Introduction to
Open-Grade Friction Courses (OGFC)

by

Gregory J. Taylor, P.E.
COURSE OBJECTIVES

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

The primary 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 advantages of using open-graded courses; limitations or past problems; current OGFC mix design and 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 (OFGC).

INTRODUCTION

What are open-graded friction courses (OGFC)?

The term "open-graded friction course" is defined as a thin, permeable layer of asphalt that incorporates a skeleton of uniform aggregate size with a minimum of fines. The pavement's ability to resist trucks and carry the loads without undergoing permanent deformation is due to this true aggregate skeleton. The load is carried by the stone and the asphalt holds everything in place. The voids of an OGFC plus its stone-on-stone skeleton give this type of mix many positive attributes. The porous nature of the OGFC allows immediate drainage of water from the pavement surface. Much like
the stone matrix asphalt (SMA) mixes imported from Europe in recent years, 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 (example: 1970s "popcorn" and porous asphalt mixes). The voids also absorb sound energy as tires roll over the pavement and reduce surface noise.

Since 1950, open-graded friction course (OGFC) has been used to improve the surface frictional resistance of asphalt pavements. The Federal Highway Administration (FHWA) developed a OGFC mix design procedure in 1974 to be used by state departments of transportation (DOTs). Initially, many DOTs reported good performance using OGFC but many others stopped using OGFC due to unacceptable performance. Since then, many significant improvements have been made in the gradation and binder type used in the OGFC. Although experience of states with OGFC has been varied, half of the states surveyed in a recent National Center for Asphalt Technology (NCAT) study indicated good performance with OGFC. More than 70 percent of the states reported an OGFC service life of eight or more years. Plus, approximately 80 percent of the states have standard specifications for the design and construction of open-graded mixes.

Since water is the greatest enemy of pavements, the roadway benefits from any quick drainage of water that open-graded friction courses 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. The result is an
elimination of tire spray and hydroplaning, improved wet pavement friction, increased surface reflectivity, and reduced traffic noise which make a safer pavement.

Research in the United States and overseas shows OGFC provide instant noise reduction by as much as 5 decibels (dBA). An immediate reduction in roadway noise is due to the diminishing effect that the open-graded structure of the asphalt layer provides to the sound energy generated at the road surface.

OGFCs offer state transportation departments a better-performing, driver-friendly pavement, but at a 30 to 40% cost premium over conventional asphalt mixes. However, open-graded mixes are lighter in weight than conventional pavements. A ton of material is able to cover more square yards of pavement surface area. This 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.

<table>
<thead>
<tr>
<th>Mix Control</th>
<th>Typical Tolerance</th>
<th>Gradation Requirements</th>
<th>Design Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Concrete</td>
<td>FHWA Guidelines</td>
</tr>
<tr>
<td>±0.0</td>
<td>% Passing 19 mm Sieve</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>±6.1</td>
<td>% Passing 12.5 mm Sieve</td>
<td>100</td>
<td>85-100</td>
</tr>
<tr>
<td>±5.6</td>
<td>% Passing 9.5 mm Sieve</td>
<td>95-100</td>
<td>55-75</td>
</tr>
<tr>
<td>±5.7</td>
<td>% Passing 4.75 mm Sieve</td>
<td>30-50</td>
<td>15-25</td>
</tr>
<tr>
<td>±4.6</td>
<td>% Passing 2.36 mm Sieve</td>
<td>5-15</td>
<td>5-10</td>
</tr>
<tr>
<td>±2.0</td>
<td>% Passing 75 µm Sieve</td>
<td>2-5</td>
<td>2-4</td>
</tr>
</tbody>
</table>

(Ref: FHWA, Georgia DOT & Tennessee DOT)

The recent generation of open-graded friction-course pavements that are being 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 4 to 7 percent. The newer OGFC mixes are much more open with more voids.
Today’s OGFCs are polymer-modified and include spun mineral or cellulose fibers. Use of polymer modifier or fiber complements the other in the liquid asphalt. The polymer modifier stiffens the asphalt binder and adds flexibility which helps it resist raveling. The fibers disperse, overlap and form a mat, which keeps the liquid asphalt from draining to the bottom of the layer before it cools.

DISCUSSION

ADVANTAGES
Open graded friction courses exhibit the following advantages:

- 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

SAFETY
From a safety aspect, open-graded mixes are very advantageous due to their rapid drainage surfaces and excellent skid resistance. Any risk of hydroplaning after a heavy rain is greatly reduced by the OGFC’s void structure. With a 15 to 25 percent void range within the surface, water can quickly enter and drain through the structure.

NOISE REDUCTION
Tire pavement noise is only one source of vehicle noise. Engine and exhaust noise, as well as wind shear can also contribute to the overall noise heard at roadside. For roadways with high speed vehicles, tire noise is the dominant noise source.

Recent studies show that OGFCs reduce road noise levels for drivers as well as those who live and work near the roadway. Tire noise is dissipated through the void structure.
within the open graded mix. These voids also cause the riding surface to absorb other noises instead of deflecting them.

In their 1998 paper Comparative Field Measurements of Tire Pavement Noise of Selected Texas Pavements, McNerney, Landsbeger, Turen, and Pandelides presented the results of field tests that showed that open graded friction courses were the quietest surfaces tested. All of the top five quietest pavement types were HMA-based, as were seven of the top nine.

The quietest roadways were obtained when road surfaces are used in conjunction with noise structures, effective buffers and speed control. Any contribution that the pavement can make to reduce noise will pay off for local governments and road agencies since the cost of noise barriers can be very expensive. On new projects, sound walls that were once considered an extravagance now are standard operating procedure. Placing OGFC to mitigate noise may prove to be a viable alternative to the construction of noise structures. Barriers generally reduce the noise level by 3 to 5 decibels and cost between $15 and $20 per linear foot. Therefore, a considerable cost saving may be achieved by using OGFC rather than barriers.

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.

New research from the Nordic Road & Transport Research journal indicates immediate reduction of noise emissions of 3 to 5 dBA when an optimum drainage asphalt with air voids of 22 percent 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.

OGFC pavements produce noise at different frequencies than those produced by conventional dense HMA mixes, and this causes bystanders to assume that noise levels have dropped, even when the instruments do not indicate a relative reduction in noise. Open graded mixes reduce the more aggravating, high-pitched frequencies.
On the other hand, instruments can measure a decline in noise, but humans may not perceive it. The subjectivity of human perception of noise and dBA levels is a continuing challenge to acoustic researchers. In general, the clogging of the drainage structure of the porous asphalt will lead to a reduction in its drainage ability and in its ability to reduce noise.

HIGHER COSTS & LONGER LIFE
The higher initial costs for open-graded friction courses are balanced by long-term lower costs and maintenance savings. The cost of OGFC typically runs 30 to 35 percent higher than that of conventional mixes. This additional cost is the result of including extra components in the mix plus the equipment needed to properly introduce these components into the mix production. Increased production temperatures and slower production rates also contribute to increased production costs. After factoring in user costs and traffic delays, it proved to be much cheaper to use OGFC when considering the whole life-cycle costs of a system. Based on annualized costs, open-graded mixes are a cost-effective alternative by lasting a minimum of 19 months longer than the conventional mix. Therefore, OGFC are an attractive, cost-effective alternative over conventional mixes.

An important advantage of open-graded mixes is their resistance to rutting and deformation. OGFCs are less susceptible to deformation than most dense-graded mixes because of the interlock between the larger aggregates and the use of highly fractured aggregates. Durability of open-graded pavements has been a problem in some areas although several have provided 10 to 15 years of service. Over time, the pavement may age and 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. This minimizes potential oxidation and reduces the tendency for raveling.

Today’s OGFC also provide excellent durability and resistance to wear in 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. Typically, the open-graded friction courses that were built in the past had a void content as low as 12 percent and as high as 15 to 16 percent. But the new generation of OGFCs and the European OGFC pavements have
considerably higher air void contents, in the 17 to 22 percent range. Therefore, asphalt cement does not flush to the surface.

LIMITATIONS
When compared to other high type roadway surfaces, OGFCs have demonstrated the following limitations:

- Raveling and shoving potential.
- Increasing the potential for stripping
- Requiring special snow and ice control methods
- Needing special patching and rehabilitation techniques;
- Not increasing structural value to the pavement

PAST PROBLEMS
Disappointment with the performance of OGFC led to a movement away from the mixes. The FHWA pushed open-graded mixes to the state agencies in the 1960s and '70s, but there were some problems with those mixes. The extremely hot summer of 1980 accentuated the pavement distresses that gave many DOTs reason to reconsider use of open graded mixes. A task force conducted a comprehensive pavement damage survey, in which significant cases of rutting, shoving, texture loss, blisters, slippage and stripping were found in most OGFC mixes, but most critical was the delamination of the mix immediately beneath the OGFC. These problems proved to be severe enough to force many of the states to place a moratorium on the use of OGFC by the early 1980s.
Raveling in OGFC was also a major problem due to the presence of moisture and air which accelerated the oxidation process. Open-graded courses 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. In the summertime sun, the liquid asphalt cement would flow if exposed for a long period of time. The resulting liquid asphalt without refinements would flow downward in the OGFC. The upper layer then would become starved for asphalt and start to come apart.

A 1998 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. Modified asphalt mixes are now mixed at higher temperatures and more efficiently dried in drums to improve adhesion. Hydrated lime is now used as an anti-stripping agent in OGFCs. The addition of fibers eliminates any drain-down of asphalt cement. Half of the agencies surveyed in this study indicated good experience with OGFCs. More than 70% of the agencies that use open-graded surface courses reported service life of eight or more years. About 80% of the agencies using such pavements have standard specifications for design and construction. Their secret to longer-life success is polymer modification of the asphalt binder.

**CURRENT USAGE**

Currently, Georgia, Florida, and Alabama require open-graded friction courses to be used on all 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 joining lead state Alabama in the study. In the past, northern states were reluctant to look at OGFCs because of the snow and ice removal issues and the amount of water draining through the pavement. Due to safety benefits and the improved performance of the newer mixes, these open-graded pavements are being re-examined.

Washington, Oregon and California are using open-graded asphalt surface mixes to provide environmental benefits, skid resistance and added durability to new construction and asphalt 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 in northern California for both new construction and rehabilitation overlays. These mixes are being specified on an increasing basis throughout the
Northwestern US. Much of their popularity is due to the several environmental benefits they provide plus their proven durability.

The safety characteristics of OGFC mixes include good skid resistance and a quick draining surface. Even following heavy rains, there is a minimum of standing water on the pavement surface. Open-graded mixes are designed and constructed with 15 to 25 percent voids, a range that allows surface water to enter the pavement structure, then quickly drain through and out of the structure. Standing water will cause hydroplaning but when the water has drained through the pavement, no risk remains.

**GEORGIA**

After declaring its own moratorium on OGFCs in 1981, the state of Georgia did not abandon research into them. Their investigation into moisture intrusion in the early 1980s led to revisions in mix design plus changes in quality control and placement specifications. Georgia now uses open-graded mixes on all its interstate hot-mix asphalt (HMA) pavements. Depth of placement depends on the condition of the existing pavement. But it is less thick than that of a conventional mixes.

Georgia DOT’s 0.5-inch standard mix has been used statewide since 1993. It is composed of aggregate, polymer-modified asphalt cement, stabilizing fibers, and hydrated lime. The inclusion of stiffer polymer-modified asphalt cement gives the mix greater film thickness and safeguards against the weathering problems experienced by earlier asphalt cements. Mineral fiber has also been added, typically 0.4% of the total mix. Georgia adds hydrated lime as an anti-stripping agent.
In 1992, Georgia specifications were changed to require a coarser gradation. The coarser gradation enhances permeability and resistance to rutting. Georgia DOT primarily uses two polymers to modify asphalt cements used in open-graded mixes.

The conventional OGFC was placed at very low temperatures (110 to 120 degrees C, or 230 to 248 degrees F) because of excessive asphalt cement drain-down during production and hauling. The modified open-graded asphalt can be produced at much higher temperatures than conventional OGFC without drain-down problems because of the addition of polymers and fibers. Typical mix temperatures now range from 160 to 170 degrees C (320 to 338 degrees F).

While the standard open-grade friction course had a typical service life of eight years, Georgia’s modified OGFC is expected to last 10 to 12 years. Based on annualized costs, the modified pavement would become a cost-effective alternative if it lasted just 19 months longer than the conventional mix.

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. 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. As with other states, early disappointments were followed by a reconsideration of the mixes.

Oregon’s Type F mix is similar to the European porous asphalts, which typically use three-quarter-inch minus aggregate placed in thicker lifts. Oregon will place the Type F mix two inches thick, as opposed to the thinner popcorn mixes, using a three-quarter-inch minus aggregate, instead of the half-inch or three-eighths minus and will use void ranges from 14 percent to 18 percent.
This mix performs much better than the old popcorn mix since it's coarser, with larger stone, and thicker. There is a certain degree of interlock that affords it more durability and stability and better drainage characteristics than thinner OGFCs. It can handle more rain, and still reduce splash and spray, while getting the same kind of frictional characteristics.

ARIZONA
The Arizona Department of Transportation (ADOT) began to use open graded friction courses as early as 1954. The primary reason for using this material was to provide a surface with good skid resistance, good rideability and appearance. Over the years the gradation has changed slightly. In particular, more emphasis has been placed on the use of a single size aggregate.

ADOT has used crumb rubber to primarily reduce reflective cracking. In 1988, they started to use crumb rubber mixed with hot asphalt, commonly referred to as asphalt rubber (AR) as a binder in hot mix asphalt (HMA). Open-graded mixes generally contain 9 to 10 percent AR binder. To date, field performance has been very good. As an extra benefit, the ground tire rubber from over five and one half million tires in Arizona has been recycled since 1988, in the making of HMA with AR.

In addition to reducing reflective cracking, it was noted early on that AR is a waterproofing membrane. Several projects were built to control subgrade moisture in order to control expansive (swelling) clays or to reduce structural pavement sections. In general, ADOT is using AR as a binder in HMA mixes to reduce reflection cracking, improve durability of surface courses, and in urban areas to reduce noise.
Cost comparisons would indicate that AR can be from up to twice as expensive as asphalt. The finished AR product is generally from 80 to 160 percent more expensive than the 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. The comparable repair strategy of grinding the concrete costs about $5.00 dollars per square yard. The AR-ACFC continues to provide a smooth riding, virtually crack free, good skid resistant, quiet and virtually maintenance free surface for ten years.
NEW YORK
In 1982 after seven years of service, the performance of two 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. The open-graded mixes provided a better frictional performance. Traffic volume determined the extent to which the OFGCs improved the frictional performance of the pavement. The best performance occurred where the Average Annual Daily Traffic (AADT) was a minimum of 3000 vehicles per lane.

NYDOT 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). Although the evaluation was based on a small sample size, it validates the use of OGFCs at surface-related, wet-weather accident sites. Open-graded mixes and pavement grooving greatly improve areas with higher than expected wet pavement accidents.

EUROPEAN DESIGNS
While Americans were debating OGFC, European researchers were improving porous asphalt pavements to get the performance they desired. Much of this research work was done not by road agencies or DOTs, but by contractors. Unlike the United States, there is a close working relationship between contractor and government road agency with centralization of authority in a national road agency, and fewer but more influential, vertically organized road contractors.

Usually the European contractor develops his own proprietary techniques and mixes, which are placed and warranted by the contractor for the road agency, but without the oversight and inspection by the road agency that is common in the US. This tradition has been an incubator for new technologies that have been of benefit to the U.S. road users, such as stone matrix asphalt (SMA), proprietary modified asphalt cements and perfected porous asphalt pavements.
The European practice in the early '90s was to use porous mixes as surface courses. The gradation was coarser, larger top-size aggregate was used and it was placed in thicker layers. The Europeans used additives and modifiers in the asphalt in order to achieve thick film coatings and get higher AC contents in the mix which would increase durability.

European open-graded mixes have the same basic coarse aggregate skeleton as stone matrix asphalt, but without the fines. SMA mix is an impermeable mix that is resistant to water. Mineral filler and fine aggregate tends to plug up voids in SMA, while in an open-graded or porous mix, those fines are taken out. Mineral or cellulose fiber can also be used to prevent migration of liquid asphalt.

**SUMMARY & CONCLUSIONS**

Open-graded friction courses (OGFC) have been used to improve the surface frictional resistance of asphalt pavements for over 50 years throughout the United States. OGFC improves wet driving conditions by allowing the water to drain through and away from the roadway. The benefits of this improved surface drainage include: reduced hydroplaning; improved wet pavement friction; less vehicle splash and spray; better surface reflectivity; and quieter roadways. The Federal Highway Administration developed a mix design procedure for OGFC in the early 1970’s, which was used by several state DOTs. Although many states reported good performance, others stopped using these open-graded courses due to unacceptable performance, inadequate
durability, etc. With recent OGFC modifications, significant improvements in mix performance have already been noted. In some states, it is now policy to use modified OGFC as the final ride surface on all interstates and on state routes with daily traffic volumes over 25,000.

A coarser gradation for OGFC mixes seems to provide a better performing roadway pavement. Most open-graded friction courses are 0.75-inch thick, and never thicker than 2 inches. Gradations near 15% passing the No. 4 (4.75 mm) sieve performed much better than finer gradations. Modifiers (polymer and/or fiber) were also shown to enhance the performance of OGFC mixes.

A thin film of asphalt and compaction is required to keep the OGFC mix glued together. The final density of these mixes directly reflects the strength and durability of the mix. But OGFC uses a grading of mostly 0.375-inch stone, the idea being to build up a thick film of asphalt on the stone without the mixture draining or flushing and increasing the life of OGFC pavements. The asphalt film viscosity is usually 4 to 6 times that of a dense-graded mix.

Recently, the National Center for Asphalt Technology (NCAT) conducted a survey on the experience of states with OGFC. Although OGFC experience has been varied, half of the states surveyed in this study indicated good performance. More than 70 percent reported an OGFC service life of eight or more years. When any failures occurred, many were resolved by refining the mix design and construction procedures for local conditions. About 80 percent of the states have standard specifications for the design and construction of OGFC. A vast majority of states reporting good experience use polymer modified asphalt binders. Also, aggregate gradations used by these states tend to be somewhat coarser compared to earlier gradations used.
Good design and construction practices appear to be the key to improved performance of OGFC mixes. Presently, there continues to be a need to develop improved mix design procedures to help in the successful use of OGFC. A well-designed and properly constructed OGFC should not have raveling problems plus it should be able to retain its high permeability and texture.

**RECOMMENDATIONS**

In selecting an open-graded friction course (OGFC), a number of factors such as the environmental conditions, alignment, accident rates and the frictional properties of the State's standard surface mixes should be considered. Not all locations or pavements may be appropriate for an OGFC. Therefore, it is important that proper project selection be considered.

Experts recommend that OGFCs be used on high-volume, high-speed roadways such as interstate highways, where the suctioning action of the tires on the pavement tend to remove material residue from the porous layer. Open-graded pavements on lower-volume, slower-traffic local roads have been less successful.

For an OGFC to perform as intended, it must be properly designed, constructed, and maintained.
An open-graded mix should only be placed 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.

Any underlying pavement should be sealed. 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.

The coarse aggregate should be specified as polish resistant and crushed material since the frictional qualities of an OGFC are affected by its microtexture.

An OGFC should be designed in accordance with the mix design procedures. These basic steps determine asphalt content, mixing temperature, air voids, and moisture damage susceptibility.

Silicone can be added to asphalt cement to improve mix workability and reduce the potential of tearing.

An OGFC is placed as a thin lift and loses heat quickly. It should only be placed when the underlying pavement surface and ambient temperature have been reached, otherwise raveling may result.

OGFC should be placed 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.

Longitudinal and transverse joints should be kept to a minimum to avoid roughening of the surface.

An OGFC generally has a higher asphalt content than a dense graded mix and uses an equal or harder grade of asphalt. A very heavy asphalt film on the aggregate has proven to be essential for longevity. The film helps to resist 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 the potential for stripping. The mix should be tested for retained coating and retained strength. If stripping is observed, the mix design must be revised.

Open-graded friction courses are best suited for high-speed, high-volume roadways. The action of the vehicles actually cleans the dirt and other materials that can clog the OGFC, reduce permeability, and limit sound-absorption.

REFERENCES


Introduction to Open-Graded Friction Courses (OGFC)
A SunCam online continuing education course

Federal Highway Administration, FHWA Technical Advisory T 5040.31 4-34 Materials Notebook:
Open Graded Friction Courses, December 1990.

Fitts, Gary, The New and Improved Open Graded Friction Course Mixes, Asphalt Institute, Asphalt Magazine, Fall 2002.

Georgia Department of Transportation, Georgia Department of Transportation’s Progress In Open-
Graded Friction Course Development, Transportation Research Record 1616.


Kandhal, Ken and Mallick, Rajib, NCAT Report No. 98-7 Open Graded Asphalt Friction Course: State
of the Practice, National Center for Asphalt Technology at Auburn University, May 1998.

Kuennen, Tom, Open-Graded Mixes: Better the Second Time Around,
American City & County, August 1996.


McNerney, Michael T., Landsberger, B.J., Turen, Tracy, and Pandelides, Albert, Comparative Field

Moore, Walt, Research Investigating the Tire/pavement Interface is Aimed at Building Quieter


Tennessee Department of Transportation, Standard Specifications for Road and Bridge Construction, March 1, 1995.