QUIETER PAVEMENTS SURVEY

WA-RD 688.1

Research Report
April 2008

Washington State
Department of Transportation

Research Report

QUIETER PAVEMENTS SURVEY

by

Nichols Consulting Engineers Chtd
1885 S. Arlington Ave Ste 111
Reno NV 89509

Prepared for

Washington State Transportation Commission
Department of Transportation

March 2008

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. **WA-RD 688.1**	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE QUIETER PAVEMENTS SURVEY		5. REPORT DATE March 2008 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Newton C. Jackson, Adriana Vargas, Jason Pucinelli		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Nichols Consulting Engineers Chtd. 1885 S Arlington Ave., Suite 111 Reno, NV 89509		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. Y9631 AE
12. SPONSORING AGENCY NAME AND ADDRESS Research Office Washington State Department of Transportation Transportation Building, MS 47372 Olympia, Washington 98504-7372 Kim Willoughby, Project Manager, 360-705-7978		13. TYPE OF REPORT AND PERIOD COVERED Research Report 14. SPONSORING AGENCY CODE
15. SUPPLEMENTARY NOTES This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.		

16. ABSTRACT

This study looked at the performance of quieter pavements in use in the United States of America and Europe with specific emphasis on those states that are using open-graded mixes for both friction or porous courses on an ongoing basis. All States were contacted and 34 states responded with information on their use of open-graded mixes and stone matrix asphalt (SMA) mixes. Eleven states were able to provide an estimate of the range and average service life of their open-graded mixes and three states provided information on the service life of their SMA mixes. Specifications for open-graded mixes and SMA mixes were compiled from 20 states and compared to Washington State's open-graded friction course mix and the open-graded mix used on recent test sections built by the Washington State Department of Transportation.

17. KEY WORD Quieter Pavements, Open-graded Friction Course, SMA, Service lives, Specifications		18. DISTRIBUTION STATEMENT No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616	
19. SECURITY CLASSIF. (OF THIS REPORT) None	20. SECURITY CLASSIF. (OF THIS PAGE) None	21. NO. OF PAGES 260	22. PRICE

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Transportation Commission, Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

TABLE OF CONTENTS

Executive Summary v

Introduction 1

Problem Statement 1
Research Objectives 1

Review of Current Practice 3

Mix Types 4
Open-Graded Friction Courses 4
Stone Matrix Asphalt 5

Pavement Service Life 5
European Experience 5

Procedures 8

State Surveys 8
Construction Specifications 8

Findings/Discussion 9

State Surveys 9
Construction Specifications 19

Conclusions and Recommendations 23

References 26

Appendix A 27

Appendix B 29

Appendix C (available only in .pdf version) 31

LIST OF FIGURES

FIGURE 1 States that reported using OGFC or SMA mixes 11
FIGURE 2 States Actively Using OGFC Mixes 14
FIGURE 3 States Reported Using SMA Mixes 15
FIGURE 4 Air-Freezing Index (°F-Day) for the 100-year Return Period 16
FIGURE 5 States with Specifications for Asphalt Rubber 17
FIGURE 6 Mid-Line Grading of Smaller and Larger Aggregate OGFC 20

LIST OF TABLES

TABLE 1 Range in Service Lives Reported by States 15
TABLE A1 Summary Service Life Estimates from Agency Survey 28
TABLE B1 Summary of States OGFC Mix Specifications 30

EXECUTIVE SUMMARY

A study was conducted that looked at the relative performance of quieter pavements in Europe and the United States based on pavement management data. A phone survey was conducted to get the best response and to specifically talk to those people in the state agencies that were involved with their pavement management system (PMS). Contact was made with 35 of the 50 states on the performance of open-graded mixes and stone matrix asphalt (SMA) mixes in their respective agencies. None of the states were able to provide sufficient information to accurately estimate the service life of the different quiet pavements types to the accuracy that can usually be accomplished from the Washington State Pavement Management System (WSPMS). About half the states contacted were able to provide an estimate of the service life they were experiencing from their open-graded mixes and a few were able to estimate the service life experienced from their SMA mixes. The estimated service life for the open-graded mixes provided by the states ranged from seven to fifteen years. Where states were able to provide an estimate of service life of their dense graded mix performance, the open-graded mixes were providing about 70 percent of the service life of the dense graded mixes.

Based on the authors experience and comments from other states there is a concern with the use of open-graded mixes in areas which require snow plowing in the winter and those that experience increased pavement wear from studded tire use. The survey found that those states that have continued to use open-graded friction course (OGFC) mixes tend to be in the southern part of the country, which do not have the same maintenance issues with snow plowing and studded tire wear. Consequently, most of the states in the northern part of the country do not appear to be using OGFC mixes as consistently as the more southern states.

As part of the state survey the current standard specifications for open-graded mixes were reviewed and summarized for those states that made them available. A collection of the state specifications for OGFC indicates that there are in general two sizes of stone gradations used in the United States. The gradation with the larger aggregate size (3/8" median) is used by states in the southeast which fit NAPA's guidelines for OGFC mixes. The rest of the states use the gradation with the smaller aggregate size (1/4" median) which originally came from the FHWA Technical Advisory for friction courses. There is no indication that the different gradings for the OGFC provide more or less service life.

Most states in the survey used a polymer modified binder (PG 76-22) with fibers to control drain-down and provide the thick asphalt film that is required for OGFC mixes. Some states used an asphalt rubber binder but these were in the minority and all tended to be located in the southern portions of the United States. There was also no indication in the survey that either binder type provided better service life. Those states that do use asphalt rubber binder are specifying a higher percentage of asphalt rubber binder compared to polymer asphalt binder. The OGFC mixes constructed at this time in Florida and Arizona with stiffer asphalt binders and thicker asphalt films (higher asphalt content) are performing better than those constructed in the 1970's and 1980's. However they are still not being used extensively by many northern states or by many states that allow the use of studded tires like Washington State. The Washington State Department of Transportation (WSDOT) can expect that the OGFC mixes constructed with stiffer asphalt binders and thicker asphalt films will perform better than the old mixes, but it is doubtful that they will obtain comparable service lives as that reported by Arizona and Florida, given Washington's weather and studded tire use.

INTRODUCTION

PROBLEM STATEMENT

Noise produced by the tire-pavement interaction disturbs drivers and residents of neighborhoods adjacent to urban highways. Many states, including California, Arizona and Texas, have experimented with pavements that reduce the tire-pavement production of noise. Quieter pavements technologies have included rubberized asphalt friction courses, open-graded friction courses (OGFC), stone matrix asphalts (SMA) and several others. Questions concerning performance surround both the durability of the noise reduction (how much is the noise reduced initially and does that noise reduction decrease over time) and the durability of the wearing surface of the pavement (the pavement life before structural failure and required replacement).

RESEARCH OBJECTIVES

The Washington State Department of Transportation (WSDOT) wants to document, to the extent possible, the performance of these pavements from a pavement management perspective.

Specifically WSDOT wanted to:

Evaluate each state's pavement management system to determine if accurate data on a project level basis can be used to determine life cycle costs and life cycle durations (system level performance may only be considered if project level performance is unavailable). Identify the life cycles performance of the variety of quieter pavements, including:

- *The average life cycle of each type of quieter pavement*
- *The maximum average life cycle of each type of quieter pavement*
- *The minimum average life cycle of each type of quieter pavement*
- *The performance criteria used to determine those life cycles (rutting, smoothness, structural condition, etc)*
- *Compare and contrast this performance with performance of the typical life cycle of hot mix asphalt (HMA) in Western Washington State*
- *Compare and contrast the climatic differences between other states using the various quieter pavements and that of urban Western Washington. Select similar climatic zones in Arizona, California, Texas and other states using quieter pavements and examine life cycle performance*

Collect state departments of transportation specifications for pavement design, mix design and construction of the various quieter pavements. Note any specifications and any constructability issues, especially related to weather constraints.

The following discussion documents the results of the study performed to meet those goals.

REVIEW OF CURRENT PRACTICE

Typically, reduction of highway traffic noise has been accomplished through the use of noise barrier walls. However, barrier walls can be costly to build and difficult to maintain. Furthermore, noise barriers are not completely effective. Buildings located on hillsides or near any openings (driveways, intersections, etc.) will not benefit from noise reduction because the sound diffracts over the top as well as around the end of the walls.

Starting in the 1980's, European studies found that noise reduction could also be accomplished by changing the pavement surface, eliminating the noise at the source rather than building a barrier. These studies found that quiet pavements can be built by using one or more of the following approaches (Sandberg 2002):

1. A surface with a smooth surface texture using small top size aggregate
2. A porous surface, such as an OGFC with a high air void content
3. A pavement-wearing course that has an inherent low stiffness at the tire/pavement interface.

MIX TYPES

Several mix types can be considered quiet pavements due to their aggregate and binder characteristics. These include OGFC, OGFC with asphalt rubber binder, SMA and several others.

Open-Graded Friction Courses (OGFC)

An OGFC consists of an HMA mixture that is designed to have a large number of air voids (typically 18 to 22 percent). This large void content is created by using a larger percentage of coarse aggregate and a lower percentage of fine aggregate (usually less than 20 percent of the material passes the No. 8 sieve).

OGFC can reduce the noise level because the larger air void content provide a means for air trapped between the tire and the pavement surface to escape which provides for increased sound absorption.

The binder used in the OGFC can be either polymer modified asphalt (PG 76-22, PG 70-22) with fibers or rubberized asphalt. Rubberized asphalt consists of regular asphalt cement mixed with ground "crumb rubber" from used tires. Used tires are processed by separating the casings, fabric and steel. The recovered rubber then is granulated to the consistency of ground coffee. Rubberized asphalt contains between eight and 20 percent tire rubber that is blended into the liquid asphalt. When the rubberized asphalt contains over 15 percent tire rubber it is usually referred to as asphalt rubber by the Rubber Pavements Association. Details concerning asphalt rubber can be found at the Rubber Pavements Association web site at:

http://www.rubberpavements.org/index.html

Stone Matrix Asphalt (SMA)

SMA is a mixture of crushed coarse aggregate, crushed fine aggregate, mineral filler, asphalt binder and stabilizing agent. The stabilizing agent is used to prevent drain-down of the asphalt binder and typically consists of fibers, polymers or a combination of both.

SMA mixtures are designed to have a high coarse aggregate content (typically 70 to 80%), with stone on stone contact, a high asphalt content (typically over 6%) and high filler content (approximately 10% by weight). This produces a mix with an improved aggregate structure with thick binder films and low voids which minimizes the aging and oxidation of the binder which usually provides improved service life.

These mixes have been used for many years to provide wearing courses with improved surface properties compared to normal dense graded mixes, which are being looked at again for their potential noise reduction properties.

This report will summarize the pavement performance aspect of these mixes not their ability to reduce tire-pavement noise, since the noise reduction characterization has been a relatively recent consideration.

PAVEMENT SERVICE LIFE

European Experience (FHWA 2004)

Quieter pavement technology originated in Europe, where the systematic reduction of noise associated with roadway operations has been a critical issue for more than 20 years. Because the preservation of historic vistas prevents the use of noise barrier walls, European countries have focused on eliminating the noise at the source.

The two main approaches to quieter pavements in Europe include the use of thin overlays with negatively textured, gap-graded mixes such as SMA mixtures, as well as single or double layers of open-graded porous surface mixes.

In 2004, a Quiet Pavements Scan Team composed of a cross section of State, Federal, academic, and industry representatives visited five European countries (Denmark, the Netherlands, France, Italy and the United Kingdom) that have successfully used pavement technologies that reduce tire/pavement noise. Findings from this study revealed that the durability of low-noise pavement systems varies from seven to 15 years depending on the pavement system and the experience level of the owner agency. Acoustical durability is about four dB(A) over the pavement life.

Pavement life is mostly affected by raveling and increased winter maintenance activities (snowplows scarring the pavement, use of studded tires, etc.). On the other hand, acoustical durability is mostly affected by clogging, especially on low-speed facilities. Some disagreements exist regarding the effective maintenance of these negatively textured and often highly porous pavements. Although some countries require pressure washing and vacuuming of the pavements at least twice a year, other countries contend that the practice may not only be useless, but perhaps even harmful. The team was unable to discover any reliable data to substantiate either claim. Winter maintenance remains a challenge, especially on the highly porous pavements. Winter maintenance relies on advanced use of prewetted salt to fight formation of black ice on the highly porous pavements, resulting in a winter maintenance cost increase of 25 to 50 percent.

Some countries have stopped using highly porous pavements in snow and ice regions, and instead are using SMA-type pavements with smaller top size aggregate.

PROCEDURES

STATE SURVEYS

In order to estimate the service life of quieter pavements, a state survey of current activity throughout the United States was performed. All 50 states were contacted by phone to determine what pavement performance data is available.

CONSTRUCTION SPECIFICATIONS

Specifications for OGFC and SMA mixes were collected from all applicable state departments of transportation. Those specifications are located in Appendix C Standard Specifications for OGFC and SMA mixes (available in the .pdf version of the report).

A summary of the more relative OGFC mix design items for each state can be found in Appendix B Summary of OGFC Materials Specifications.

FINDINGS/DISCUSSION

STATE SURVEYS

A total of 35 states responded to the survey. Of those states that responded, 28 have used either open-graded mixes or a form of SMA, but only half had information on their estimated service life. Most of the states that had some experience with open-graded mixes based that experience on the use of OGFC which were used in 1970's and later. In many cases the individuals contacted indicated that the agency now had only limited use of open-graded mixes or had discontinued that use for various reasons. None of the states contacted had detailed information in their pavement management system (PMS) that could be used to provide project specific information on the performance of these mixes. In many cases the Pavement Management staff deferred questions of service life to their Materials Engineer or their Pavement Design Engineer. It was not known if that was because of a lack of information or reflected the Agencies policy on releasing service life information. Some general information on the performance of these mixes can be developed from the results of the phone interviews but not to the level desired by WSDOT in the request for proposals for this project.

It should be noted that no other state monitors and compiles project level pavement condition data over time to the detail that WSDOT does. It has been the author's experience that many states still only collect network level condition data while others collect project level data. However, those states that collect project level data do not attempt to develop project specific trends by project with time for their entire highway system as WSDOT does. The States may collect project level pavement condition data but they predict future pavement condition based on average or estimated deterioration trends extended from the last condition survey. Thus most states cannot provide detailed PMS information on specific mix performance. The information on service life that is presented in this report was based on either specific studies or general experience from individuals within those states.

Another issue is that many states like Arizona use ride values as their primary measure of pavement performance. Because of this, the trends that are monitored cannot be matched to trends in Washington State directly because WSDOT also defines pavement service to moderate levels of pavement cracking. States that use ride values as the primary distress indicator must experience significant changes in ride values before they take action and that can represent greater levels of crack severity and extent. As an example where Arizona would estimate pavement service life of 15 years that would represent the time to a significant change in IRI or ride values. Washington State may look at that same pavement and determine a service life of 10 to 12 years based on a specific amount of fatigue cracking (10% to 25% of the wheelpaths), which occurs well before there is significant change in ride value. Because Arizona conducts only a very limited cracking survey along with their ride survey it is unlikely one could make a good correlation between the service life in Arizona and one in Washington State. The estimate of pavement service life reported for each state was provided by the person who was interviewed. There was no attempt made to correlate those estimates to a common terminal pavement condition. The states that responded that they had used either OGFC's or SMA's are shown in Figure 1.

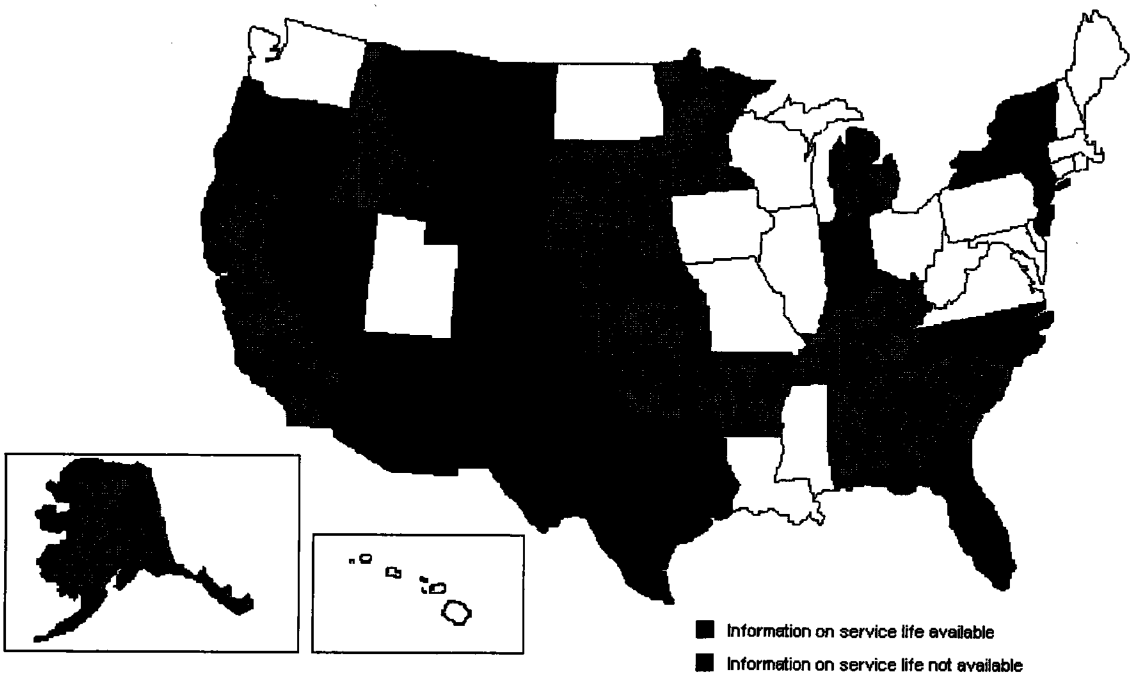

FIGURE 1 States that reported using OGFC or SMA mixes

In general, many states have used open-graded mixes and those mixes are still shown in their specifications. It appears however that the number of states that continue to actively and aggressively use open-graded mixes is limited. Many states experience with open-graded mixes is similar to Washington States. One of the authors of this report was involved with the use of open-graded mixes from the mid 1970's through the late 1980's. WSDOT started using OGFC in the mid 1970's in an attempt to reduce wet skidding accidents and in response to the FHWA guidance and a technical advisory on OGFC's. It should be noted that most states still refer to their open-graded mixes as OGFC's. WSDOT determined that wet skidding accidents were reduced with the use of OGFC's, but what was more apparent was that they reduced water spray from trucks and cars and were noticeably quieter and smoother. At about the same time WSDOT initiated a significant effort in utilizing recycled HMA pavements. Due to concerns with the high percentage of recycled HMA in new HMA overlays, WSDOT placed OGFC's on all recycled HMA overlays to protect the recycled mix. Consequently there was a significant amount of OGFC placed on I-5, I-90 and SR 520 in the 1980's. All of these pavements experienced extensive raveling in the wheelpaths within five to seven years. A few sections provided up to 15 years of service on I-90 because they received light fog seals at 3 to 5 year cycles. There were also a couple of projects in Seattle and Spokane that were paved in late summer which began raveling in the wheel paths within a couple of months. The problem was traced to exceeding the high temperature limitation and increased drain-down. To minimize that risk WSDOT began placing fog seals on OGFC's after construction to improve film thicknesses. In the early 1990's WSDOT started using both a polymer modified and a rubber modified binder to improve film thickness. Because of the construction problems and relatively short service life, WSDOT has limited use of OGFC since the early to mid 1990's. Though WSDOT has all but stopped using OGFC's by the mid 1990's, the Class D OGFC remained in the Standard Specifications through 2002 and was only dropped when WSDOT implemented the Superpave specifications.

WSDOT also placed several test sections of ¾ inch OGFC using the Oregon DOT's Class F specification in the early 1990's on I-5 and on I-90. WSDOT has continued to use this OGFC mix as modified D. The WSDOT Pavements Engineer notes that WSDOT is still using modified D in Eastern Washington with good success. There are sections of I-90 where modified D is still in service from those earlier projects on the inside lanes. Modified D is also performing well on sections of SR 211, SR 904, and SR

902. Modified D was recently placed on I-90 in 2005 and 2006. Though the modified D is performing better than the standard D mix, the larger stone size may not provide the same quieter pavement benefits as the standard OGFC mix. The use of this larger stone OGFC mix is unique to Washington State and Oregon State.

Many states appear to have limited use of OGFC but continue to include them in their specifications. Other states, however, have modified their OGFC specifications and have continued to use them as a standard part of their paving program. Georgia and Florida along with other southeastern states moved to a little larger open-graded aggregate with either polymer asphalt or asphalt rubber binder. Arizona and California have used about the same sized aggregate as the old OGFC but use an asphalt rubber binder developed in Arizona. Oregon developed a large aggregate (¾ inch) open-graded mix that they have continued to use since the early 1990's. Texas has worked with several different open-graded mix designs and has settled on a mix that is in-between the old OGFC and the new mixes used in the Southeast with polymer binder.

Figure 2 shows those states that actively use OGFC mixes as the final wearing course on either their Interstate or Principal Highways.

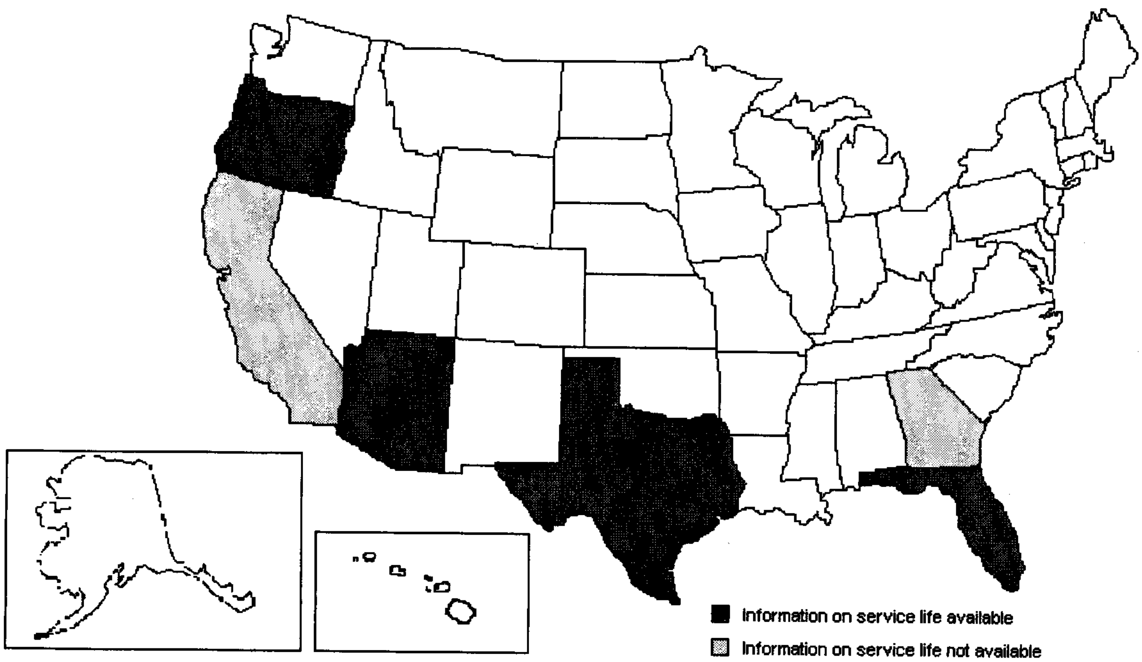

FIGURE 2 States Actively Using OGFC Mixes

In the case of SMA pavements, 11 states currently use this type of mixture, but only four of them had information on service life (Figure 3). As with OGFC mixes, SMA mixes are often placed for reasons other than noise reduction (such as increased rutting resistance). The SMA mixes are included in this survey in that they were identified in the RFP for this project as quieter pavements.

Like OGFC the SMA pavements are included in the list of potential quieter pavements. The states use of SMA pavements has been largely due to rut resistance, resistance to studded tire wear and longer service life. Consideration for use as a quieter pavement has been a recent development.

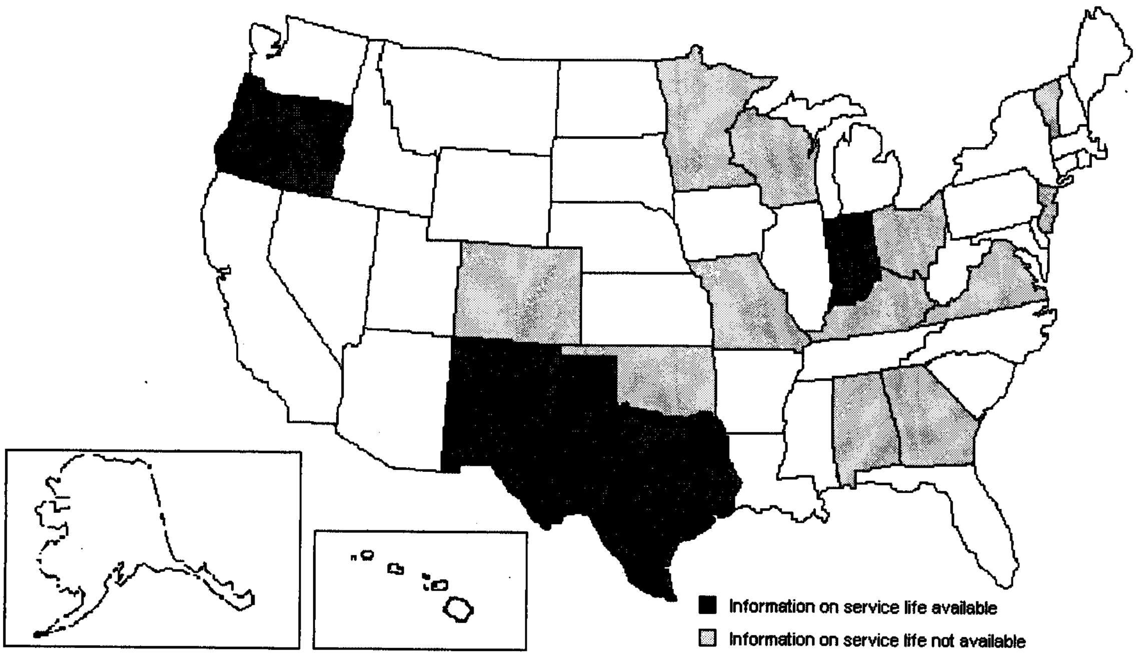

FIGURE 3 States Reported Using SMA Mixes

The general range in service life reported for all states is shown in table 1.

TABLE 1 Range in Service Lives Reported by States

Surface Type	Service Life (Years)
HMA	10-20
SMA	10-20
OGFC	7-15
Rubberized Asphalt OGFC	9-13

The full range in service life reported by the states is shown in Appendix A Summary of State Responses.

In general the states that had made improvements in their OGFC specifications and continued to use them, now report service life expectations around 10 years. That is, in general, a couple of years less service life than what they would expect from dense graded mixes. The states response on the service life of SMA's was very limited but most expected them to provide a couple of year's more service than dense graded mixes.

It should be noted that several states indicated problems with winter snow removal on OGFC. This was observed in Washington where several maintenance personnel reported to one of the authors that the OGFC seemed to hold the snow more than normal dense graded mixes and was harder to plow without damaging the pavement. Colorado reported that they had only placed one OGFC and removed it "due to increased accidents after snow fall".

The use of OGFC appears to be limited in the more northern states because winter activities, such as snow plowing, can significantly reduce the service life of the pavement. Figure 4 shows the air-freezing index distribution for a return period of 100 years. Air temperature records can be used to gauge the severity of ground freezing by using the degree-day concept (if the daily mean air temperature is 31°F this will be one degree-day). The "Freezing Index" is simply the accumulated total of degree-days of freezing for a given winter.

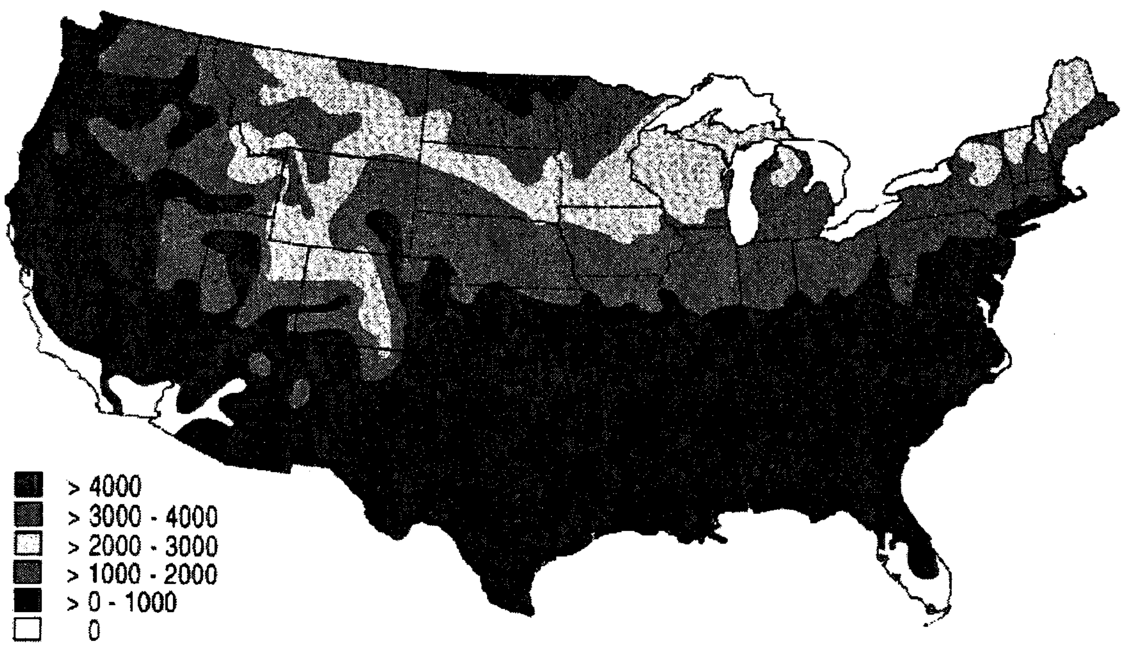

FIGURE 4 Air-Freezing Index (°F-Day) for the 100-year Return Period

As expected, the majority of states consistently using OGFC have freezing indices below 1,000 °F-Day (southern states). Those that continue to use OGFC the most (California, Arizona, Georgia, and Florida) tend to be in the warmer band of that zone.

A number of states use asphalt rubber in their OGFC pavements. Arizona and California routinely specify asphalt rubber for their OGFC pavements. The states of Florida and Texas include both polymer asphalt and asphalt rubber provisions in their specifications. A number of other states have experimented with the material. Those states that have studied and/or used rubberized asphalt include Nebraska, South Carolina, New York, New Mexico, and Washington. However, on the state survey only Arizona reported some information on the service life of these mixes. Those states that have asphalt rubber in their specifications are shown in figure 5.

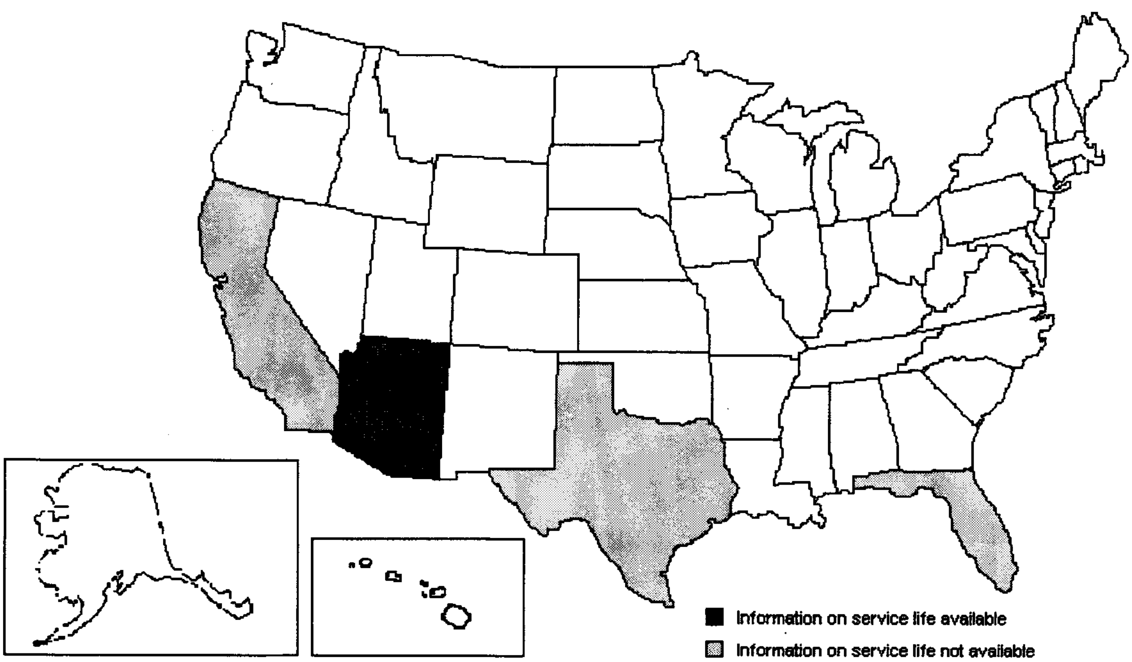

FIGURE 5 States with Specifications for Asphalt Rubber

WSDOT has used asphalt rubber as a binder in chip seals and in several early test sections of OGFC. A report in 1992 indicated that there was no difference in pavement performance between the asphalt rubber sections and polymer asphalt sections (5). However, that experience was based on using about the same percentage of polymer asphalt or asphalt rubber binder as was called for by the old FHWA Technical Advisory for OGFC which was about five percent. The OGFC that are used today in Arizona, California, Florida and Georgia use binder contents in the seven to nine percent range.

WSDOT is in the process of placing three test sections with the new generation OGFC with binder contents around nine percent. Considering that the environment in Washington is significantly different from that found in the states noted, these test sections will be critical for WSDOT to best quantify service life in their environment. WSDOT should also make an effort to record any problem with snow removal or frosting problems noted by maintenance on those sections of pavement. Based on earlier experiences with similar test sections, those who have to maintain those pavements often don't report any problem unless it is an unusual problem or a safety concern. It is recommended that annual reports on the performance of those pavement test sections should include a specific query of maintenance regarding any maintenance issues with those pavement sections.

The authors would not expect that WSDOT would experience the same service life as experienced in states like Arizona or Florida because of the use of studded tires allowed in Washington. The use of studded tires is not allowed in most states that commonly use OGFC today.

There was very limited information from the states interviewed on the service life experienced for SMA mixes. It seems that they provided longer service lives than dense graded mixes but that is based on very limited information. Some states did note that they had moved on to SMA mixes over OGFC but that trend is not clear.

CONSTRUCTION SPECIFICATIONS

As a very general statement the grading for Idaho's PMS-OG, Nevada's OGFC, New Jersey's OGFC, New Mexico's OGFC I & II, North Carolina's FC-1 and Oklahoma's OFGC are similar to WSDOT's old Class D which was adopted from the FHWA Technical Advisory for OGFC in the 1970's. The mean standard aggregate size for those mixes is about ¼ inch thick. Alabama's OGFC, Florida's FC-5, Georgia's OGFC, New Mexico's OGFC III, North Carolina's FC-2 and South Carolina's OFGC call for a larger aggregate size with the median aggregate size around 3/8 inch. The gradation used by these states matches or come close to the National Asphalt Paving Association's (NAPA) guidelines for OGFC mixes. Arizona and California's OGFC gradings fall between these sizes but are closer to the old FHWA Technical Advisory. Oregon has been using an OGFC mix with a much larger aggregate size with a median size of around ½ inch.

Most of the noise studies have been based on the smaller aggregate mix. There is some evidence that the larger aggregate mix may not be as quiet as the smaller aggregate mix (Jones 2005). Washington's test sections have utilized the Arizona mix design which falls into the smaller aggregate size group. It should be noted that several countries in Europe place a two layer open-graded system with the larger aggregate size on the bottom and the smaller aggregate size on the top (FHWA 2004). The general mid line gradation of the two more predominate gradings for OGFC are shown in figure 6.

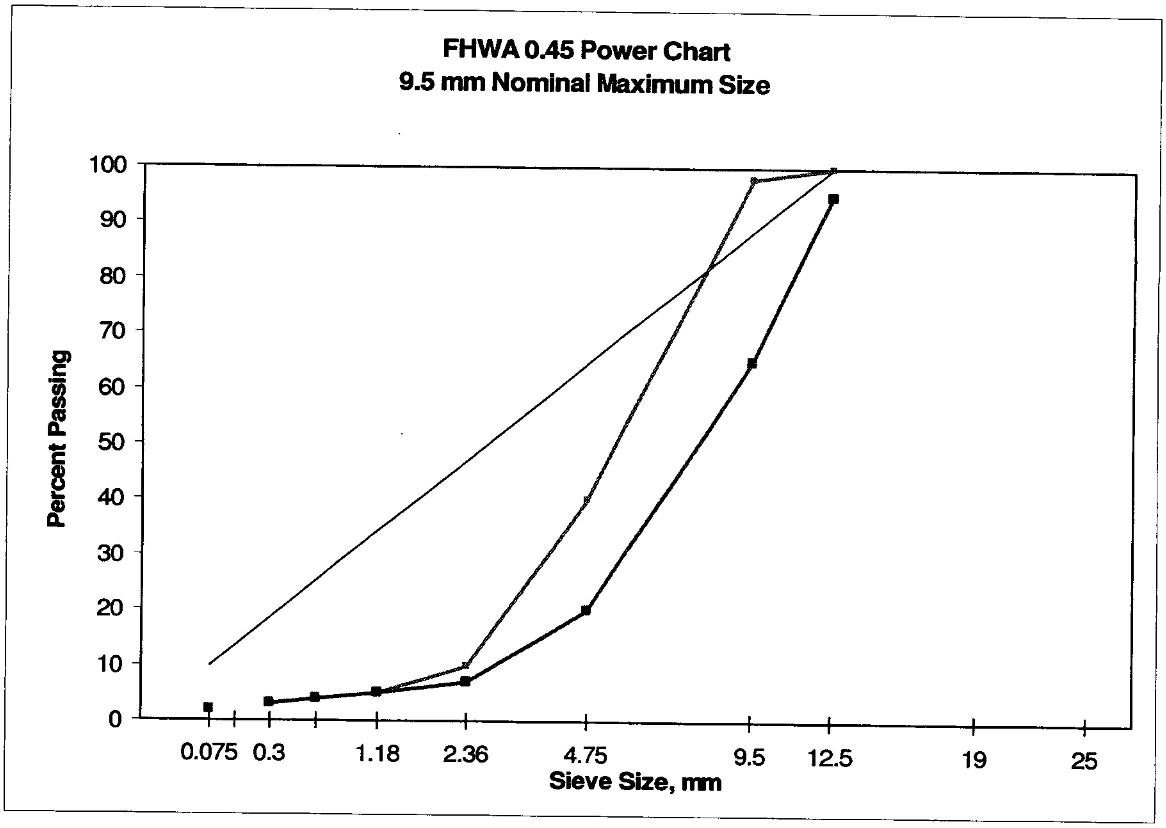

FIGURE 6 Mid-Line Grading of Smaller and Larger Aggregate OGFC

In figure 6 the straight blue line is the maximum density line for a 9.5 mm nominal maximum aggregate. The green line is the mid-line gradation for the old FHWA OGFC mix. The red line is the mid-line gradation for the OGFC used by many south eastern states.

There are two basic binder types found in use today for OGFC mixes. Most of the states are using polymer modified asphalt (PG 76-22) with fibers to control drain-down. A few states (Florida, New Mexico, and Texas) also include a provision for asphalt rubber binder. Two states (Arizona and California) exclusively use the asphalt rubber binder.

From the state responses to the phone survey it was not clear that there was any difference between the two binder types in service life. In general the amount of binder called for seems to be a little higher for asphalt rubber binder compared to polymer asphalt binder. The study did not look at the costs of OGFC mixes in the various states. In Washington the cost of the OGFC with asphalt rubber binder at the test section on I-5 (Contract 7134) was $130.00 per ton compared to $90.00 per ton for the OGFC with polymer modified asphalt and fibers. On the SR 520 project (Contract 7353) the costs were $285.00 per ton compared to $155.00 per ton. The second project was a much smaller project with less tonnage which may account for the higher costs. To be cost effective, the OGFC with the asphalt rubber binder should provide a proportionally greater service life compared to the OGFC mix with polymer modified asphalt and fibers.

The authors are aware that ADOT has constructed test sections of both polymer modified asphalt and asphalt rubber on I-10 south of Phoenix along with sections of SMA pavement. Based on personal observations the polymer modified asphalt binder sections do not appear to be performing as well, but those sections also had about three percent less binder than the asphalt rubber sections. The sections with the higher binder content should survive longer than those with lower binder content provided that rutting does not become a problem. The performance of these sections has not been monitored or documented by ADOT at this time.

The minimum air temperature range called for by the different states ranges from 40° F to 70° F with Arizona additionally calling for an 85° F surface temperature. The 40°

F minimum is unique to one state that does not seem to place much open-graded mix. Based on the authors experience the OGFC mix tends to cool down quicker after placement than a comparable thickness of dense graded mix. For that reason, the higher minimum temperatures may reduce the construction risk associated with the placement of OGFC mixes. As a general observation, the more southern states tend to set higher minimum temperatures while the more northern states set lower minimum temperatures. That may reflect more what is practical rather than what is preferred. It is doubtful that WSDOT could use a 70° F minimum temperature requirement as is used by many southern states. The use of a 60° F minimum placement temperature is more the norm for the more northern states but that may still be fairly hard to meet with night paving in western Washington. For night paving in western Washington the 55° F minimum temperature requirement may be the only temperature practical since most night temperatures in the summer drop below 60° F. For daytime paving WSDOT should consider going to the 60° F minimum placement temperature to reduce construction risk.

One item that does not show up on the summary sheet was tack rate. For most of the states the tack rate for OGFC was about 50 percent higher than that indicated for dense graded mixes. Based on the author's experience WSDOT did experience some early raveling problem that was associated with low tack rates. Increasing the normal tack rates by 50 percent is a carryover from the early OGFC specifications which should be continued to reduce the risk of early raveling.

CONCLUSIONS AND RECOMMENDATIONS

After reviewing the data collected in this study, it is evident that there is insufficient information to accurately estimate the service life of the different quiet pavement types to the accuracy that can usually be accomplished from the WSPMS. While it is clear that climate plays an important role in the selection of the pavement type, there is not enough data to establish a relationship between service life and weather conditions. The fact that the durability of OGFC type pavements is reduced in areas that experience winter related maintenance activities is indicated based on European and North American experience. Additionally, Washington State's experience with the early OGFC mixes indicates that studded tire wear was a problem and had a significant effect on the performance of those mixes. It can be assumed that stud wear will be a continuing problem with the new generation OGFC mixes which will likely reduce the service life of those mixes in Washington State compared to other states that do not allow the use of studs.

The definition of service life is also different in various agencies. Some states allow more pavement distress before the DOT takes some form of action to rehabilitate the pavement. Arizona's PMS is largely driven by changes in pavement roughness based on ride values. Washington States PMS is primarily driven by pavement cracking and tends to rehabilitate pavements before there is a significant change in roughness. Because of this there may be several years' difference between the service life of pavements in Arizona and that in Washington State. It also should be noted that those states that have continued to use OGFC mixes tend to be in the southern part of the country, which do not have the same maintenance issues with snow plowing and stud wear. Consequently, most of the states in the northern part of the country do not appear to be using OGFC mixes as consistently as the more southern states.

A collection of the state specifications for OGFC shows that there are in general two sizes of aggregate gradations used in the United States. The gradation with the larger aggregate size (3/8" median) is used by states in the southeast which fit NAPA's guidelines for OGFC mixes. The rest of the states use the smaller aggregate size (1/4" median) which originally came from the FHWA Technical Advisory for friction courses. There is no indication in the state responses that any of the different OGFC aggregate gradations provide more or less service life. The authors did not find any study that compared the performance of the different OGFC aggregate gradation mixes as far as service life or performance. A study by NCAT indicates that the smaller rock size may be quieter but there is no indication that they remain quieter over their service life (Jones 2005). WSDOT's current measurements are indicating that the noise reduction of the OGFC mixes they placed in two test sections may not continue over even relatively short periods of time. It would seem that the larger aggregate mix may not plug as quickly and thus it may provide better long term noise reduction capacity over time, but no studies were found that looked at that issue.

Most states in the survey used a polymer modified binder (PG 76-22) with fibers to control drain-down and provide the thick asphalt films that is required for OGFC mixes. Some states used an asphalt rubber binder but these were in the minority and all tended to be located in the southern portions of the United States. Arizona and California are the only states that use exclusively asphalt rubber binder. There was also no indication in the survey that either binder type provided better service life. Those states that do use asphalt rubber binder are specifying a higher percentage of asphalt rubber binder compared to polymer asphalt binder. The study did not look at the costs of these mixes in the various states. In Washington the cost of the OGFC with asphalt rubber binder at the test section on I-5 was about 1/3 more costly compared to the OGFC with polymer modified asphalt and fibers. To be cost effective the OGFC on I-5 with the asphalt rubber binder will have to provide about 30 percent greater service life compared to the OGFC mix with polymer modified asphalt and fibers.

It should be noted that those states currently using OGFC mixes on an ongoing basis are all located in the southern area of the United States. There is more limited use of OGFC documented in the central or northern area of the United States. Colorado has specifically removed the one OGFC pavement it placed because of problems after snowfall. The new generation OGFC mixes clearly are performing better than those placed in the 1970's and 1980's. However, they are still not being used extensively by many northern states nor by many states that allow the use of studded tires like Washington State. WSDOT can expect that the new generation of OGFC mixes will perform better than the old mixes, but it is doubtful that they will survive as long as reported by the Arizona Department of Transportation given Washington's weather and studded tire use.

REFERENCES

FHWA, 2004. Quiet Pavements: A Scanning Tour of Denmark, the Netherlands, France, Italy and the United Kingdom. Federal Highway Administration International Technology Exchange Program and American Association of State Highway and Transportation Officials.

Jones, W, 2005. Quiet Pavement – Coming to a Highway Near You.

National Center for Asphalt Technology, 2007. *Tire/Pavement Noise.*

Swearingen, David L., Jackson, N. C, Anderson, Keith W., 1992. *Use of Recycled Materials In Highway Construction* WA-RD 252.1 Washington State DOT Olympia WA.

Sandberg, U. and J.A. Ejsmont, 2002. *Road/Tyre Noise Reference Book*, Informex.

APPENDIX A

Summary of State Phone Survey

TABLE A1 Summary Service Life Estimates from Agency Survey

Agency	OGFC	SMA	HMA	Comments
Alabama				With new mix design (poly mod, fibers) OGFC is lasting longer.
Alaska				OGFC haven't worked in the past due to studded tire wear.
Arizona	9-13			OGFC 7-10 yrs, OGFC with rubber 9-13 yrs, no service life on HMA.
Arkansas				Crumb rubber has been used but no service life information
California				Asphalt Rubber in use but no service live provided
Colorado				OGFC removed due to increased accidents after snow.
Florida	7-15			Original OGFC's 7-15 years. Rubber since 1994 no service life.
Georgia				Have been using OGFC and SMA for 10 years, no service life.
Hawaii				No information on OGFC/SMA/gap-graded
Idaho				No info on service life
Indiana		15+		HMA service life is 15+ years, expecting 20+ from SMA's.
Iowa				Don't use SMA or OGFC layers.
Kansas				Just put down first SMA last year.
Kentucky				No service life data because of high variability.
Louisiana				No information on OGFC/SMA/gap-graded
Maine				No OGFC or SMA layers constructed in Maine.
Michigan				Using gap-graded Superpave since 2002, no service life information
Minnesota				Limited use of SMA. No service life.
Montana	10-12			Built OGFCs in the 1980's which lasted 10-12 years.
Nebraska				Just starting coming back to OGFC.
Nevada	7-10		10	OGFCs last 7-10 years in lower elevations. HMA lasts 10 years
New Hampshire				Don't use OGFCs or SMA layers.
New Jersey	10			OGFC used in the 1970s.
New Mexico	10-12	15	15-20	OGFC's 10-12 years. SMAs are 15 years old. HMA 15-20 years.
New York				Use Novachip but no study. Typical life is 5-8 years
North Carolina	12-15			Poly-mod OGFC 12-15 yrs. Old OGFC 8 years.
Oklahoma				OGFC have shorter life than typical HMA.
Oregon	8-10	10-12		OGFC 8-10 yrs (to .75" rut), SMA 10-12 (to .75" rut).
South Carolina				These are used but no service life
South Dakota				OGFC is used but no information on service life.
Tennessee				First OGFC and SMA put down last year.
Texas	12-15			Some plant mix seals in service for 12-15 years
Vermont	8-10			OGFC lasts 8-10 years and then fails very quickly.
Wyoming				Design life for OGFC averages 20 years.

APPENDIX B

Summary of State's OGFC Mix Requirements

TABLE B1 Summary of States OGFC Mix Specifications

Grading	WSDOT Class D	WSDOT OGFC Test	WSDOT OGFC-AR Test	Alabama OGFC	Arizona ARFC	California O-G RAC	Florida FC-5	Georgia OGFC 12.5mm	Idaho PMS-OG	Indiana OGFC OG19.0	Nevada OGFC
3/4"				100		100	100	100		70-98	
1/2"	100			85-100		95-100	85-100	85-100	100	40-68	100
3/8"	97-100	100	100	55-65	100	78-89	55-75	55-75	95-100	20-52	90-100
#4	30-50	35-55	30-45	10-25	30-45	28-37	15-25	15-25	30-50	10-30	35-55
#8	5-15	9-14	4-8	5-10	4-8	7-18	5-10	5-10	5-15	7-23	
#16						0-10					5-18
#200	2-5	0-2.5	0-2.5	2-4	0-3	0-3	2-4	2-4	2-5	0-8	0-4
% Asphalt	4-6	9	9	5.6-9			ARB12	5.75-7.25			
Asphalt	PG 58-22	PG 70-22	A-R	PG 76-22	A-R	A-R	PG 76-22	PG 76-22			
Min Air Temp.	55° F	55° F	55° F	40° F	70° F *	70° F	65° F	55° F	60° F	60° F	
					* + 85° F Surface						

Grading	New Jersey OGFC	New Mexico OGFC I & II	New Mexico OGFC III	North Carolina OGFC FC-1 Mod	North Carolina OGFC FC-2 Mod	Oklahoma OGFC	Oregon OGM 1/2"Open	Oregon OGM 3/4" Open	South Carolina OGFC	Texas PGFC	Texas A-R
3/4"		100	100		100		99-100	85-96	100	100	100
1/2"	100	100	70-90	100	85-100	100	90-98	55-71	85-100	80-100	95-100
3/8"	80-100	90-100	40-65	75-100	55-75	90-100			55-75	35-60	50-80
#4	30-50	30-55	15-25	25-45	15-25	25-45	18-23	10-24	15-25	1-20	0-8
#8	5-15			5-15	5-10		3-15	6-16	5-10	1-10	0-4
#10		0-20	6-12			0-10					
#40		0-12	0-8								
#200	2-5	0-6	0-5	1-3	2-4	0-5	1-5	1-6	0-4	1-4	0-4
% Asphalt				5-8	5 - 8				5 - 7	5.5-7.0	8-10
Asphalt				PG 76-22	PG 76-22				PG 76-22	PG 76-22	A-R
Min Air Temp	60° F	70° F	70° F			60° F		60° F	60° F	70° F	70° F