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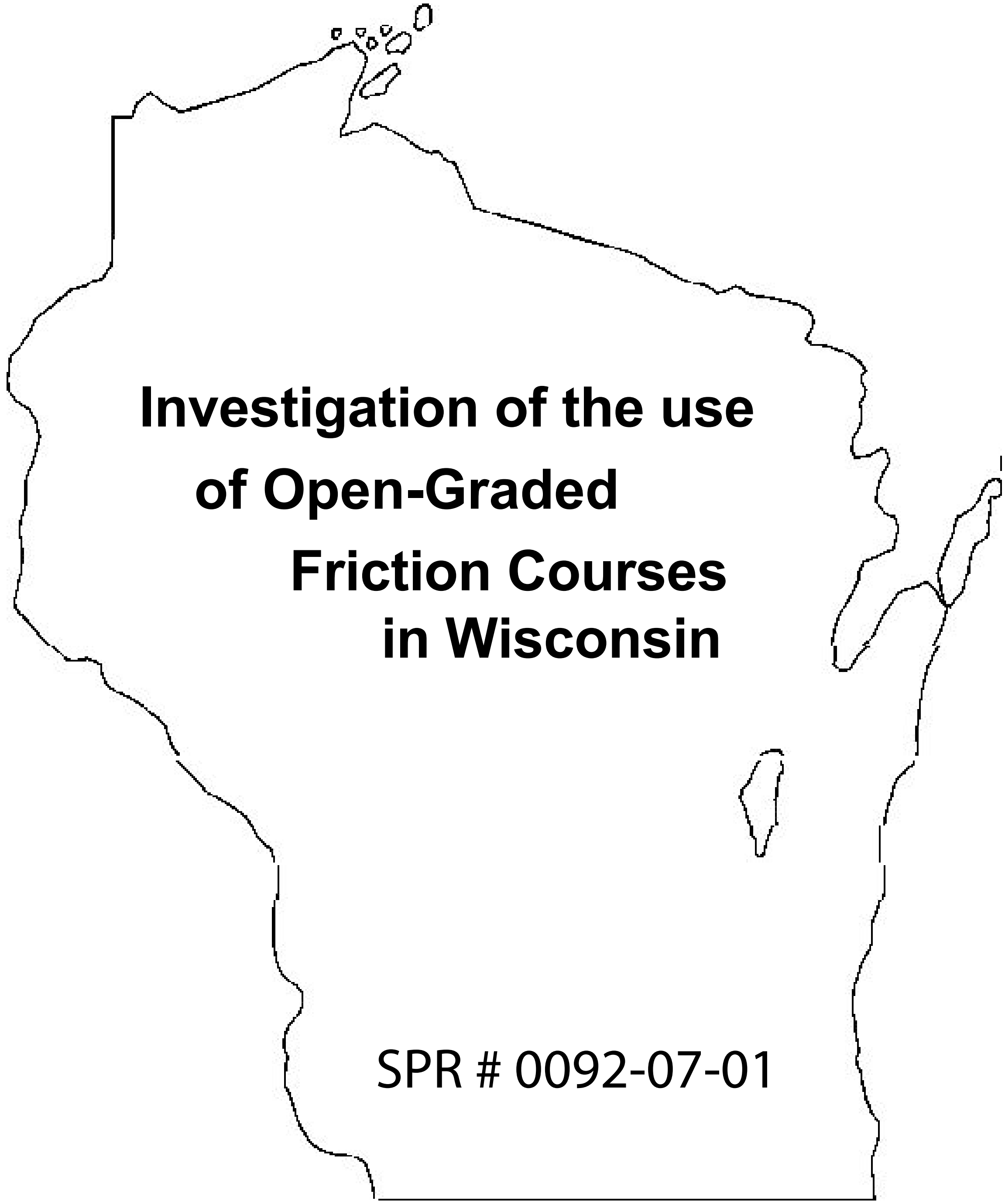

Investigation of the use of Open-Graded Friction Courses in Wisconsin

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16. Abstract

The primary objectives of this study are to determine if the OGFC mixture can be successfully and economically used in Wisconsin, evaluate the likely benefits for the Wisconsin climate, recommended applications processes and procedures, and to develop appropriate mixture design and construction specifications.

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INVESTIGATION OF THE USE OF OPEN-GRADED FRICTION COURSES IN WISCONSIN

By
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The use of open-graded friction course (OGFC) mixtures has changed over recent years across the United States. The OGFC mixtures designed and produced prior to 2000 experienced numerous performance problems that resulted in premature failures due to raveling, debonding and stripping of the underlying layer. Additionally the use of these mixtures in northern climates created additional seasonal problems with winter snow and ice control compared to dense graded Hot Mix Asphalt (HMA). As a result of these failures almost all Northern states that tried, and in some cases, frequently used OGFC mixtures discontinued their use. In or around 2000, several states and the National Center for Asphalt Technology (NCAT) started recommending and using European type OGFC mixtures with larger coarse aggregate, less fine aggregate, higher air voids (18 to 20 percent+) and polymer modified asphalt and/or fibers (1). These new generation OGFC mixtures (as they are called) were promoted as a method to improve poor performance due to raveling (caused by aging of the AC binder and thin asphalt films on the aggregate) and pavement fat spots and areas of bleeding (caused by drain down of the AC binder from the aggregate during the construction process).

As Wisconsin is looking at increasing its usage of the perpetual pavement concept, OGFC may provide another option for use as the renewable surface layer. OGFC has historically not been used in Wisconsin due to concerns about its performance in a climate with a large number of freeze-thaw cycles. Questions also exist about the cost/benefit of these mixtures.

PROJECT DESCRIPTION

The primary objectives of this study are to determine if the OGFC mixture can be successfully and economically used in the Wisconsin climate (Part 1), to recommend application and process procedures, and to develop appropriate mixture design and construction specifications (Part 2). The completion of Part 2 of the project is predicated on the results of Part 1.

BACKGROUND

The development of OGFC has evolved over the years from field trials of placing precoated aggregate chip seal coats with a paving machine in the 1930's in Oregon (11). One of the first recorded mixture design procedures came out of Colorado in the early 1970's. It involved the compaction of trial mixtures in the laboratory and identifying the level of asphalt drain-down in the mixture by sawing the samples open. The idea was to seal the lower third of the mixture to prevent water penetration into the binder/base layers and provide an asphalt rich layer that would stick to lower layers. In the mid 1970's, Dr. Richard Smith working for the FHWA developed a mixture design procedure that is still in use in some parts of the United States today. The method developed by Smith determined asphalt binder content by a variation of the Hveem procedure and established construction-mixing temperature using a drain-down test (3). NCAT has published work on updating the OGFC mixture design procedure to include a) coarser aggregate gradations, b) possible use of polymer modified asphalt binders and/or fibers in the mixture, c) use of air voids to determining optimum asphalt binder content and d) a mixture durability test (1).

The wet weather benefits of improved pavement friction at high speed and reduced tire spray of the early OGFC mixtures led to a rapid expansion of their use across the country in the mid 1970's. As a result of this expansion (in some cases into areas where these mixtures were less suitable), a number of failures began to occur that caused a rapid decrease in OGFC use in the 1980's. The most numerous of these problems were pavement raveling and stripping of the lower asphalt layers because of the introduction of water into the binder and/or base. Previously, when water got into the top of somewhat porous asphalt layers, it dried out rapidly because of the warm pavement temperatures due to the sun shining on a black surface and evaporation. With the OGFC on top, the water in the lower layers was unable to evaporate or drain away and led to stripping. Additional problems occurred particularly in northern states with OGFC delaminating, damage from snow plowing, air voids plugging and problems with snow and ice control in cold weather. A number of construction related problems also occurred due to asphalt drain down creating fat spots (asphalt bleeding) on the surface and raveling due to handwork and construction in cooler temperatures.

Over the last ten years, the increased use of polymer binders in OGFC mixtures, better design procedures (NCAT procedure (1)) and improved construction control procedures (QC/QA) has lead to a rapid resurgence of the use of OGFC mixtures in warm climate states. Agencies have also resolved the stripping problems in lower layers by improved design procedures for the lower layers. The recognized benefit of pavement noise reduction (3 to 6 decibels (2, 4, 6, 8)) has further increased the use of these mixtures. In the Phoenix area, Arizona DOT is placing a form of crumb rubber modified OGFC mixture on all major interstate highways for noise reduction.

The primary goal of this project is to develop the information for the Wisconsin DOT (WisDOT) to determine if the wet weather benefits of less water spray, improved speed gradient (ability to maintain friction number at high speeds with water present) plus reduced noise outweigh increased winter maintenance problems, increased costs, reduced pavement life and the consideration that most pavement thickness design procedures do not give the OGFC layer any structural value. One of the means that will be used to accomplish this goal is the establishment of a *"cold states study area"* (15 neighboring states, two high use states with mountains and four Canadian provinces with a similar climate to Wisconsin). Details on all aspects of OGFC usage in the *"cold states study area"* will be obtained to try to establish the current "state of the art" for pavements in a cold environment.

LITERATURE REVIEW AND SURVEY OF STATES PRACTICES

A detailed literature review was conducted concentrating on studies by individual highway agencies on the use and performance of OGFC layers in their states. A number of reports were found that contained national surveys on the use of OGFC mixtures. These surveys covered a time period starting around 1988 with the last one conducted in 2006. This time period covers from when OGFC mixtures were built according to the original OGFC mixture design methods characterized by the 1974 FHWA design procedure (3) to current OGFC mixtures designed according to the so-called new generation OGFC procedures represented by the 2000 NCAT recommendations (1).

A reference to an earlier state survey conducted in 1978 indicated that 15 states were using OGFC and several additional states were considering its use (4). The report further indicates that the use of the mixture was declining by the mid 1980's.

The first significant state survey found in the literature was summarized in NCHRP Synthesis 180 (4). This report includes the results of a 1988 AASHTO Subcommittee on Construction survey along with a literature review of OGFC usage combined with visits and interviews with select states. A total of 47 states, one territory and three Canadian provinces responded to the survey. The report indicates that 27 agencies were reporting continued use and that 21 agencies had stopped using the OGFC mixture. The report indicated, "One of the most serious causes of premature OGFC failures is the oxidation of the asphalt binder film". A summary of the effectiveness of de-icing chemicals on OGFC surfaces indicated that two states had better results, 12 states reported no difference and eight states had worse performance when compared to dense graded HMA surfaces. The states provided limited documentation of these results. The primary reasons given by the states for limited or discontinued use of OGFC mixtures were, a) early failures, stripping of the underlying courses, b) construction difficulty, c) reduction in friction and d) loss of internal drainage characteristics with time. The report also indicated that OGFC mixtures cost was approximately 21% more than dense graded HMA surfaces. It also pointed out that in general agencies did not give any credit to the OGFC layer in the pavement structure. This means that the cost of the OGFC layer is an add on to the total contract price and it can't be offset in part by a reduction in the thickness of the HMA layers on the project.

In December of 1998 the Transportation Research Board (TRB) Committee on Characteristics of Bituminous-Aggregate Combinations to Meet Surface Requirements published a Transportation Research Circular on the results of a national survey on the use of OGFC mixtures (E-C005) (5). This survey was conducted during the time some states were beginning the transfer from the original OGFC mixtures to the new generation mixtures. Forty-two states responded to the survey. Of those states, 19 were currently using some type of OGFC mixture, four had never used the OGFC mixture, 19 states had discontinued using the mixture and eight states did not respond to the survey. This survey showed that only Illinois and Wyoming were using OGFC in the *"cold state study area"* for this project.

In 2000, NCHRP published their third Synthesis (284) titled "Performance Survey on Open-graded Friction Course Mixes" (6). This survey summarized for a second time the results of the 1998 TRB Committee survey and included additional information that indicated the current usage of OGFC in all of the US States and Canadian Provinces with the exception of the state of Mississippi. The results of this survey indicate that the only agencies using OGFC in this report's *"cold state study area"* were Wyoming and Ontario. It also showed that the 12 agencies in the *"cold state study* area" that discontinued use of OGFC did so before the development of the new generation mixtures.

In 2004, a research project idea was advanced in NCHRP by Texas DOT to look at the winter performance of OGFC mixtures. The project was titled, "Cold Weather Performance of New Generation Open-Graded Friction Courses". However, prior to final funding and selection of a research agency, the project scope was expanded and the title was change to "Performance and Maintenance of Permeable Friction Courses" (NCHRP Project 9-41 (7)). The term Permeable Friction Courses was developed for use during this project in place of New Generation Open-Graded Friction Courses. The project was funded in the spring of 2005 with an expected completion date for the end of 2006. It is currently understood that the final report for this project has not been submitted yet. Copies of a draft report have been provided to allow the NCHRP results to be used in this project. The study included a new industry survey (conducted in 2005 or 2006) on the use of OGFC in the United States and Canada and a detailed literature search for papers on the use of OGFC.

The NCHRP 9-41 survey received responses from 36 states plus information gained from personal contacts with some of the states that did not respond (7). Only 14 states and one Canadian province responded that they were using OGFC type mixtures and of those, nine states indicated that they were using the new generation OGFC mixture. None of the nine states using the new OGFC mixture were in the *"cold state study area"* established for this WisDOT project. The NCHRP survey results indicated that only Iowa and Nebraska were currently using some form of older OGFC mixture in the *"cold state study area"*. The researchers reported that even though Indiana did not reply to their survey, they are using a new generation OGFC. Further information has shown that Indiana has only placed one small new generation OGFC mixture (asphalt binder modified with crumb rubber) on an interstate highway primarily for noise reduction (12). Specific details of the individual state responses to the survey were not included in the NCHRP 9-41 report. Requests have been made to both the project research team and the NCHRP project manager for information on specific state responses to the questioner. To date we have not received any of the information that was requested.

In 2006, the University of Texas Center for Transportation Research (CTR) sent out another survey on the use of new generation OGFC mixtures. This work was part of a larger research project on "Cold Weather Performance of New Generation Open Graded Friction Courses" (9). The second report for this study, which presented the survey results, was completed in early 2007. CTR got survey replies back from 26 states. Eleven states indicated that they were using the new generation OGFC mixture. Five states said that they had never used OGFC and 10 states indicated that they had discontinued use primarily because of performance and maintenance issues. In the *"cold state study area"* Nebraska and Kansas were listed as using the new generation OGFC mixture and Indiana and Montana were listed as having discontinued using OGFC mixtures. Specific details of the individual state responses to the survey were not included in the CTR report. Requests have been made to both the project research team and the TxDOT project manager for information on specific state responses to the questioner. To date we have not received the requested information.

Table 1 has been developed to provide a summary of OGFC usage history based on a number of reports, the above referenced surveys and individual contacts for the selected states (17) and Canadian provinces (4) with climates that are somewhat similar to Wisconsin (*"cold state study area"*).

Table - 1
History of OGFC Usage in Northern Climates

Colorado	
Transportation Research Circular E-C005 (5) 1998	Discontinued use of OGFC. Moisture damage in underlying layers. Used polymer.
NCHRP Synthesis 284 (6) 2000	Discontinued use of OGFC before 1993.
Idaho	
Transportation Research Circular E-C005 (5) 1998	Discontinued use of OGFC. Sanding caused filling up of voids. Used antistripping agent.
NCHRP Synthesis 284 (6) 2000	Discontinued use of OGFC before 1993.
Illinois	
Transportation Research Circular E-C005 (5) 1998	Using OGFC. Using polymer
NCHRP Synthesis 284 (6) 2000	Discontinued use of OGFC.

Indiana	
Transportation Research Circular E-C005 (5) 1998	Discontinued use of OGFC.
NCHRP Synthesis 284 (6) 2000	Never used OGFC.
Field Evaluation of Porous Asphalt Pavement (12) 2004	INDOT has “virtually no experience with porous asphalt surfaces.” This research project built and evaluated one New-OGFC mixture on I-74.
The Porous Fortune (13) 2005	Indiana experimented with the first generation OGFC mixes in the 1980’s. They experienced long term problems with the voids closing up due to road grime and winter abrasives used for snow and ice control.
University of Texas Report 0-4834-2 (9) 2007	Discontinued use of OGFC.
NCHRP Project 9-41 (7) 2008	Using OGFC – personal knowledge of the research team.
Contact – Rebecca McDaniel – North Central Superpave Center, 2008	The only use of any OGFC mixture in Indiana for at least 20 years is one small new generation OGFC with a crumb rubber modified asphalt binder as part of a pavement noise reduction study built in 2003.

Iowa	
Transportation Research Circular E-C005 (5) 1998	Discontinued use of OGFC. Removal of ice very difficult. Did not use polymer or additives.
NCHRP Synthesis 284 (6) 2000	Never used OGFC.
NCHRP Project 9-41 (7) 2008	Using OGFC.
Contact – Mike Heitzman former Iowa DOT Bituminous Engineer – Currently with NCAT, 2008	Iowa does not use OGFC mixtures. It was considered for an urban Des Moines freeway to reduce noise, but was not used because of concerns for cost and winter safety. Iowa has used a proprietary OGFC-like product on I-35 near the Minnesota border. The IDOT had problems with winter maintenance on this surface.

Kansas	
NCHRP Synthesis 180 (4) 1992	Kansas DOT Report – “Open Graded Asphalt Friction Courses”, 1986 (4-18). Seven test sections built in 1974 and evaluated until 1982. All sections performed satisfactorily. Dense graded sections with high friction aggregates also had good friction properties. Economic analysis considering rainfall and wet weather accidents could only justify the use of OGFC in high traffic areas of the state based on rainfall and evaporation rates. Problems were encountered with frost on OGFC and not on adjacent dense graded pavement, and the open texture also trapped snow and ice, requiring additional salt applications.
Transportation Research Circular E-C005 (5) 1998	Discontinued use of OGFC. During winter snow and ice storms, voids filled with water and froze; developed icy surface; took substantially higher amount of salt to melt ice. Did not use polymer or additives.
NCHRP Synthesis 284 (6) 2000	Discontinued use of OGFC in the 1970’s
University of Texas Report 0-4834-2 (9) 2007	Kansas is just beginning to use PFC (new generation OGFC), based on the Oklahoma and Texas experience.

Michigan	
NCHRP Synthesis 180 (4) 1992	Michigan DOT Report – “Michigan’s Experience with Open-Graded Asphalt Friction Courses”, 1987 (4-20). Eighteen OGFC projects (5 on runways) were evaluated. The experience was generally good with some failures occurring. They used latex rubber to improve performance. They did not experience problems with ice buildup or clogging due to sand.
Transportation Research Circular E-C005 (5) 1998	Discontinued use of OGFC.
NCHRP Synthesis 284 (6) 2000	Discontinued use of OGFC in 1982.

Minnesota	
Transportation Research Circular E-C005 (5) 1998	Discontinued use of OGFC. Deicing sand clogged voids and stripping of OGFC. Did not use polymer or additives.
NCHRP Synthesis 284 (6) 2000	Discontinued use of OGFC.
Contact - Rich Walter Minnesota Asphalt Pavement Association 2008	Minnesota's use of OGFC resulted in early failures due to stripping of the underlying layers and abrasion of the OGFC mixture from transverse cracks in the pavement.
Missouri	
Transportation Research Circular E-C005 (5) 1998	Do not use OGFC.
NCHRP Synthesis 284 (6) 2000	Never used OGFC.
Montana	
NCHRP Synthesis 284 (6) 2000	Discontinued use of OGFC before 1993.
University of Texas Report 0-4834-2 (9) 2007	Discontinued use in the 1990's due to stripping.

Nebraska	
Transportation Research Circular E-C005 (5) 1998	Does not use OGFC.
NCHRP Synthesis 284 (6) 2000	Never used OGFC.
University of Texas Report 0-4834-2 (9) 2007	Using new generation OGFC
NCHRP Project 9-41 (7) 2008	Using something other than new generation OGFC.
Contact – Mick Syslo – Nebraska DOT Pavement Design Engineer, 2008	Nebraska has used OGFC on 3 separate projects. Two were placed on Rural Interstate (I-80 & I-180) about 3 years ago. The third section on a medium volume state highway about 5 years ago. The I-80 project used crumb rubber and the other two projects used PG 70-28 Polymer modified binder. Winter operations (plugging) and raveling were some of our initial concerns, but we have not had any issues. We fog sealed the I-80 project last year; the I-180 was just fog sealed this fall and we are waiting another year before we fogseal the remaining section.

North Dakota	
NCHRP Synthesis 284 (6) 2000	Discontinued use of OGFC.

South Dakota	
Transportation Research Circular E-C005 (5) 1998	Discontinued use of OGFC. Sand and salt plugged up the voids. Did not use polymer or additives.
NCHRP Synthesis 284 (6) 2000	Discontinued use of OGFC.
University of Texas Report 0-4834-2 (9) 2007	Not using new generation OGFC.
Contact – Joe Feller – South Dakota DOT Program Manager, 2008	South Dakota currently uses an “S Class Wearing Course”. This mixture is more like a SMA rather than OGFC. It has a coarse surface texture (3/8” aggregate) but is not porous. Most often used on high traffic roads and has a polymer modified asphalt binder. It often contains fibers based on a drain down test. This mixture could be considered a lower cost form of SMA.
Wisconsin	
Transportation Research Circular E-C005 (5) 1998	Discontinued use of OGFC.
NCHRP Synthesis 284 (6) 2000	Discontinued use of OGFC in 1975.
Wyoming	
Transportation Research Circular E-C005 (5) 1998	Using OGFC. Using hydrated lime.
NCHRP Synthesis 284 (6) 2000	Placing approximately 200 lane miles per year. Total of over 6,200 lane miles.
Contact – Rick Harvey – Wyoming DOT Materials Engineer, 2008	Wyoming currently uses a “Plant Mix Wearing Course”. This mixture is more like a SMA rather than OGFC. It has a coarse surface texture (3/8” aggregate) but is not porous. Most mixtures used on high traffic roads (above 2,000 ADT) and have a polymer modified asphalt binder. This mixture could be considered a lower cost form of SMA.

Other States – Major OGFC Users	
California	
Transportation Research Circular E-C005 (5) 1998	Using polymer.
NCHRP Synthesis 284 (6) 2000	Placing approximately 250 lane miles per year. Total of over 6,200 lane miles.
NCHRP Project 9-41 (7) 2008	Restricted from snow/icy areas.
CalTrans – Open Graded Friction Course Usage Guide (11), 2006	In snow or icy areas where tire chains, studded tires, or snowplows are commonly used, OGFC has exhibited raveling distress.
Oregon	
Transportation Research Circular E-C005 (5) 1998	Using polymer and hydrated lime.
NCHRP Synthesis 284 (6) 2000	Placing approximately 250 lane miles per year. Total of 2,500 lane miles.
NCHRP Project 9-41 (7) 2008	Restricted from snowplow zones.
Contact - Gary Thompson Oregon Asphalt Pavement Association -2008	Two issues with the snow zones and open-grades; the first is resistance to snowplowing and chain digs from spinning tires is not good. The second is plugging with sanding rock (for ice and snow control) soon kills the free-draining nature of the open-grades.
Canadian Provinces	
Alberta	
NCHRP Synthesis 284 (6) 2000	Never used OGFC.
Manitoba	
NCHRP Synthesis 284 (6) 2000	Never used OGFC.

Ontario	
NCHRP Synthesis 284 (6) 2000	Placing approximately 20 lane miles per year. Total of 62 lane miles. Primarily used for noise reduction.
NCHRP Project 9-41 (7) 2008	Discontinued use of OGFC.
Contact – Anil Virani Ontario Ministry of Transportation, 2008	Pavement durability primary reason for the halt in use - experienced less than 10 years service life. Variable performance with trap rock mixes and poor performance with steel slag and dolomitic sandstone mixes. Lost the benefits of spray and noise reduction due to gradual plugging of the mixture with time. Ontario believes that the necessity of night paving on freeways and the general trend of doing the work later in the year resulted in cooler paving temperatures that contribute to the durability problems.
Saskatchewan	
NCHRP Synthesis 284 (6) 2000	Never used OGFC.

The states and provinces included in the *"cold states study area"* are highlighted on Figure 1.

The results in the above table show that 12 of the 15 states in the *"cold states study area"* are not currently using any type of OGFC mixture. One or two of the 12 states has never tried the mixture (not sure about Wyoming because survey results give conflicting views). The other ten states had various levels of experience with the original OGFC mixtures. Three of the states (Colorado, Illinois and Michigan) that no longer use OGFC mixtures had used polymer in their first generation OGFC mixtures

Three of the 15 states are using some form of OGFC in varying degrees. Nebraska appears to be using either the original OGFC mixture or some modification of it. Two states (Indiana and Kansas) using OGFC are reported to have conducted some trials. Kansas had previously discounted using the original OGFC mixture. However, the University of Texas CTR study indicates that Kansas is currently conducting trials with the new generation mixture (9). Indiana previously tried OGFC on a very limited basis and had since discontinued usage. In 2003, Indiana built a short test section using an asphalt crumb rubber binder in a study to determine the potential noise reduction of the new generation OGFC mixture (12). They have not used any additional OGFC mixtures since.

Figure 1
Cold States Study Area

Three of the four Canadian provinces studied have never used any form of OGFC. However, Ontario appears to have used a significant quantity of OGFC for highway noise reduction. The OGFC mixture generation that Ontario was using is not known, but recently they discontinued using the mixture because of poor durability (pavement life less than 10 years) and a rapid reduction in function (increased spray and noise) due to gradual clogging of the voids. Ontario also had difficulties with construction operations due to the need to place the mixture at night and later in the season (cool weather).

Based on the latest surveys, the regular use of new generation OGFC mixture is restricted to southern and some costal or warm weather western states. It is interesting to note that California and Oregon, both large users of the OGFC mixtures, have "restricted OGFC from snow/icy areas" and "restricted from snowplow zones" respectfully. The primary concern expressed by both agencies is snowplow damage to the surface and what appears to be accelerated raveling in the cold temperature environment.

The net result of the surveys is that no state or province in the *"cold states study area"* is using OGFC with any degree of frequency. It is also interesting to note that the one Canadian province that was using OGFC has recently discontinued using it.

In the TTI Synthesis it was reported that England has stopped using the OGFC mixture and instead they are currently using SMA or other thin surfacings (8). The report did not provide any reasons for the decision. A contact was made to the expert quoted in the TTI Report (Dr. Hussain A. Khalid – The University of Liverpool)(8). Dr. Khalid indicated that construction related problems due to lack of experience and restrictive aggregate specifications (which limited the source of available materials) caused England to discontinue the use of OGFC mixtures. Dr. Khalid also indicated that there is renewed interest in using these mixtures and that some companies have gained the needed experience for OGFC construction and are now offering proprietary mixtures with warranties.

Winter Maintenance of OGFC Mixtures

The winter maintenance requirements for the new generation OGFC are not known in the United States because the use of these mixtures is new and they have primarily been used in warm weather states. As stated previously, the new mixtures do provide better mixture performance, but characteristics of these mixtures in the winter are unknown. However, these mixtures have been used in Europe for a number of years and therefore their experiences with winter maintenance in similar climates to Wisconsin should generally apply to winter conditions in the United States.

In mid 2006 researchers at Texas Transportation Institute (TTI) (Texas A&M University) published a report for the Texas DOT titled "Synthesis of Current Practice on the Design, Construction and Maintenance of Porous Friction Courses" (8). This report was the first of three reports for a major project titled "Optimizing the Design of Permeable

Friction Courses (PFC)". The information gathered in the report comes from a worldwide literature review focusing on the construction, performance and maintenance of PFC (OGFC).

The following indented passages are taken directly from page 36 of the TTI report (8) to illustrate the concerns about the winter maintenance of OGFC mixtures.

{*The acronym DGHMA in the following quote refers to Dense Graded Hot Mix Asphalt.*}
{*The TTI references have been changed to the following format (Y-XX). The Y refers to the TTI report referenced in this report and the XX refers to the reference in the original TTI report.*}

> In general, open-graded mixtures exhibit lower thermal conductivity and reduced heat capacity compared with DGHMA (8-*18*). Elevated air voids contents in OGFC reduce the flow rate of heat through the material. In fact, the thermal conductivity of OGFC can be 40 to 70 percent the magnitude of that for DGHMA, making OGFC operate as an "insulating course" at the surface (8-*16*).
>
> As a result of these thermal properties, the surface of OGFC can exhibit temperatures 1 to 2°C (1.8 to 3.6°F) lower than the surface temperature of adjacent DGHMA, producing earlier and more frequent frost and ice formation (8-*6,* 8-*16*). Longer periods under such conditions, compared with DGHMA, are thus expected. The occurrence of this phenomenon in PA (Author note - *Porous Asphalt – European term*) has been identified in Europe (8-*3,* 8-*16*), in the United States (8), and specifically in Texas (9). Thus, the time to reach adequate pavement friction values after ice formation has occurred is longer in porous pavement (8-*16*). In fact, formation of black ice and extended frozen periods are currently considered the main problems associated with OGFC maintenance in the United States (8).
>
> Consequently, OGFC requires specific winter maintenance practices. For example, in addition to conventional practices for winter maintenance, the use of pavement condition sensors, meteorological instrumentation, and connecting hardware and software is suggested to monitor the road system and support the decision process involving when and how to treat an OGFC surface (8-*5*).
>
> More salt (or deicing agents) and more frequent applications than on DGHMA are required to perform winter maintenance on OGFC and PA (8-*15,* 8-*16,* 8-*18,* 8-*32*). In Texas (9?), deicing agents are currently considered the most effective winter treatment, followed by liquid deicer agents and sand. However, FHWA recommends developing snow and ice control using chemical deicers and plowing and avoiding the use of abrasive materials to improve traction (8-*20*). Spreading of sand to enhance friction and hasten deicing contributes to the clogging of voids, causing a decrease in drainage and noise reduction capabilities, which are considered two of the main OGFC advantages (8-*5*).
>
> Since the deicer can flow into an OGFC instead of remaining at the surface, Oregon DOT has suggested research on organic deicers with higher viscosity and electrostatic charge

technology (similar to that employed in emulsified asphalt) to improve bonding of deicers on the surface (8-*15*).

Intensive application of liquid deicing salts has allowed Belgium to obtain similar conditions between dense and porous mixtures subjected to snowy weather. Further, higher frequency of application and 25 percent more liquid salting are reported in The Netherlands to address winter maintenance difficulties in PA (8-*3,* 8-*6*). Furthermore, the use of liquid chloride solutions was reported in the cold Alpine regions of Italy, Austria, and Switzerland as more effective than the use of solid salt (8-*5*). On the contrary, a Japanese study concluded that fundamental modifications are not required to practice winter maintenance in PA surfaces, since considerable differences between these mixtures and DGHMA were not found (8-*33*).

Britain practices preventive salting just before snowfall and more frequent application of salt in comparison with DGHMA (8-*18*). They recommend increasing the amount of salt applied on DGHMA sections that are adjacent to PA segments. This recommendation is due to the reduction in the transfer of salt from the PA to the DGHMA and the differences in response of each material. Additionally, they propose prompt plowing of snow using plows fitted with rubber edges on the blades (to prevent surface damage). Finally, greater control in the homogeneous application of deicing chemical is required in OGFC, as the traffic has minimal contribution in its distribution over the OGFC surface (8-*5*).

In early 2008 TTI published a second report for Texas DOT titled “Guidelines on Construction and Maintenance of Porous Friction Courses in Texas” (10). This report was the second of three for the major study “Optimizing the Design of Permeable Friction Courses (PFC)”. The report included the results of interviews with TxDOT district personnel on the use and performance of new generation OGFC mixtures. The following excerpt from the TTI report summarizes the TxDOT response to winter maintenance issues with OGFC.

In Texas, severe weather events are generally confined to the northern section of the state. It is in these areas that district personnel must prepare for winter maintenance strategies for PFC pavements *(*10-*25)*.

As is indicated from the literature and the current practice of TxDOT districts, anti-icing procedures may produce the best result to combat black ice, freezing rain, and light snow events *(*10-*25).* Anti-icing procedures involve a combination of liquid, dry solid, and prewetted chemicals applied at the appropriate times, taking into consideration temperature, the amount of moisture and traffic conditions. De-icing procedures should be reserved for events in which ice and snow have already bonded. These procedures generally require more materials and do not maintain safe road conditions as well as anti-icing procedures.

Sand should only be used in emergency situations where quick friction is needed, for instance, during a surprise ice or snow event *(*10-*25)*. Use of sand on these pavements may cause clogging to occur, which reduces the draining benefits of PFC. The use of other materials may be used to generate the needed friction.

Based on the above information, it is obvious that winter maintenance is a major issue for pavements with an OGFC surface. For the winter maintenance to be effective, it requires more weather information, flexible de-icing operations, more chemicals, varied chemicals to handle different conditions and detailed training of winter maintenance workers. These added requirements could be a significant concern in Wisconsin because the individual counties provide winter maintenance for WisDOT.

To assist in these endeavors, TxDOT, based on the CTR research, is establishing a pavement temperature management system that includes real-time pavement temperature and site temperature along with moisture measurements to predict the formation of potentially future hazardous conditions on the pavement surface. It is intended that this information will be provided to maintenance personnel to assist in the decision of what to do and when and where to do it (9).

SERVICE LIFE (DURABILITY) OF OGFC MIXTURES

A wide range of data exists on the expected service life for the OGFC mixture. The following data (Table 2) has been generated based on the performance of the original OGFC mixtures in the United States. The table provides a comparison of mixture service life:

Table 2
Comparison of OGFC Service Life in Years (6)

State	OGFC – AC	OGFC – Modified AC
Arizona	7	13
Georgia	8	12
California	3-5	-
Wyoming	15	-

A better indication of the service life of the new generation OGFC mixtures can be assessed from the European experience. A summary of a number of European countries in the NCHRP 9-41 report indicates an average total service life of 10 years (7). Australia reported OGFC pavement life of 8 to 10 years (7-16). The TTI Synthesis presented a similar summary of European experience with a range of pavement life from 7 to 10 years for England, 7 years for Denmark and 8 to 12 years for France (8).

FUNCTIONAL LIFE OF OGFC MIXTURES

The functional life of an OGFC mixture is defined as the length of time the desired characteristics of the mixture (lower noise, lower speed gradient, less splash and spray and better visibility of traffic markings) remain effective. In almost all cases, these properties are gradually reduced with time due to clogging of the air voids in the pavement surface and/or further compaction of the mixture due to traffic.

A Danish study of the new generation OGFC mixtures showed a loss of the noise reduction property in 5 years on a high-speed roadway and after only 2 years in an urban environment (6-8). A British study also conducted on the new generation OGFC mixtures showed a loss of spray reduction after 6.3 years (47 sections average) on pavement that had an average service life (durability) of 7.3 years (89 sections) (6-9). This represents a functional life of 86 percent of the total service life.

The TTI Synthesis reports a functional life for Australia OGFC mixtures of 3 to 6 years (8-52). If this is related to the service life range provided in NCHRP Report 9-41 (7-16), the functional performance equals 38 to 60 percent of total service life.

If we use the average service life of 10 years for the European new generation OGFC mixtures (7) and compare that to the typical function life provided in the TTI report for European Countries (8) (5 to 8 years), you get a functional life of 50 to 80 percent of the service life.

Significant efforts have been made in Europe and Japan to extend the functional life of pavements by cleaning the voids in the OGFC mixture to reduce clogging. Denmark, the Netherlands and Japan frequently apply various cleaning techniques (8). The types of cleaning processes include cleaning with a fire hose, high-pressure cleaner and specifically manufactured cleaning machines with a vacuum device to pick up the debris (7). Several machines have been developed for this purpose in Europe and Japan. There is little evidence that cleaning is used in the United States or England (8). There is little data that quantifies the results of cleaning OGFC mixtures with regard to functional life.

OGFC Mixture Cost

The cost of an OGFC mixture is difficult to determine because of the many possible variations for OGFC mixtures that exist. The one thing that is certain is that on a cost per ton basis, an OGFC mixture will cost significantly more than the comparable HMA mixture (see Table 3) because of the special gradation, higher asphalt binder content and in most cases modified asphalt binder. However because the unit weight of the OGFC mixture is much lower than a HMA mixture, the yield on OGFC will be approximately 15 percent greater countering part of the increase in cost of the mixture.

In 1996, the Georgia DOT indicated that new generation OGFC mixtures cost 30 to 35 percent more per ton than conventional HMA mixtures (15).

Table 3
Comparison of Cost per Ton Premium for OGFC Mixtures (6)
Percent increase over standard dense graded HMA

State	OGFC – AC	OGFC – Modified AC
Arizona	38	81
Georgia	-	57
California	6	-
Wyoming	23	-

Confounding this whole issue is the fact that most agencies currently do not give any structural value to the thickness of the OGFC in the structure. This means that the agency has to place the same pavement thickness with or without the OGFC layer. This could cause problems on roadways with limited overhead clearance because the final surface elevation of the road will be higher.

One possible offset for the added cost of using of an OGFC mixture would be the possible use of a lower quality surface layer in the pavement structure. This would include using something like a surface layer without polymer under the OGFC layer when a polymer modified mixture would have normally been required in the standard pavement section.

ALTERNATE MIXTURES

Several researchers have looked at alternate mixtures to determine if they would provide some or all of the benefits of the OGFC mixture. The general consensus is that if you increase the macrotexture of a mixture you begin to gain some of the wet weather and noise benefits of an OGFC mixture. A chapter in NCHRP Synthesis 284 discusses the use of “Alternate Surface Mixture Types” (6). The conclusions are that the increased macrotexture of both coarse graded HMA and SMA (to a greater degree) provide improved wet weather performance and noise reduction when compared to dense graded mixtures. The author noted that the only mixture that performs better than SMA is OGFC (6).

NCAT conducted pavement noise studies on various pavement surfaces and concluded that the relative noise reduction on OGFC pavements was 4 dB and on SMA pavement 2 dB when compared to a dense graded HMA pavement (14). Similar studies conducted by the North Central Superpave Center on a project in Indiana found similar results for noise and friction testing on an OGCF and SMA mixtures. Both the OGFC and SMA had better wet weather friction than the dense graded HMA. However, they found that the SMA pavement was the noisiest (12).

In the TTI Synthesis it was reported that England is using SMA or other thin surfacing in place of the OGFC mixtures.

Factors to Consider for the Use of New Generation OGFC in Wisconsin

Most studies and reports indicate that new generation OGFC mixtures are a significant improvement from what was used and failed in the 1970's and 1980's. The use of polymer modified asphalts and fibers in the mixture help to reduce draindown and allows an increase in the asphalt film on the aggregate particles. The reduced draindown prevents fat spots (bleeding) and isolated pavement raveling. The thicker asphalt films reduce age hardening of the asphalt binder that contributes to raveling of the aggregate particles from the surface as the pavement ages (6). It is also theorized that the increased air voids in the new OGFC mixtures (there is some question on how long they last) allow high speed traffic to partially clean the sand and dirt (grit) out of the surface voids and reduce clogging of the mixture which causes a decrease in mixture functionality.

The general consensus indicates that the greatest values from the use of OGFC mixtures come in areas of high-speed traffic and high rainfall. The pavement must be designed so that the edges of the pavement drain away the water running through the layer. This restricts the use of OGFC from many urban areas because of curb and gutter sections and high amounts of grit (dirt and sand) and possibly on some bridge decks because of a lack of drainage.

When you place OGFC mixtures in a cold environment you begin to add factors that counteract some of the wet weather benefits. The OGFC layer allows early formation of ice on the road and it is more difficult to clear ice and snow from the surface. OGFC mixtures also require the use of a greater amount of chemicals as well as a highly coordinated program for de-icing chemicals. Also, OGFC pavements may receive significant damage (gouging and raveling) from the use of snow plows.

Part of the WisDOT OGFC decision process should include accident surveys of interstate highways and major primary routes (roads most suited for OGFC usage). These surveys should try to identify areas that have a high frequency of wet pavement accidents and determine if the problem is a localized issue (particularly on a hill or curve) or a general roadway issue. For the locations that are identified, an evaluation of the length and severity of winter conditions should be made. The winter accident rate (ice and snow related) should be evaluated at the sites of high wet weather accidents. Only sites identified with a significantly higher wet weather accident history should be considered for use of the OGFC mixture because you can expect OGFC usage to cause an increase in winter accidents.

Studies have indicated that OGFC does not work well when placed in short segments (it prevents the carryover of salts from the OGFC section to the adjoining dense graded HMA pavement in the winter) or on bridge decks (it retains water and is subject to early freezing). Therefore, the optimum use would appear to be on longer pavement segments in rural areas without a lot of bridges.

Construction of OGFC mixtures in northern climates has also been a problem as illustrated by the pavements placed in Ontario experience. Shorter construction seasons and the requirement to do night work in high traffic areas have resulted in placement of the OGFC mixture in less than desirable temperature conditions. This can lead to premature raveling and early failure. Wisconsin could be expected to experience similar problems.

It has been shown that the total service life of OGFC mixtures is in the 10 to 12 year range. Additionally, research has shown that the functional life of the pavement is somewhere in the range of 50 to 80 percent of the service life. Based on a combination of these two numbers, Wisconsin could be looking at functional life in the range of 5 to 10 years. This life is about one-half of what could be expected from an SMA pavement surface. Assuming that the surface is replaced at the end of the functional life, WisDOT would be required to conduct twice as many construction projects on a specific segment of road. This could turn the decision from an OGFC mixture to a SMA mixture when traffic delays and possible construction accidents are considered. If the replacement of the OGFC is delayed to the end of the service life, a somewhat higher frequency of construction activity will still be required on the road compared to SMA mixtures. (A possible significant negative identified in the literature with repairing the OGFC layer at the end of its service life is that at times this failure has been a very rapid disintegration of the layer due to raveling of the entire surface layer in a mater on weeks in the worst cases.)

CONCLUSIONS

One can understand the high usage of OGFC mixtures in southern states. You get all the wet weather benefits without the winter downside. However, in northern climates, where the winters are longer and the number of freeze/thaw cycles and ice and snow events occur more frequently, the wet weather benefits may be entirely canceled out.

The decision on whether or not to use OGFC in Wisconsin is difficult. Everyone can appreciate the wet weather benefits of the mixture. However, the problems associated with winter maintenance are significant and the performance of the mixture could conceivably cause more problems than the benefits gained in warm weather. Current use of OGFC mixtures in northern states indicates mixed results. It is reported in the literature that Indiana, Kansas, and Nebraska are currently using some form of the OGFC mixture. This usage is very limited and amounts to a few trial projects in each state (Indiana – one project). We have not been able to confirm the performance of the OGFC mixture in these three states. However, Nebraska has already fog sealed their three projects, which were only 3 to 5 years old.

South Dakota and Wyoming do not use OGFC mixtures and are using a SMA type mixture for the final surface on high traffic roadways. Indications are that other northern states are doing the same thing.

The Province of Ontario recently discontinued use of the OGFC because of construction and performance problems.

Independent of the decision to use OGFC mixtures, the literature reviewed for this project indicates that Wisconsin may gain some wet weather performance improvements if it changed current surface mixtures to a coarser texture. The idea would be to develop a “poor mans’“ SMA type of mixture for the lighter traveled rural roads.

RECOMMENDATIONS

While the use of OGFC mixtures in warm southern climates has been successful, this pavement has not proven to have the same successes in the northern freeze/thaw environment. None of the states or Canadian provinces with climates that duplicate Wisconsin’s use OGFC mixtures.

In a normal situation the construction of a trial section could be recommended. However, because of the large influence that weather plays on the serviceability of the mixture, a trial is not a good idea in Wisconsin.

On a routine basis, it is recommended that Wisconsin should not currently build pavements with an OGFC surface with two exceptions.

> First, if the previously recommend accident study indicates a large number of wet weather accidents on SMA pavements without a corresponding number of winter accidents, then a OGFC surface should be considered with the understanding that extra efforts will have to be made to develop deicing and snow removal procedures and to train the local maintenance personnel in these procedures. If the accidents are occurring on a HMA pavement surface, then an SMA mixture should be used to fix the problems.
>
> Second, if in the future OGFC pavements are routinely used by another northern state, and the winter maintenance and performance of the OGFC mixture are successfully dealt with, then Wisconsin should reconsider this recommendation.

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