generally contain 9 to 10 percent AR binder. Field performance results have been very good. ADOTs use of asphalt rubber has resulted in over five and one half million tires in Arizona being recycled since 1988.

In addition to its other properties, AR is a waterproofing membrane as well. Several projects were built to control subgrade moisture in order to control expansive (swelling) clays or to reduce structural pavement sections. In general, ADOT uses AR as a binder to reduce reflection cracking, improve surface durability, and reduce noise.

Cost comparisons have shown that asphalt rubber can be twice as expensive as conventional asphalt - with finished AR products being generally 80 to 160 percent more expensive than typical open-graded friction course. These higher costs need to be examined in light of actual usage. One inch AR-ACFC typically cost about $2.45 per square yard versus the comparable repair strategy of grinding the concrete costs of $5.00 dollars per square yard. The AR-ACFC continues to provide a smooth riding, crack free, skid resistant, quiet and virtually maintenance free surface for ten years.

New York State Department of Transportation

NEW YORK

In 1982, the performance of two separate 7-year old open friction course pavements were evaluated by the New York Department of Transportation. Both OGFCs continued to equal or exceed the performance of conventional state top-cover pavements with the open-graded mixes provided a better frictional performance.

Traffic volume determined the extent to which the open-graded mixes improved the frictional performance of the pavement. The best performance occurred at sites with minimum Average Annual Daily Traffic (AADT) of 3000 vehicles per lane.

New York also evaluated the performance of two different types of open-graded friction courses (a high-friction, dense-graded mix and a modified OGFC mix) at wet-weather sites in 1986. Overall, both types of pavements performed well and reduced wet-weather accidents from 61% (high-friction, dense-graded mix) to 100% (modified open-graded friction mix). The evaluation validated the use of OGFCs at surface-related, wet-weather accident sites. Open-graded mixes and pavement grooving can greatly improve areas with higher than expected wet pavement

EUROPEAN DESIGNS

While Americans were debating OGFC, Europeans were improving porous asphalt pavements to improve their performance. The majority of research was done by contractors and not by road agencies or DOTs. Unlike the United States, there is a close working relationship between contractor and government road agencies with centralized authority in a national road agency, and fewer (but more influential) vertically organized road contractors.

European contractors typically develop their own proprietary techniques and mixes, which are placed and warranted by the contractor (without any oversight and inspection) for the road agency. This tradition produced many new technologies that have benefitted the U.S. road user, such as stone matrix asphalt (SMA), proprietary modified asphalt cements and perfected porous asphalt pavements.

Stone Matrix Asphalt (SMA)

(Steve Muench; hawaiiasphalt.org)

In the early 1990's, the European practice was to use porous mixes as surface courses. Coarser gradation with larger top-size aggregate was used and placed in thicker layers. Additives and modifiers in the asphalt were used to achieve thick film coatings and get higher AC contents in the mix to increase durability.

European open-graded mixes have the same basic coarse aggregate skeleton as stone matrix asphalt (SMA), but without the fines. The SMA mix is a water-resistant, impermeable design. While mineral filler and fine aggregate tend to plug up voids in SMA, open-graded or porous mixes flush out those fines. Mineral or cellulose fiber is also be used to prevent migration of liquid asphalt.

MAINTENANCE

Maintenance issues that apply to open-graded friction courses include patching that must be done without disrupting surface permeability. Any surface treatment should depend on the size and severity of the failure. **Proper maintenance of the OGFC high void structure is the key to its performance.**

Severity	Description	Treatment
Low	Localized distress – small cracks, potholes	Seal or patch with dense graded mix
Medium	Localized distress	Open graded fill material
High	Expansive distresses – raveling	Mill existing top layer & overlay

Mix design, job selection, and suitable construction practices can help to minimize any pavement distress.

Special Pavement Patching

(Steve Muench; hawaiiasphalt.org)

Any OGFC maintenance activities should ensure unimpeded water flow through the pavement. Small failed areas may require only crack sealing or densely graded asphalt concrete. However, OGFC should be replaced with OGFC for large patch areas.

Due to its different thermal characteristics, ice and frost will accumulate faster and remain longer on than typical pavements. Maintenance forces may need to adjust any winter maintenance programs to deal with any OGFC roadways. Open-graded mixes may need more de-icing agents due to OGFC openness and rapid draining properties.

SUMMARY & CONCLUSIONS

For over 60 years, open-graded friction courses (OGFC) have been used to improve the frictional resistance of asphalt surfaces throughout the United States. OGFC allows surface water to drain through and away from the roadway. Benefits include: reduced hydroplaning; improved wet pavement friction; less vehicle splash and spray; better surface reflectivity; and quieter roadways.

During the early 1970’s, the Federal Highway Administration developed an OGFC mix design procedure which was used by several state DOTs. Although many states reported good initial experiences, others stopped using these open-graded courses due to unacceptable performance. Recent OGFC modifications have produced significant improvements in mix performance. Many states now use modified open-graded mixes as the final surface on all interstates and state routes with daily traffic volumes over 25,000 vehicles.

Coarse gradation for OGFC mixes provides a better performing roadway pavement. Most open-graded friction courses are 0.75-inch thick with a maximum thickness of 2 inches. Gradations near 15% passing the No. 4 (0.187-inch) sieve performed much better than finer gradations. Polymer and/or fiber modifiers were also shown to enhance the performance of open-graded mixes.

A thin film of asphalt and compaction keep the OGFC mix together. The final density of these mixes reflects its strength and durability. By using a grading of mostly 0.375-inch stone, open-grading mixes build up a thick film of asphalt on the stone without allowing the mixture to drain or flush - increasing the service life of the pavement. The asphalt film viscosity is usually 4 to 6 times that of dense-graded mixes.

The National Center for Asphalt Technology (NCAT) conducted a recent survey regarding state experiences with OGFCs. Although results varied, half of those surveyed indicated good performance from open-graded mixes. More than 70 percent reported an OGFC service life of eight or more years. Failures were normally resolved by refining the mix design and construction procedures for local conditions. Eighty percent of the states reported that they have standard specifications for the design and construction of OGFC. A vast majority of states reported good experiences with polymer modified asphalt binders. The states also used a coarser aggregate gradations compared to earlier gradations used.

Good design and construction practices appear to be crucial to improving OGFC performance. There continues to be a need to develop improved mix design procedures for the successful use of open-graded mixes. A well-designed, properly constructed OGFC should prevent raveling and be able to retain its high permeability and texture.

RECOMMENDATIONS

When selecting an open-graded friction course (OGFC), a number of factors (environmental conditions, alignment, accident rates, frictional properties, etc.) should be considered. Not all locations or pavements may be appropriate for an OGFC. Open-graded mixes should be used on high-volume, high-speed roadways, where the suctioning action of the tires on the pavement help to remove material residue from the porous layer. This action actually cleans the dirt and other materials that can clog the OGFC, reduce permeability, and limit sound-absorption. Open-graded pavements on lower-volume, slower-traffic local roads have produced mixed results. Therefore, it is important that proper project selection be considered.

An OGFC must be properly designed, constructed, and maintained in order to perform as intended. Experts make the following recommendations:

- **Place open-graded mixes only on structurally sound pavements with minimal cracks, ruts, bleeding and depressions.**
  Cracks are as likely to reflect through an OGFC as with any other thin asphalt course. Ruts may restrain lateral flow and cause water to pond which could separate the OGFC from the underlying pavement.

- **Seal any underlying pavement.**
  OGFC increases the amount of time that the underlying pavement will be wet. Stripping potential is increased if the underlying pavement has a high air voids content,.

- **Specify the coarse aggregate as polish resistant and crushed material** since the frictional qualities of an OGFC are affected by its microtexture.

- **Design any OGFCs in accordance with the mix design procedures.**
  These basic steps determine asphalt content, mixing temperature, air voids, and moisture damage susceptibility.

- **Add silicone to asphalt cement to improve mix workability and reduce the potential of tearing.**

- **Place OGFCs as a thin lift since they lose heat quickly.** It should only be placed when the underlying pavement surface and ambient temperature have been reached, otherwise raveling may result.

- **Install OGFCs full width, from outside edge to outside edge of the shoulders,** to provide a cross-section with uniform frictional properties. Otherwise, the lateral flow of water may become obstructed.

- **Keep longitudinal and transverse joints to a minimum to avoid roughening of the surface.**

Open-graded friction courses typically have a higher asphalt content than a dense graded mix and use an equal or harder grade of asphalt. **A very heavy asphalt film on the aggregate has proven to be essential for longevity** by resisting stripping and oxidation of the asphalt cement. It is critical that no reduction in asphalt content be made based on the OGFC appearance.

An open-grade course should be tested for its susceptibility to moisture since its high air voids content increases stripping potential. The mix should be tested for coating and strength retention → if stripping is observed, the mix design must be revised.

OGFCs are likely to remain a part of roadway networks due to their specific utility. Any past longevity issues can be managed with intelligent design and proper installation methods. Open-graded mixes can positively impact roadway safety and the surrounding environment. OGFCs will continue to be a beneficial ingredient of roadways as long as transportation agencies continue to search for better pavement.

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