IMPROVING WINTER MAINTENANCE FOR OPEN GRADED FRICTION COURSE (OGFC) PAVEMENTS IN TENNESSEE

Research Final Report from The University of Tennessee at Chattanooga | Mbakisya Onyango (PI), Weidong Wu (Co-PI), and Joseph Owino (Co-PI) | May 30, 2022

Sponsored by Tennessee Department of Transportation Long Range Planning Research Office & Federal Highway Administration

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This research was funded through the State Planning and Research (SPR) Program by the Tennessee Department of Transportation and the Federal Highway Administration under **RES2019-25:** ***Research Project Title: Improving Winter Maintenance for Open Graded Friction Course (OGFC) Pavements in Tennessee*****.**

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Technical Report Documentation Page

1. Report No. RES 2019-25	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle *Improving Winter Maintenance for Open Graded Friction Course (OGFC) Pavements in Tennessee.*		5. Report Date April 2022 6. Performing Organization Code
7. Author(s) Mbakisya Onyango, Weidong Wu, Joseph Owino		8. Performing Organization Report No.
9. Performing Organization Name and Address The University of Tennessee at Chattanooga (UTC) 615 McCallie Avenue Chattanooga, TN, 37403-2598		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address Tennessee Department of Transportation 505 Deaderick Street, Suite 900 Nashville, TN 37243		13. Type of Report and Period Covered Final Report May 2019 to April 2022 14. Sponsoring Agency Code
15. Supplementary Notes Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.		

16. Abstract

Open Graded Friction Course (OGFC) is a thin permeable surface layer on pavements constructed to ensure higher air void content that provides drainage from the pavement surfaces. This results in a safer riding surface, especially on wet conditions. OGFC pavements have been reported to reduce about 30% more wet crashes compared to densely graded surfaces in similar conditions. However, durability and winter maintenance are some of the challenges facing OGFC pavements. This study was conducted to document the winter maintenance practices on OGFC pavements. The study was limited to literature review and survey to state DOTs. This report presents the research results and the recommended winter maintenance guidelines for Tennessee Department of Transportation. Some best practices on winter maintenance of OGFC pavements worthy of highlighting include the use of anti-icing. It was reported that using anti-icing before snow and ice events results to faster cleaning of roadways. Likewise, dedicating a snow operation vehicle on some trouble sections or inclines has resulted to clearing the sections faster. It should also be noted that it is expected that OGFC will use more material for winter maintenance than densely grades surfaces and abrasives are not recommended on OGFC. Therefore, it is advised to plan for winter maintenance with this knowledge in mind.

17. Key Words **PAVEMENTS, OPEN GRADED FRICTION COURSE (OGFC), WINTER MAINTENANCE**		18. Distribution Statement No restriction. This document is available to the public from the sponsoring agency at the website http://www.tn.gov/.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 79	22. Price TBD

Acknowledgement

The authors would like to thank the State Planning and Research (SPR) Program by the Tennessee Department of Transportation (TDOT) and the Federal Highway Administration for funding this research project. Appreciation is also extended to TDOT Maintenance Division Director and Engineers for their tireless support on this study. Furthermore, the authors acknowledge the maintenance and design engineers from state DOT's that took time to respond to the survey. Their input and experience are very valuable to this study. Thanks are due to the students that worked on this project at different times. It was a difficult time with COVID-19, but we were able to get students that dedicated time to assist in the conduct of this research project. Lastly, we thank the University of Tennessee at Chattanooga research and accounts offices for their guidance and support on the execution of this project.

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Executive Summary

Open graded friction course (OGFC) is a thin permeable surface layer on pavements constructed with an open gradation asphalt mixture, that serves as an avenue for draining off water from the pavement surfaces. OGFC is used worldwide and in many parts of the United States and has provided many benefits to road users. OGFC pavements improve the surface frictional resistance of asphalt pavements, hence, providing safe driving conditions. Studies have shown that OGFC reduces more wet crashes compared to densely graded surfaces. Apart from enhancing road user safety, the use of OGFC has been found to equally lead to reduced noise levels by about 3 to 5 decibels, increased pavement life and decreased long-term cost, enhanced high speed and friction qualities, reduced hydroplaning, decreased splash and spray, and improved visibility of pavement markings.

With all the benefits of OGFC, many state DOTs face challenges with OGFC pavements. According to a study conducted in 2014 by the University of Tennessee, 42% of states that used OGFC no longer use it mainly because of reasons such as clogging, de-bonding, higher cost, poor performance of the mixtures, and high winter maintenance cost due to usage of more salts. The main reason for Northern states to stop using OGFC was higher winter maintenance cost and clogging when sand was mixed with salts.

Winter maintenance is the biggest challenge to most state DOTs that use OGFC including Tennessee DOT. TDOT funded this study to investigate winter maintenance practices from other state DOTs that could benefit Tennessee highways. This report provides insights from the survey conducted, the proposed guidelines or protocol for winter maintenance of OGFC and types of de-icing agents suitable for different situations like snow, freezing rain or black ice.

The objectives of this research project are to document the state of practice in OGFC winter maintenance technologies from other state DOTs. Identify appropriate de-icing agents and techniques for OGFC winter maintenance in Tennessee. And develop OGFC winter maintenance guidelines for the state of Tennessee. The scope of this study includes a literature review and state DOT survey to establish current DOT practices in winter maintenance of OGFC pavements. The study also summarizes the state of practice of winter maintenance of OGFC pavements, selects winter maintenance agents and maintenance techniques to be further evaluated for Tennessee, and proposes winter maintenance guidelines for OGFC pavements for the State of Tennessee.

The survey was sent to all 50 states DOTs, twenty-seven state DOTs (54%) responded to the surveys. From the respondents, sixteen participants (59 %) currently use OGFC pavements in their states while eleven participants (41 %) do not use OGFC pavements. Out of those not currently using OGFC, 5 participants (19%) used it in the past and six (22 %) never used it in their state. This report provides a summary of responses and best winter maintenance practices that TDOT can benefit from. Winter maintenance guidelines are also provided in Chapter 4.

The findings from this research project will benefit TDOT twofold. Firstly, TDOT will have statewide guidelines on winter maintenance. Secondly, TDOT will be able to plan ahead knowing that OGFC maintenance is costlier than densely graded surfaces, but there are best practices that may either save cost or time or both if implemented correctly.

Key Findings

The findings from this study are summarized below:

- The winter maintenance materials used in Tennessee are rock salts (NaCl), salt brine, pre-wetted salts, brine additives ($CaCl_2$), and potato juice. Abrasives (sand) are rarely used and are not recommended on OGFC pavements because they clog the pores.
- The techniques commonly used for OGFC winter maintenance are anti-icing, pre-wetted salts and chemicals, de-icing, and snow plowing. The application rates range depending on the snow event and type of material used.
- The use of NaCl before the snow events as anti-icing treatment has shown to improve the ability to clean OGFC roadways faster.
- Training by venders on the usage of the materials is very effective in improving the performance and reducing cost.
- During the winter storm, dedicate the equipment to stay on a route with a steep mountain. This will reduce the cycle time for the materials to be spread, which results to cleaner road sections providing safe driving conditions.
- No state DOT was able to share OGFC winter maintenance guidelines, it seems as if most DOTs work through experience or follow the general winter maintenance guidelines. Nothing was specific for OGFC pavements.
- Initial guidelines for OGFC winter maintenance are proposed based on literature review and state DOTs survey results and are reported in section 4.2 of this report.
- Using a latex or tire rubber modified binder in OGFC mix design provides more resistance to stripping and shelling/raveling of OGFC surfaces.
- For a good performing OGFC, mix moisture absorption of aggregates should not exceed 2.5 % (≤2.5%) and asphalt binder absorption should not exceed 1% (≤1%).

Key Recommendations

Provided is a short summary with potential benefits of the recommended course of action:

- A future study is recommended on how to improve joints between OGFC and bridge ends or at transitions since several sections were identified with either pavement coming up, complete base failure or raveling at transition joints and bridge ends.

- Planning of material and manpower ahead of time for sections CNP292 and CNL957, identified to be challenging, is recommended to timely remove snow/ice in winter events and provide safe driving conditions.

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Glossary of Key Terms and Acronyms

OGFC	-	Open Graded Friction Course
DGAC	-	Densely Graded Asphalt Course
TDOT	-	Tennessee Department of Transportation
DOT	-	Department of Transportation
LRRB	-	Local Road Research Board
HMA	-	Hot Mix Asphalt
PFC	-	Porous Friction Course
FHWA	-	Federal Highway Administration
NHS	-	National Highway System

Chapter 1 Introduction

Open graded friction course (OGFC) is a thin permeable surface layer on pavements constructed with an open gradation asphalt mixture comprising of mostly coarse aggregate of uniform sizes with very little fines, to ensure a higher air voids content such that can serve as an avenue for draining off water from the pavement surfaces. This way, the layer helps to improve road users' driving experience and safety during wet conditions.

> *Apart from enhancing road user safety, the use of OGFC has been found to equally lead to reduced noise levels by 3 to 5 decibels, increased pavement life and decreased long-term cost, enhanced high speed and friction qualities, reduced hydroplaning, decreased splash and spray, and improved visibility of pavement markings.*

Apart from enhancing road user safety, the use of OGFC has been found to equally lead to reduced noise levels by about 3 to 5 decibels, increased pavement life and decreased long-term cost, enhanced high speed and friction qualities, reduced hydroplaning, decreased splash and spray, and improved visibility of pavement markings (Alvarez, 2006). With all the benefits of OGFC, many state DOTs face challenges with winter maintenance.

According to a study conducted in 2014 by the University of Tennessee, 42% of states that used OGFC no longer use it mainly because of reasons such as clogging, de-bonding, higher cost, poor performance of the mixtures, and high winter maintenance cost due to usage of more salts. The main reason for Northern states to stop using OGFC was higher winter maintenance cost and clogging when sand was mixed with salts, and sometimes they used more salt than on Densely graded Asphalt Course (DGAC) (Onyango & Woods, 2017; Taylor, 2014).

Winter maintenance is the biggest challenge to most state DOTs that use OGFC including Tennessee DOT. TDOT funded this study to investigate winter maintenance practices from other states DOTs that could benefit Tennessee highways. This report provides insights from the survey conducted, the proposed guidelines or protocol for winter maintenance of OGFC and types of de-icing agents suitable for different situations like snow, freezing rain or black ice.

1.1 Objectives

The objectives of this research project were to:

1. Document the state of practice in OGFC winter maintenance technologies from other state DOTs.
2. Identify appropriate de-icing agents and techniques for OGFC winter maintenance in Tennessee.
3. Develop OGFC winter maintenance guidelines for the state of Tennessee.

1.2 Scope of Work

The scope of this study included:

1. Literature review and survey to establish current DOT practices in winter maintenance of OGFC pavements.
2. Summarizing the state of practice of winter maintenance of OGFC pavements.
3. Selecting de-icing agents and maintenance techniques to be further evaluated for Tennessee.
4. Proposing winter maintenance guidelines for OGFC pavements for the state of Tennessee.
5. Providing and submitting to TDOT a finalized this technical report on OGFC winter maintenance.

Chapter 2 Literature Review

2.1 Background

OGFC is a thin permeable surface layer on pavements constructed with an open gradation asphalt mixture, comprising of mostly coarse aggregates of uniform sizes with very little fines to ensure higher air void content and to provide drainage from the pavement surfaces. The layer provides safe driving conditions and improves road users driving experience. OGFC is also useful for noise reduction, reduction of hydroplaning, to decrease water splashing, and to improve visibility of pavement markings, especially in wet conditions (Yildirim Y., 2006).

OGFC was developed in the early 1950s and had garnered widespread popularity in different parts of the United States and Europe as a useful material to improve frictional resistance of asphalt pavements (Kandhal & Mallick, 1998). However, the birth of OGFC was complemented with backlash due to durability and service life issues (Xie, 2019). A typical challenge with OGFC was the development of mixture (or mix design) that is durable and can provide long-term service. Some other limitations include the high potential for raveling and shoving, which is of great concern in snowy or icy areas; lack of structural value to the overall pavement structure, which questions the additional cost in excess of that for conventional asphalt material (DGAC); and need for special patching and rehabilitation techniques, and need for special snow and ice control measures which constitute the winter maintenance practices (Taylor, 2014). Moreover, OGFC costs more (between 30 – 40%) than conventional asphalt mixes (DGAC) and considering the cost being more than DGAC and that the OGFC layer does not provide any structural value to the pavement structure, it was necessary to justify the long-term performance of OGFCs (Taylor, 2014). These challenges caused some early adopters to discontinue its use while other entrants were discouraged from adopting OGFC. Figure 2-1 below show the surfaces of Densely graded Asphalt Course (DGAC) and Open graded Friction Course (OGFC).

Figure 2-1 DGAC (left) and OGFC (right)

Despite the challenges, OGFC has yet survived as a useful pavement material over the years. The improved ride quality and other possible safety benefits associated with new generation open-graded friction course pavements have made them highly attractive to engineers and contractors (Yildirim Y., 2006). The cost disadvantage is also not a serious problem due to the realization that open-graded paving is lighter in weight than conventional mixes and is able to cover more pavement surface area, thus resulting in an offset of the cost disadvantage, the reduction in life-cycle cost of maintenance, and cost of delays to users during maintenance operations (Taylor, 2014).

Many developmental efforts have also been directed towards the improvement of OGFC in the last three decades. According to Taylor (2014), as of the late 1990s, a study conducted by the National Center for Asphalt Technology (NCAT) indicated positive developments of OGFC with over 70 percent of the states reporting service life of eight or more years while about 80 percent of them had successfully developed standard specifications for open-graded mix designs, hence eliminating the fundamental challenges recorded in the 1970s (Taylor, 2014). Specifically, the survey reported that problems experienced by some states - raveling, delamination, and loss of permeability after a few years of being in service, have been solved (NAPA, 2002).

More recently, studies conducted have reported positive developments of OGFC pavements. In 2013, the University of Tennessee at Chattanooga conducted a survey on open-graded friction course among state Departments of Transportation (DOTs) in the USA. Thirty nine of the 50 state DOTs contacted responded to the survey. Of the 39 states, 45 percent used OGFC at the time, 42 percent used in the past and 13 percent never used. The study shows that OGFC is a viable pavement material with 81 percent of the respondents that use it, rating the performance of OGFC as good or very good (Onyango & Woods, 2017). Another study on the performance effectiveness and cost-benefit of open-graded friction course pavements in Tennessee was conducted by (Chen, 2017). With statistical analysis of the available data on OGFC pavements, it was found that the cost-benefit ratio was significantly acceptable and that the OGFC overlays were effective in improving pavement performance and repairing deterioration.

Maintenance is a fundamental aspect that needs to be considered in any project that involves the use of porous layers like OGFC. The maintenance practices for OGFC cannot be performed in a similar manner as that on DGAC. The maintenance activities that are performed on the OGFC surface includes, but are not limited to, winter maintenance, surface maintenance, corrective surface maintenance, and rehabilitation (Alvarez, 2006).

Despite the developments, OGFC has remained plagued by durability problems and maintenance issues such as rapid ice and frost accumulations during winter conditions. Generally, OGFC layers are known to freeze rapidly and thaw slowly. In rapid freezing conditions, some moisture may be trapped in the open pores of the OGFC layer and can cause black ice, an extremely hazardous situation for vehicles driving at high speeds with poor tires which can cause issues such as tire stud rutting, gouging and scarring from snowplows, and clogging (Yildirim Y., 2006).

As with other pavement materials, winter maintenance of OGFC pavements is critical, and the practices can vary from one place to another. Moreover, OGFC mixes behave differently than dense-graded pavement mixes in freezing conditions (D. Rogge & Hunt, 1999). Because of these variations, development of adequate, and encompassing, maintenance techniques specific to open-graded friction course under winter conditions have been challenging.

2.2 Methods Used for Winter Maintenance

For winter maintenance, different methods are used prior to and during a winter storm. Some typical methods used are as follows (Board, 2016; Wegman, Sabouri, & Intertec, 2018):

Anti-icing: This is a proactive method; it involves the application of liquid chemicals to the roadway before a winter storm to prevent ice from bonding to the pavement. One of the benefits of anti-icing is the reduction of the amount of time required to restore the roads to bare pavement. Anti-icing can be performed before the storm during a regular shift, and this may offer cost savings over de-icing (in material, personnel, and equipment). In other cases, pre-treatment of roads before a winter storm may be performed with solid materials. However, the application of an anti-icing procedure requires precise weather forecasts since the material may be washed away if rain comes first, or wasted if forecasts are wrong (Board, 2016).

De-icing: This involves the application of chemicals during or after a storm, which improves the ability for plows to clear ice and snow from the road by loosening compacted snow and ice. This method can either be used as a complement to the plowing method to help make the process easier and more effective, and/or as an independent approach for getting the bare pavement goals. The best practice for de-icing methods to improve effectiveness is by using pre-wetted deicers (Board, 2016).

Pre-wetting: This involves the addition of brine or other liquids to granular materials to help jump-start the melting process. Pre-wetting can be applied at the spinner, in the pile, or by adding brine in the spreader box. The benefits that come with this method include achieving faster melting, decreasing material use, and, because it is in a semi liquid state, helping to prevent material scatter (Board, 2016).

Snow Plowing: This involves the removal of snow and ice from the roadway by mechanical means. Plowing is typically complemented with addition of de-icing chemicals. For some conditions, it may be necessary to plow the roadway while adding sand or other abrasives. Plowing alone may have no environmental impacts from chemical use, but the trade-off is less effective snow removal, lower levels of service, and potentially a higher risk to public safety (Board, 2016).

2.3 Winter Maintenance Materials

A variety of winter maintenance materials are available to manage snow and ice. Below is a summary of the commonly used winter maintenance materials as reported in terms of materials, their uses, attributes, and environmental impacts by the Local Road Research Board, Minnesota DOT (Board, 2016).

Abrasives: These are materials that are mostly mixed with salt to provide traction to slippery roads. The amount of salt added to the abrasives ranges from 20% to 30%. The typical form of abrasives is sand for paved roads or gravel for unpaved roads. The use of abrasives can be applied in places with any low form and temperature to regain the traction. One advantage of abrasives is the provision of temporary traction, which is important in emergency situations. Abrasives are more effective than chemicals at very low temperatures and for spot traction at targeted locations (hills, curves, bridges, intersections, shaded areas and windblown areas), abrasives are also useful alternatives in environmentally sensitive locations (no salt roads). On the other hand, the disadvantages of abrasives are (1) the recovery from storm is slower than chemicals when used alone or in combination with only plowing; (2) more plow passes are required; and more application of abrasives is required compared to when chemicals are used; (3) abrasives cannot achieve de-icing; (4) they also require clean up after winter seasons. The environmental drawback of using abrasives is that once they enter waterway and clog streams or clog drains, they can impact water quality and aquatic life. Likewise, once used with salt, they can cause corrosion (Board, 2016).

Solid Rock Salt (NaCl): These materials exist in a solid granular form and are mostly used for de-icing or anti-icing purposes. The lowest practical melting temperature for solid rock salt is 15^{o} F (Board, 2016). Salt is very effective when the temperature is above 25°F, fairly effective when temperature is between 25°F and 15°F, and marginally effective when temperature is between 10°F and 15°F (Watson, Moore, & Gu, 2018). The positive attributes of using solid rock salts are its excellent melting capacity, its lower cost compared to other chemicals and its ability to clear snow and ice on roads. However, the negative attributes of using solid rock salt are that it impacts roadside waterways, causes pavement deterioration and corrosion to vehicles and infrastructure. The direct environmental impacts that are caused by these materials are the impacts to roadside soil, vegetation, and waterways (Board, 2016).

Salt Brine: This is a solution of salt with water used for pre-wetting and anti-icing. Since it is a solution, salt brine typically is applied in liquid form. The lowest practical melting temperature is like that of solid rock salt (15^{o} F). The positive attribute of salt brine is that it prevents snow and ice from bonding to pavement (anti-icing); it has a lower cost compared to other chemicals; and it reduces granular scatter when used for pre-wetting compared to solid rock salt. However, the negative attributes and environmental impacts are similar to those of solid rock salt.

Magnesium Chloride ($MgCl_2$): This material can either be used in liquid or solid form for de-icing, pre-wetting, and anti-icing purposes. The lowest practical melting temperature for solid rock salt is -10^{o} F. The positive attribute of using this material is it reduces amount of product used, reduced salt and abrasive compared to rock salt, better cold temperature performance than rock salt, and it persists on the road surface, aiding in longer black ice prevention than sodium chloride. The negative attributes of using Magnesium Chloride are it causes pavement deterioration and corrosion to vehicles and infrastructure, costs more than rock salt, and is more corrosive than sodium chloride (rock salt). The direct environmental impacts that are caused by these materials are to the waterways and leaching/run-off from stockpiles (Board, 2016).

Calcium Chloride ($CaCl_2$): The typical form of this material is liquid and is used for de-icing. The lowest practical melting temperature for this material is -20˚ F. The positive attribute of using Calcium Chloride is that it has a better cold temperature performance than rock salt and reduced amount of product used. However, the negative attributes of using calcium chloride are that it causes pavement deterioration and corrosion to vehicles and infrastructure and costs more than rock salt and more corrosive than sodium chloride (rock salt). The direct environmental impacts that are caused by these materials are the impacts to roadside soil, vegetation and waterways just like sodium chloride. It may also result in mobilization of heavy metals in soil and thereafter releasing them into the water (Board, 2016).

Acetates: Acetates used are calcium magnesium acetate or potassium acetate. Both acetates have a typical liquid form and are used as anti-icing agents. The lowest practical melting temperature for calcium magnesium acetate is -20˚ F while for potassium acetate is -15˚ F. The positive attribute of both acetates is their non-corrosive property while potassium acetate being mostly used on bridge anti-icing systems(Board, 2016)(Board, 2016)(Board, 2016)(Board, 2016)(Board, 2016)(Board, 2016)(Board, 2016). On the other hand, the negative attribute of using acetates is that they are expensive, and the environmental drawback is that their decomposition consumes dissolved oxygen resulting in lower oxygen levels in water (Board, 2016).

Other additives: Additives like beet juice and potato juice are added to brine and rock salt to lower the freezing point. Beet juice can lower the temperature of freezing water up to 20 degrees below freezing point. The positive attributes include its environmental friendliness, agricultural byproduct, hold on pavements for longer and safe on bridges, lower corrosion, and fewer toxins in the soil and waterways.

2.4 OGFC Winter Maintenance Practices

In 2006 Yildirim et. al. performed a study for Texas DOT to analyze the winter maintenance methods for new generation OGFC pavements because the usage of sand resulted in clogging, hence more salt was used for winter maintenance. OGFC experiences lower temperature and longer periods of colder temperature than DGAC, this results in more applications of de-icing agents. In Texas, for instance, de-icing agents are considered the most effective method for winter maintenance on OGFC (Yildirim et. al, 2006).

Winter maintenance is among major challenges on the use of OGFC pavements. OGFC being an open-graded mixture surface, exhibits reduced heat capacity compared to Densely graded Asphalt Course (DGAC) (Alvarez, 2006; The Highways Agency, 1999). The voids in the OGFC result in decreased heat flow rate in the material leading it to act as an insulating course surface (Alvarez, 2006; Huber, 2000).

The thermal conductivity of OGFC can range from 40 to 70 percent of the magnitude of the DGAC (Lefebvre, 1993; Putman, 2012), where its surface can exhibit temperatures of 1.8 to 3.6^{o}C lower than that of DGAC. Due to these thermal properties of the OGFC surface, an early formation and more frequent ice and production of frost happens compared to that of DGAC (Alvarez, 2006; Huber, 2000; NAPA, 2002; Partl, 2010). Also, it has been shown that when the temperature of an OGFC drops below freezing, it will stay below freezing longer than regular HMA pavements thus resulting in delayed thawing (Wegman et al., 2018; Yildirim Y., 2006). Hence, OGFC experiences longer periods of ice and frost compared to DGAC and such phenomenon has been observed in Europe and in the United States (Alvarez, 2006; Cabrera, 2003; Huber, 2000). It has been observed that once frozen, the resulting layer of ice is much more difficult to remove from an OGFC layer than from a regular HMA. However, a research study conducted in Japan showed that when snow hit a wet HMA surface it melted while an OGFC surface turned the same snow to slush. Other examples from this study show that OGFC layers did not promote black ice and that precipitation was more likely to remain in the state it fell on an OGFC (Iwata, Watanabe, & Saito, 2002; Putman, 2012). The lower temperatures and greater air voids of OGFC allow water to become trapped more easily and freeze more quickly than other pavement surfaces. This is known as black ice, and it is a serious road hazard for drivers (Wegman et al., 2018; Yildirim Y., 2006). Black ice and extended frozen periods are considered to be the main problem associated with OGFC winter maintenance in the United States (Alvarez, 2006).

2.4.1 Materials and Method Used for OGFC Winter Maintenance

Sand is spread to the pavement surface to enhance friction and hasten de-icing however this method is not preferred for OGFC since it leads to clogging of voids leading to the decrease of the main advantages of using OGFC layer (drainage and noise reduction capabilities) (Alvarez, 2006; Tappeiner, 1993). Application of sand should only be done in emergency where quick surface friction is required such as during a surprise ice or snow event (Alvarez, 2006; Yildirim Y., 2006). Snow plowing needs to be done carefully because OGFC surface has less resistance to the snowplow blades. De-icing chemicals can be used, but at higher rates as the chemicals will drain through the pavement structure. Anti-icing can also be utilized on OGFC but is very sensitive to timing as ice and snow will be compacted down into the voids structure in the case of late application. OGFC approximately require 25 to 50% more salt and about 30% more anti-icing materials (Putman, 2012; Wegman et al., 2018).

Salting can be used but also needs to be done carefully. Small salt rock pieces should be used for quick dissolution and minimized pore clogging (Putman, 2012; Wegman et al., 2018). If too much rock salt is placed on roads, conditions can become slippery due to excess salt (Putman, 2012; Van Doorn, 2002).

Pre-wetted salt allows the salt to cling to the irregular surface of the OGFC and so it remains effective much longer compared to dry salt which will tend to collect at the bottom of the OGFC when applied in the dry form and when salt brine is applied it tends to run through the porous layer leaving little residue on the surface (David Newcomb, 2004).

While the need for salt is generally higher on OGFCs due to salt solution penetrating the void structure, research has shown that as long as traffic volumes remain high, the salt solution will be pumped in and out of the void structure by the traffic diminishing the need for extra salt (Greibe, 2002).This phenomenon has been observed in multiple studies as researchers have noticed higher friction numbers in the travel lane of an OGFC pavement. In fact, friction numbers in winter weather conditions on OGFCs have proven to be better than regular HMA surfaces except for the case of compacted snow (T. A. Bennert & Cooley Jr, 2006; Iwata et al., 2002; Padmos, 2003; Putman, 2012). If anti-icing measures are performed too late, ice or snow will be compacted down into the void structure of an OGFC creating a frozen layer in the pavement (Giuliani, 2002; Putman, 2012).

2.4.2 Winter Maintenance Practices - USA

Developing an adequate and efficient winter maintenance strategy has been challenging, and an interesting subject of concern, to agencies using OGFC. As mentioned in the prior section, 34 of the 50 state departments of transportation (DOTs) in the United States have used OGFC at some point since its inception.

Minnesota DOT (MNDOT) through the Clear Roads pooled fund commissioned an analysis of the cost and benefits of various winter maintenance strategies that involved material usage with plowing showed that the use of calcium chloride ($CaCl_2$) and Salt Brine had a high benefit cost ratio of 3.8 followed by magnesium chloride ($MgCl_2$) having 3.6, solid rock salt (NaCl) having

2.4 and the least being abrasives having 0.2. This analysis included safety benefits, agency resources, corrosion to infrastructure and vehicles, and environmental impacts (Board, 2016). The benefic-cost ratio of calcium and magnesium chlorides in Minnesota is higher because much as the cost of materials is higher there is more benefits on using these materials especially in cold weather. While the benefit-cost ratio of abrasives is positive, the benefits provided by OGFC in the reduction of splash and spray seems to be inhibited by the amount of sanding and other fine debris deposited on the surface (Uhlmeyer, 2012). Similarly, there have been cases in Minnesota where the use of magnesium chloride has been detrimental due to residual refreeze (Wegman et al., 2018).

MNDOT makes use of Road Weather Information System (RWIS) to obtain a detailed and timely road-weather information that is used to support operations and maintenance decisions. These RWIS are comprised of a network of field Environmental Sensor Stations (ESS) that measure atmospheric and pavement conditions. The pavement data collected are pavement temperature, condition (dry, wet, ice, frost) and subsurface temperature, where the atmospheric data collected are air temperature, humidity, visibility distance, wind speed and direction, and precipitation type and rate. MNDOT uses a Maintenance Decision Support Software (MDSS) to use the collected data to determine the treatment type required, application rates, application timing, and to predict the resulting road conditions (Board, 2016).

In Texas, de-icing agents are currently considered the most effective winter treatment, followed by liquid deicer agents and sand (Alvarez, 2006). Texas DOT (TxDOT) districts consider anti-icing agents as the most effective method for winter maintenance practice for combating black ice, freezing rain, and light snow events followed by liquid deicer and sand (Estakhri, Alvarez, & Martin, 2008; Yildirim Y., 2006). Anti-icing procedures involve a combination of liquid, dry solid, and pre-wetted chemicals applied at the appropriate times considering temperature, amount of moisture, and traffic conditions (Estakhri et al., 2008; Ketcham, 1996). De-icing procedures are to be reserved for events where ice and snow have already bonded since this procedure requires more materials and does not maintain safe road condition as well as anti-icing procedures. Due to clogging caused by the use of sand, TxDOT suggests the use of materials other than sand when friction generation is required (Estakhri et al., 2008).

To increase the effectiveness of winter maintenance TxDOT has suggested other methods to supplement the use of the conventional methods. Methods that involve the use of pavement condition sensors, meteorological instrumentation, and connecting hardware and software for monitoring the pavement condition are suggested since they can help in decision making on when and how to maintain the OGFC surface (Estakhri et al., 2008; Tappeiner, 1993).

Oregon DOT has suggested research to be done on organic deicers with high viscosity and electrostatic charge technology (similar to that employed in emulsified asphalt) for the purpose of improving the bonding of deicers on the surface since the deicers can flow into the porous friction course instead of remaining on its surface unlike how it is for densely graded mixes (Alvarez, 2006; Tappeiner, 1993).

In New Jersey , the New Jersey Garden State Parkway (NJGSP) has used liquid magnesium chloride as an anti-icing agent effectively to prevent ice buildup in OGFC (T. Bennert, et al., 2005; Wegman et al., 2018).

When Indiana DOT (INDOT) used OGFC surfaces many years ago, they experienced problems with the surface voids clogging, especially when abrasives were used for snow and ice control (McDaniel, 2010).

South Carolina DOT (SCDOT) suggests the typical use of deicers and, by doing so, to consider increasing the application rate to account the permeability of the pavement surface as de-icing salts and chemicals will eventually migrate into the pore structure of the OGFC layer and not remain on the pavement surface. SCDOT also places emphasis on avoiding the mixing of de-icing salts with sand so as to prevent clogging of the OGFC layer (Putman, 2012).

There are a lot of debates on OGFC winter maintenance practices, as often times the behavior of salt and OGFC is not predictable and varies greatly from mix to mix (Greibe, 2002; Putman, 2012). Because of this problem, some states have indicated that there is no definitive solution for OGFC winter maintenance (Padmos, 2003; Putman, 2012). Others, however, suggest that solutions can only be found through experience (Brosseaud & Anfosso-Lédée, 2005; Putman, 2012).

2.4.3 Winter Maintenance Practices - Europe

Belgium's intensive application of liquid de-icing salts has allowed to obtain similar condition to dense and porous mixtures subjected to snowy weather. The Netherlands adopted the use of higher frequency of application and a 25 percent greater quantity of liquid salt to address winter maintenance difficulties in porous mixtures (Alvarez, 2006; Cabrera, 2003; NAPA, 2002). Cold regions of Italy, Austria, and Switzerland have reported the use of liquid chloride solution to be more effective than the use of solid salt (Alvarez, 2006; Tappeiner, 1993).

Britain practices preventive salting before snowfall and greater frequency in the application of salt in its porous pavement layers compared to densely graded mix (Alvarez, 2006; The Highways Agency, 1999). They recommend increasing the amount of salt applied on densely graded sections that are adjacent to porous friction course segments. Additionally, they propose prompt plowing of snow using plows fitted with rubber edges on the blade to prevent surface damage. Also, since traffic has been seen to have minimum contribution to the spreading of de-icing chemicals, a greater control in the homogeneous application of de-icing chemicals is required for porous friction course (Alvarez, 2006; Tappeiner, 1993).

In Italy, researchers have found that reducing the maximum aggregate size from ¾ to ⅝ inches significantly improved winter weather surface conditions (Litzka, 2002; Putman, 2012). The amount of de-icing material requirements for winter maintenance for OGFC are greater than that required for DGHMA due to their difference in thermal capabilities (Alvarez, 2006; Bredahl, 2005; Huber, 2000; D. F. H. A. Rogge, U.S. Department of Transportation, & Washington, 2002; The Highways Agency, 1999). European countries anticipate that it will require as much as twice the amount of salt needed for densely graded surfaces (David Newcomb, 2004).

2.5 Conclusion

Finally, a comprehensive winter maintenance strategy was suggested in the manual for design, construction, and maintenance of open-graded asphalt friction courses. From the author's view, it is important to give special and continuous training to drivers of snow-plows and spreaders (NAPA, 2002). Also, in addition to conventional practices for winter maintenance, the use of pavement condition sensors, meteorological instrumentation, and connecting hardware and software has been suggested by researchers to monitor the road system and support the decision process involving when and how to treat an OGFC surface (Alvarez, 2006; Tappeiner, 1993).

From the literature review the techniques used for winter maintenance of OGFC pavements are anti-icing, de-icing, pre-wetting and snow plowing. Materials that are commonly used for OGFC winter maintenance are abrasives, solid rock salt (NaCl), salt brine, magnesium chloride ($MgCl_2$), calcium chloride ($CaCl_2$), acetates and other additives such as potato juice and beet juice.

It has been reported that OGFC pavements exhibits colder temperatures faster and stays cooler longer that densely graded asphalt pavements. This results to increased winter maintenance cost. Anti-icing has showed to be more cost effective in time, equipment and material usage for OGFC winter maintenance. Higher frequency of material application on OGFC can help to quickly keep ice and snow out.

On OGFC winter maintenance practices it is recommended to use Road Weather Information System (RWIS) to obtain a detailed and timely road-weather information that is used to support operations and maintenance decisions. Increase the amount of salt applied on densely graded sections that are adjacent to OGFC sections, plow the sections promptly with plows fitted with rubber edges on the blade to prevent surface damage.

It is also reported that reducing aggregate size from ¾ to ⅝ inches significantly improved winter weather surface conditions.

Chapter 3 Methodology and Data Analysis

The objective of this study was to collect and document winter maintenance techniques from other states through literature search and a survey to DOTs. A survey was sent to state DOTs to obtain more information on winter maintenance practices that could benefit TDOT. Another internal survey was sent to TDOT's four regions to obtain the current practices on OGFC winter maintenance in the state. The research team evaluated and analyzed the survey information to gather relevant winter maintenance practices that could benefit the State of Tennessee. This report is limited to literature review and survey information, no data collection or site testing was performed. From the survey and literature review, winter maintenance guidelines of OGFC pavements are recommended. Two surveys were sent: one to TDOT's four regions (internal survey) and the other to state DOTs (external survey). Reported here is the summary of responses, a more detailed report is in the Appendix.

3.1 External Survey Responses

The external survey was sent to all 50 states DOTs, twenty-seven state DOT's (or 54%) responded to the surveys as shown in Figure 2. From the respondents, sixteen participants (59 %) currently use OGFC pavements in their states, while eleven participants (41 %) do not use OGFC pavements. Out of those not currently using OGFC, 5 participants (19%) used it in the past and six (22 %) never used it in their state. Figure 3-1 shows a US map with states in different colors showing the usage of OGFC.

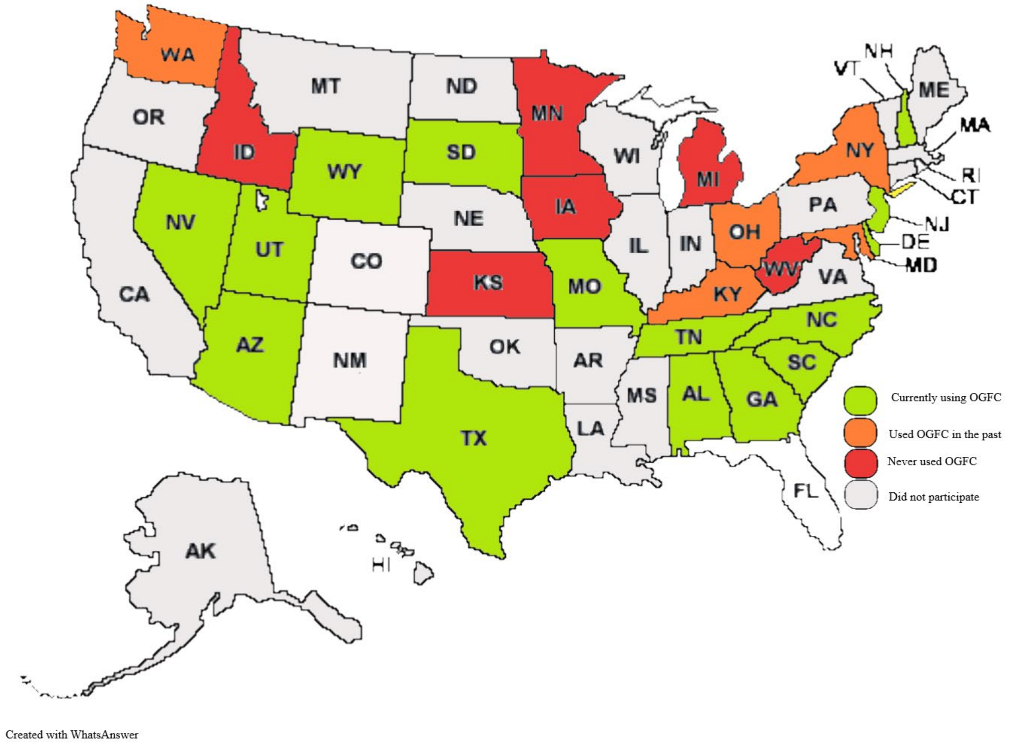

Figure 3-1 Map of USA Indicating State DOT's Participation on Survey and Their Usage of OGFC

From the survey responses, the usage of OGFC is mostly on interstates and state routes. Few participants indicated the use of OGFC on parking lots, bike routes, or where noise reduction is needed. 52% of respondents using OGFC have different considerations on winter maintenance between OGFC and densely graded pavements while the remaining 48 % provides winter maintenance of both types of pavements the same way. Moreover, responses indicate that OGFC,

- requires heavier application rates of de-icing and anti-icing materials;
- requires more salt due to additional passes;
- requires the use fan spray nozzles instead of stream spray for liquid anti icing;
- cannot apply sand/gravel;
- are generally avoided where ice events are difficult to manage. Some Northern districts of Texas do not use OGFC surfaces at all.
- Others reported a use of same techniques on all roads. Furthermore, it depends on storm events characteristics.

Techniques

Figure 3-2 shows the winter maintenance techniques adopted by participating states. The numbers on the bar graph show the number of survey respondents.

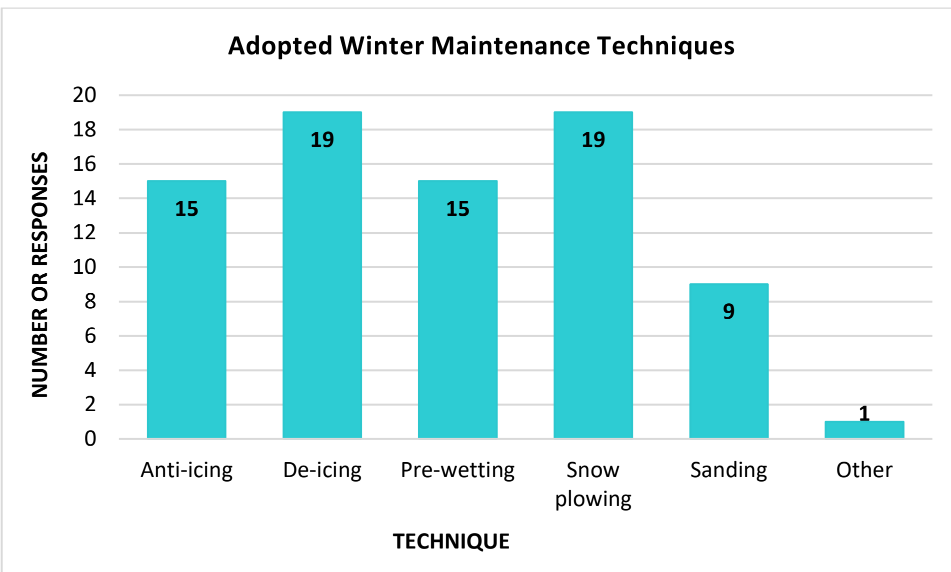

Figure 3-2 Adopted Winter Maintenance Techniques

Technique Effectiveness

On the effectiveness of techniques used for OGFC Table 3-1 summarizes the participants rating: 1 being not effective at all and 5 being very effective. From the table it can be seen that snow-plowing is the most used technique followed by pre-wetting, anti-icing, de-icing and sanding, which is the least used.

Table 3-1 Effectiveness of Technique Used

Technique	*Median rating*
De-icing	3.56
Anti-icing	3.75
Pre-wetting	3.85
Snow - plowing	4.0
Sanding	2.7

Figure 3-3 illustrates the effectiveness of the adopted techniques as reported by the surveyed states. Fifteen states provided this information; four states indicated not using the techniques. Each colored bar represents a winter maintenance technique as illustrated in the graph legend. The vertical axis indicates the rating of the adopted technique from scale of 5 points, 1 being not effective and 5 being very effective, zero indicates not used. The average shows that de-icing and snow plowing are the most effective techniques, followed by anti-icing, then pre-wetting. Sanding is not commonly used as it results to clogging of OGFC surfaces.

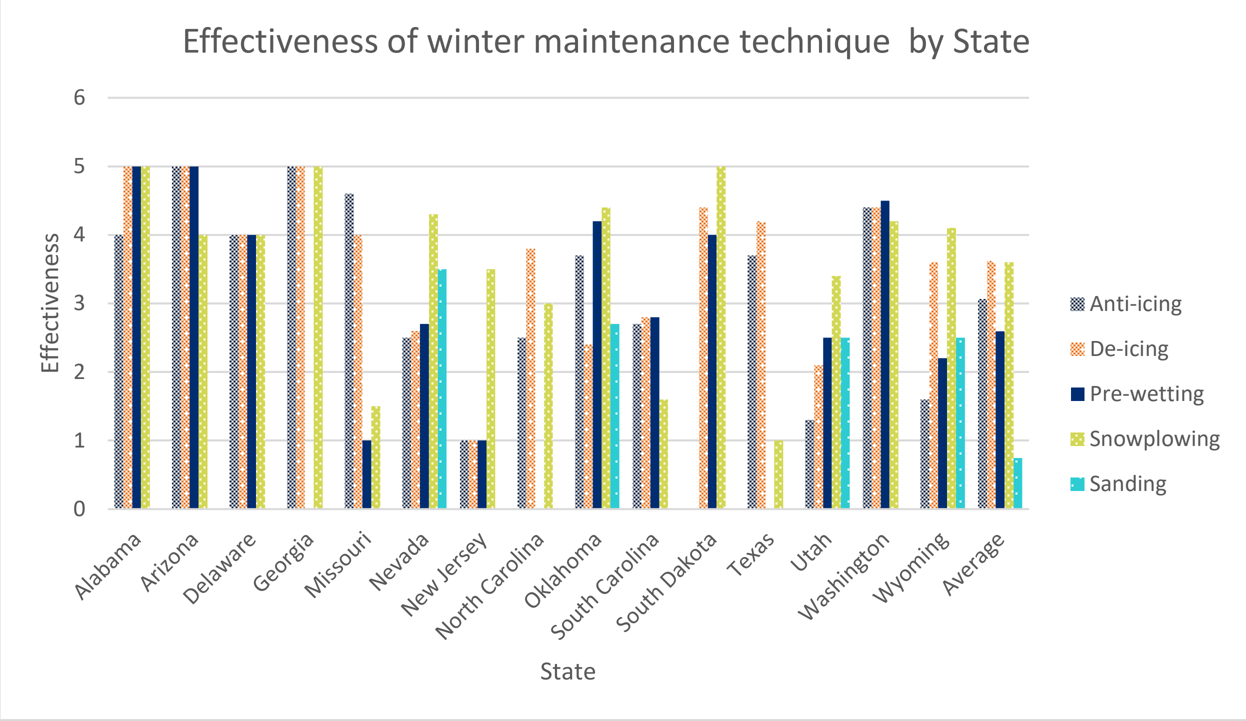

Figure 3-3 Effectiveness of Winter Maintenance Techniques Rated by State

Materials

Materials used for winter maintenance were reported by 22 participants, where the usage of abrasives is 45%, solid rock (NaCl) and salt brine use is 77% for each, calcium chloride ($CaCl_2$), 41% and magnesium chloride ($MgCl_2$), 36%. Some use $MgCl_2$ on higher elevations only, and others use beet juice. Figure 3-4 shows the effectiveness of winter maintenance materials.

The horizontal axis represents the number of states using the specified winter maintenance material.

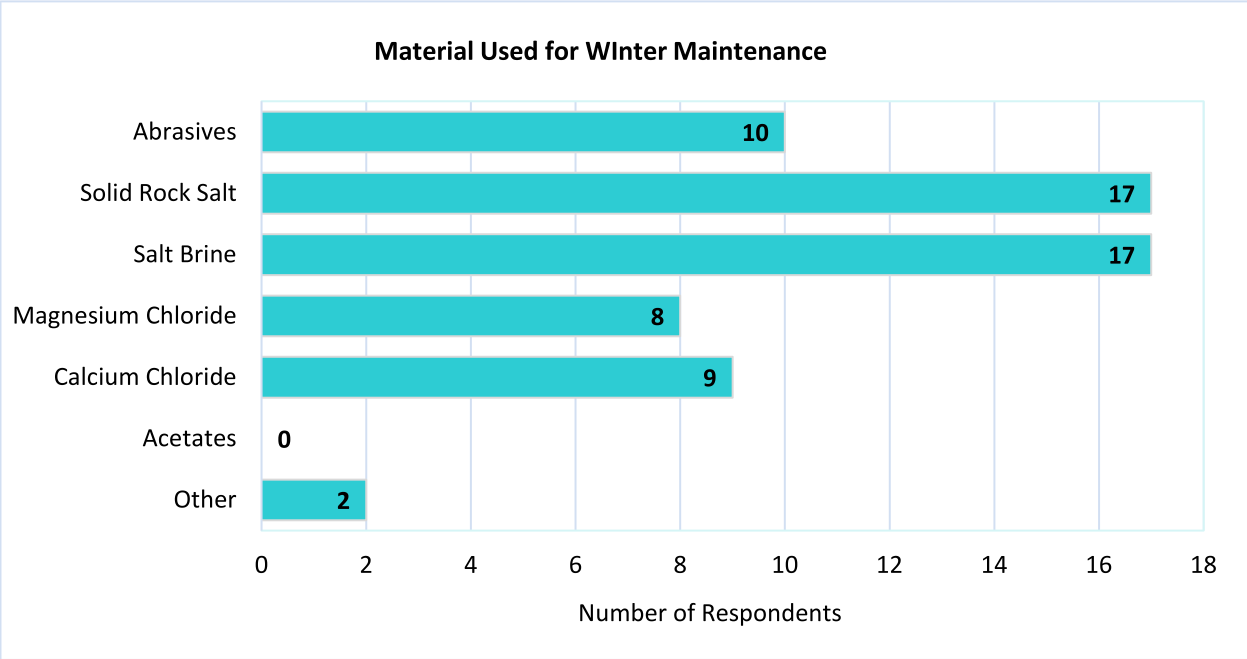

Figure 3-4 Effectiveness of Winter Maintenance Materials

Application Rates, Location of Application, and Cleaning

The application rates of winter maintenance materials for salt brine liquids range from 20 gal/lane mi. to 100 gal/lane mi., depending on the concentration, and 30 gallons per lane mile for beet juice. Salts range from 250 lb/lane mi to 500 lb/lane mi. depending on the snow event.

On pre-storm treatment, many respondents reported to have not used it. Those who use pre-storm treatment, use liquid brine at 23% concentration or calcium chloride at 25% concentration. Some respondents use just the salt brine, but when it is very cold, may consider using magnesium chloride, which is very rare. Beet juice at 30 gal/ln. mi. or beet juice mixed with brine (at 30 - 70 beetroot – brine mix) is also reported as an effective pre-storm treatment.

The paving of OGFC can be on the full shoulder width or only a portion of the shoulder. Twenty participants responded to this question. While eight reported paving the full shoulder', six participants reported paving 'roadway only', and another eight participants reported paving a 'portion of the shoulder'. Figure 3-5 below demonstrates the different practices used by the surveyed states on paving the shoulder with OGFC. The pie chart illustrates the proportion using OGFC for full shoulder, portion of shoulder, roadway only or other.

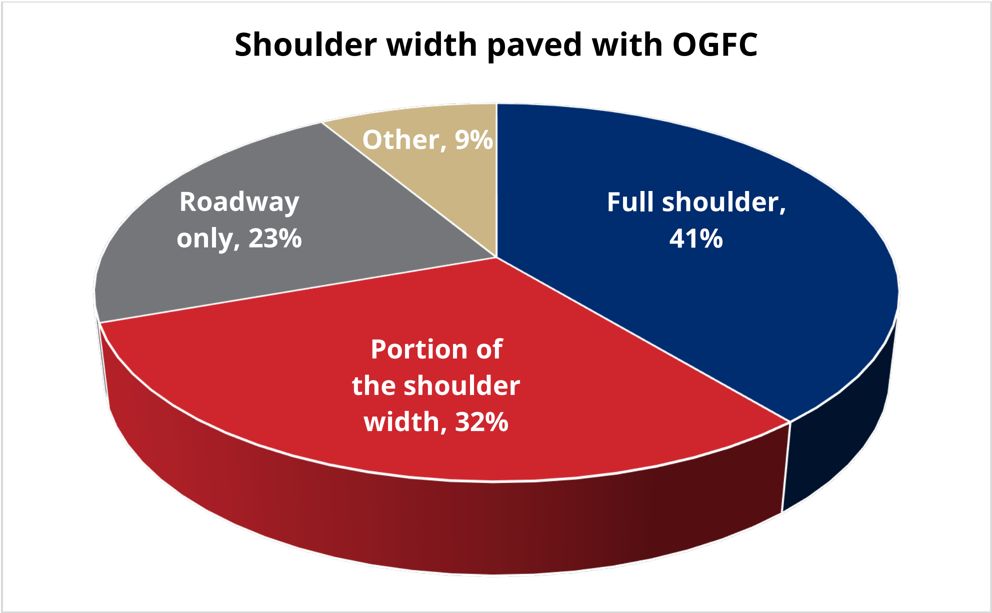

Figure 3-5 Shoulder width paved with OGFC

For the thirteen participants who responded with the "portion of the shoulder width", the exact width is as reported on Table 3-2 below.

Table 3-2 Portion of the Shoulder Paved with OGFC

Shoulder portion with OGFC	*Responded*
Before rumble strip 6"	2
Past the rumble strip >6"	5
Exactly what width	6
12 inches	1
18 inches	1
24 inches	2
Full width	2

It was also reported by the majority of respondents (75%) that they do not pave over 4 feet outside the shoulder to allow the OGFC to drain on the remaining paved 6-foot shoulder.

The participants who responded with "yes" when asked how they plow the bi-level shoulder reported (1) they normally send a plow truck down the shoulder and will run the blade down the edge of the OGFC, (2) they normally don't plow shoulders until lanes are clear, and (3) they plow as best as they can, but there is much less concern with a little snow being left on the shoulder.

When asked if they add extra salt to the outside OGFC shoulder to reduce blockage from frozen ice twenty-one participants responded: twenty answered with 'NO', and one participant responded with, "Depends upon the situation that we encounter. Typically, due to the nature of our spreaders and natural traffic kicking the salt onto the shoulders, the need for additional salt is not necessary."

When asked how they ensure continuous drainage of the shoulder fully paved with OGFC is not blocked by soil or fine aggregates at the edge of the shoulder, eight participants responded saying,

- Shoulders are not paved with OGFC.
- Drainage function for OGFC on shoulders is not considered.
- OGFC is full depth so the water drains through the pavement into the underlying base courses.
- Have not encountered this issue.
- Typically, the outside sluff of the OGFC ties in with the sluff of the asphalt pavement lift below. The topsoil on the shoulder only comes to the bottom of the sluff allowing the water to runoff the surfacing.
- Catch basin lids are recessed below the level of the OGFC so that drainage is captured.
- There is enough moisture to flush the porous material.
- Nature takes its course.

Apart from winter maintenance, 81% responded that they do not clean OGFC pavements. For those who clean OGFC pavements, sweeping is the most common method used, few would vacuum. Some sweep just to remove loose rock to minimize broken windshields and damage claims.

OGFC Service Life, Exclusions and Maintenance Guides

OGFC pavements are reported to last from 3 to 20 years with average minimum of 8 years and average maximum of 11 years. Some plan for 20 years on shoulders and parking lots. Most states (90% of respondents) do not consider winter maintenance when designing OGFC pavements, only 10 % reported to consider it when designing pavements.

71% of participants would exclude certain roads from paving with OGFC, but for the remaining 29% there are no exclusions. Most states would use OGFC on interstates or high-volume roads with a high number of wet weather crashes. The high maintenance cost and challenges of timely replacement of OGFC surfaces, in some cases, mean it is used on low volume roads and non-NHS. Places where OGFC is not preferred include where ice events are difficult to manage, on urban sections with turning and stopping motions, on roadways with curb and gutter for in mill, and inlay operations. PFC/OGFC is sometimes discouraged in order to meet environmental requirements, since quality of storm water runoff can be lost over the life of the surface course.

The research team was able to obtain only two winter maintenance documents, from Texas, which is a general winter maintenance for all pavement types, and from Arizona, which specifies OGFC mix design and mix considerations. The team was not able to obtain any winter maintenance guide, from the respondents, that was specifically for OGFC roads. Furthermore, only one participant provided additional information: "In addition to conventional preservation measures, OGFCs may also be cleaned by washing or vacuum periodically." Texas is wary of the damage ice can cause on OGFCs, so they are not favored in areas with frequent freeze/thaw cycles. Also, the binder is usually latex or tire rubber modified to provide more resistance to stripping and shelling/raveling. Each TxDOT District is responsible for the continued maintenance of their OGFCs pavements and use different maintenance and ice control strategies.

Use of OGFC: Challenges and Successes

Challenges the states are facing regarding OGFC winter maintenance and pavement performance are listed below:

- Freezing roadways due to climate in the region. Typically, it is not snow-only events, but snow and ice or snow melt and re-freeze.
- OGFC is sensitive to moisture and dirty aggregates.
- No challenges experienced yet, but there is an ongoing research project that is looking at the impacts of salt on our roadways, we will have findings after the research results are out.
- Some states have new pilot projects, no challenges reported as of yet.
- Premature surface raveling and tire damage in parking lots.
- If anti-icing is not applied adequately, it can be very challenging to reach the objective of clean, wet pavements.
- Survival of OGFC roads from snow plow.
- A lot of de-icing material is used, mostly on inclines to try and keep the roads safe.
- OGFC roadway tends to freeze sooner than other pavements. Snow and ice bond more significantly. Blades wear faster. Abrasives cannot be used because they would "clog" up the voids.
- The performance of OGFC decreases at a faster rate relative to the number of winter operations performed.
- Both plows and motor graders are used during winter storm response. The pavement surface with the OGFC is easily damaged by plows and motor grader blades.
- Shoulder cleanup during winter storms.
- Issues with brine treatment using stream nozzles, switched to fan spray to have effective coverage.
- The timing of pre-treating or anti-icing has been found to be successful for pavements with OGFC surfaces.
- Our main challenge is related to studded tires and longevity of OGFC pavements.
- Having the value of liquids to deliver double the rate. Then stay on the same application cycle time.

Successes experienced from winter maintenance of OGFC projects are below:

- Using salt brine throughout the state prior to a storm. Having this material below the snow and ice has improved the ability to clear roadways faster.
- Training by venders on the usage of the materials is very effective in improving the performance and reducing cost.
- Moving to salt with pre-wet and keeping vehicle speeds at 35 MPH and below has shown beneficial.
- During the winter storm, dedicate the equipment to stay on a route with a steep mountain. Try not to extend the equipment that would cause the cycle time to be greater for the material being spread.

Other comments shared by participants are listed below:

- Make sure aggregates' water absorption does not exceed 2.5% and Asphalt absorption does not exceed 1.0 %. OGFC is very sensitive to moisture damage.
- Some states do not use OGFC as wearing course for travel lanes. Others do not like OGFC from the winter maintenance perspective.
- Some experienced short life with OGFC pavements, and on maintenance more salt was used, so they no longer use them.
- OGFC has been primarily used on higher volume roads in areas with higher rainfall. It has been very effective in reducing wet weather crashes.
- OGFC was initially placed at test sections in Washington State to measure noise reduction. Because the noise characteristics were reduced for a short time, OGFC is not used.
- Information was shared on research conducted by Clearroads.org on OGFC "Understanding the Chemical and Mechanical Performance of Snow and Ice Control Agents on Porous or Permeable Pavements (January 2018)".

Most state DOTs do not have documented winter maintenance guidelines for OGFC pavements.

3.2 Internal survey

The internal survey was sent to all TDOT regions to be distributed to districts. TDOT has four regions and twelve districts, three in each region. Eight participants from four districts responded to the survey. This includes three participants from region 1: District 17 west, 18 west the third did not specify their district. One participant from region 2 district 29, three participants from region 3 district 39, and one participant from region 4 who also did not identify their district. Figure 3-6 displays a map of Tennessee, showing TDOT's four regions as indicated by different colors. The districts for each TDOT Region are as follows: Region 1 districts 17, 18, 19; Region 2 districts 27, 28 and 29; Region 3 districts 37, 38 and 38 and Region 4 districts 47, 48 and 49.

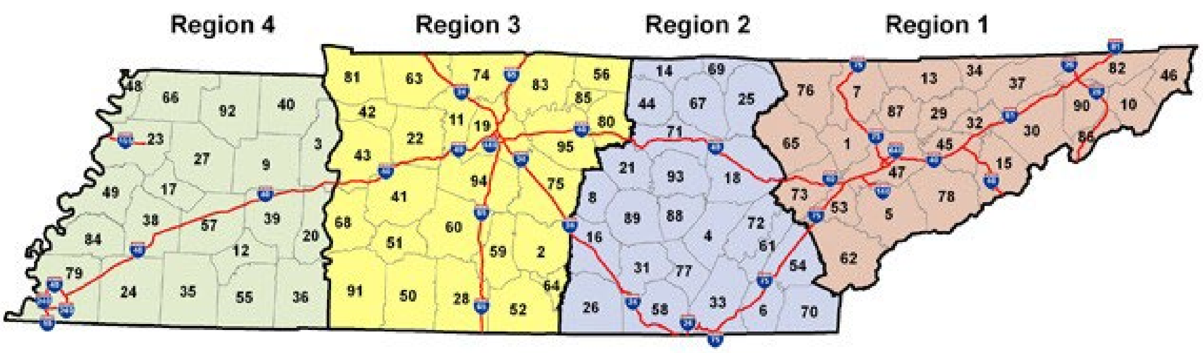

Figure 3-6 Map of Tennessee indicating the four TDOT regions

3.2.1 Internal survey questions and results

The internal survey results indicate that there is a presence of OGFC pavements in all four TDOT regions and is used mostly on interstates. The list of projects was provided by TDOT headquarters, and most participants agreed with the list of projects. Participants were asked to provide sections that posed maintenance challenges. Challenging sections are listed below.

Region 1, District 17 West

CNP292 and CNL957– Increased material and manpower to remove snow/ice from roadway when compared to other asphalt surfaces.

Region 1, District 18 West

I 275 and downtown 40 pavements coming up.

Region 3, District 39

- CNM342 – Raveling at joints, incomplete shoulder paving hard to plow.
- CNN327 – Raveling at Transitions, Joints, and Bridge Ends
- CNP075 – Raveling at Bridge Ends, Bridge End Settlement
- CNP282 – Raveling at Bridge Ends, Base Failures
- CNQ362 – Massive Base Failures throughout project
- CNQ376 – Raveling at Bridge Ends and Joints (7) CNR304 – Base Failures

Region 4 respondent did not provide feedback on challenging sections.

All eight participants reported different considerations on winter maintenance between OGFC and densely graded pavements as far as type of chemical, application rate, or triple coverage were concerned. Examples given on types of chemicals, application rate, and adopted winter maintenance techniques are listed below:

Techniques:

- Liquid solution and pressurized application system are different.
- Use little "hotter" brine on OGFC.
- Heavier salt applications and brine applications for OGFC.
- Heavier on pre-wet $CaCl_2$ application on OGFC.
- Unable to use belly plows on OGFC.
- Continuous brine operation in addition to salt application needed on OGFC.

Types of chemicals

- $CaCl_2$ on OGFC.
- No difference, use of brine, salt, and $CaCl_2$ regardless of surface.
- No difference, salt brine, calcium chloride, magic salt (potato juice), salt on all surfaces.

Application rate

- Throughout the event the OGFC sections tend to receive more material since it is thicker and porous.
- Heavier application (due to increased spread rates)
- Lower travelling speeds and shorter intervals between applications on OGFC.
- Use standard rates for salt and brine application per Standard Operation Guideline

Adopted winter maintenance techniques

Winter maintenance techniques adopted in Tennessee include anti-icing, de-icing, pre-wetting, snow plowing, and spreading salt then applying brine on top. Sanding of OGFC pavements is reported in District 18. The average effectiveness ratings by survey respondents of the techniques are as shown in Table 3-3. This is on a scale of 1 to 5, 1 being not effective at all and 5 being very effective. Zero (0) if the technique is not used. From the table it can be seen that most of the district do not use sanding for OGFC pavements winter maintenance, as it is rated as zero (0), except for district 18 West. This trend is similar to national wide survey. Sanding is not recommended on OGFC pavements as it results to clogging, but it is widely used on densely graded asphalt pavements.

Table 3-3 Effectiveness of Winter Maintenance Techniques Used in Tennessee

District	*Anti-icing*	*De-icing*	*Pre-wetting*	*Snow-Plowing*	*Sanding*
Region 1, District 17 West	1.8	1.8	2.5	3.5	0
Region 1	3.8	3.8	5	4.3	0
Region 1, District 18 West	1.8	1.4	2.5	1.3	2.1
Region 2, District 29	4	0	4.4	3.8	0
Region 3, District 39	0	4	4	4.5	0
Region 3, District 39	3.8	3.8	3.8	4	0
Region 3, District 39	5	5	3.8	4.5	0
Average District 39	4.4	4.3	3.9	4.2	0
Region 4	3.8	3	4.3	3.8	0
State Average	**3**	**2.9**	**3.8**	**3.7**	**0.3**

Figure 3-7 below displays the reported effectiveness of the adopted winter maintenance techniques. Each colored bar represents a winter maintenance technique as illustrated in the graph legend. The vertical bars indicate the effectiveness rating of the adopted technique from scale of 1 to 5 for the four TDOT regions and their districts.

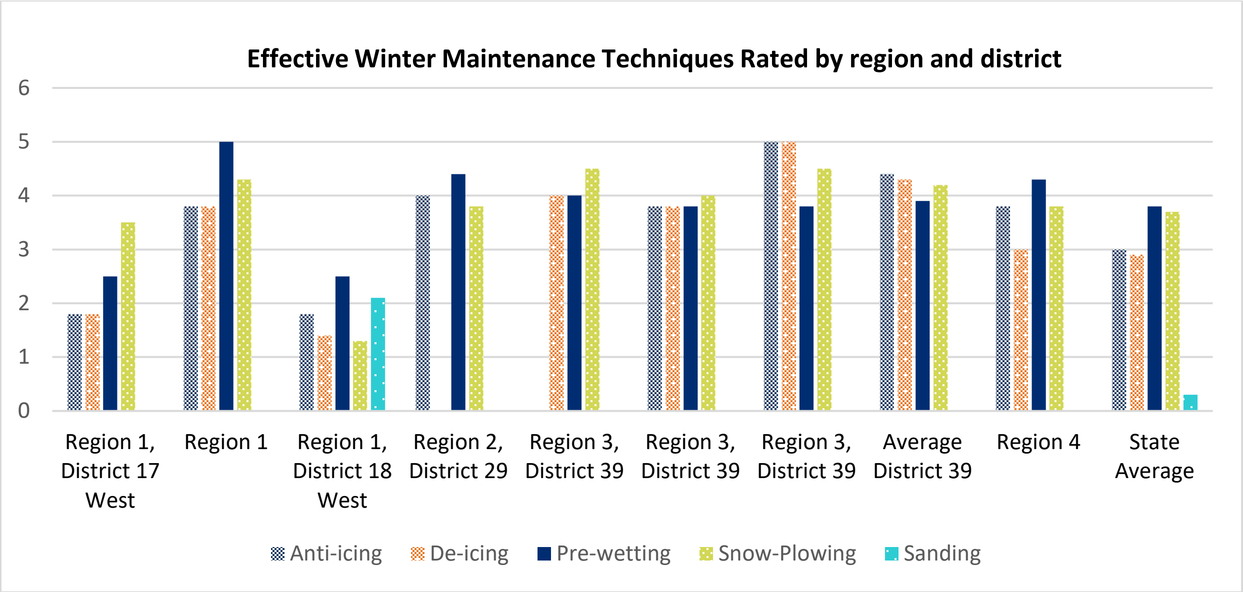

Figure 3-7 Effectiveness of the adopted winter maintenance techniques in Tennessee

The winter maintenance materials commonly used on OGFC pavements in Tennessee are solid rock salt (NaCl), salt brine, and calcium chloride ($CaCl_2$). Figure 3-8 shows the number of responses on each material used. The vertical axis displays the count of districts using three winter maintenance materials solid rock salt, calcium chloride and salt brine

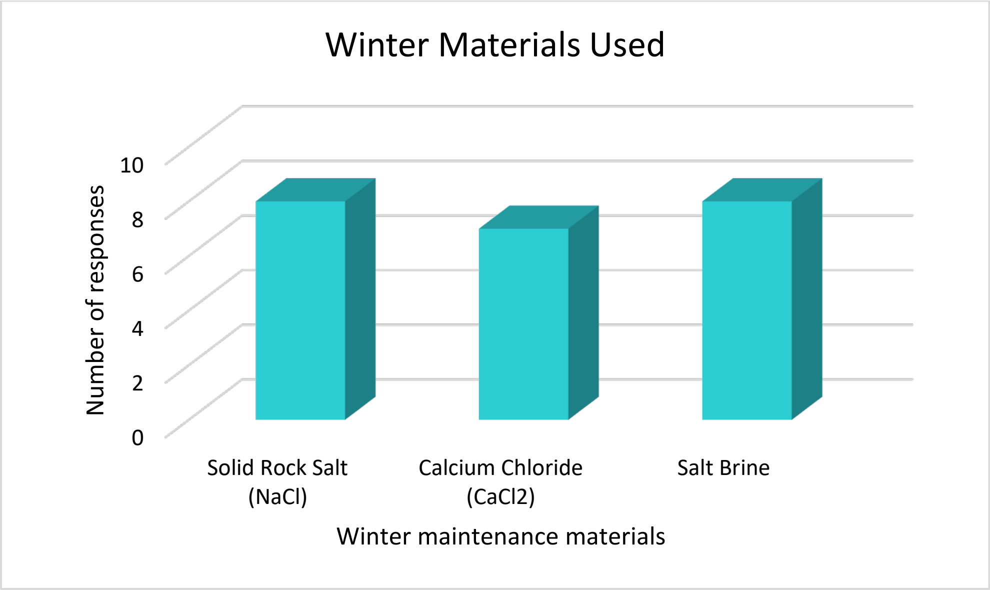

Figure 3-8 Winter Maintenance Materials Used in Tennessee

When asked on the application about rates of materials used for snow maintenance, the following were the responses from regions 1 and 4:

- Rock Salt 250 to 300 lbs/lane mi. just before snow event.

- Salt Brine and $CaCl_2$ mixture 40 – 50 gal/lane mi. before snow event in pressurized system.
- Spread Rate 200-250 lbs/lane mi.
- Blast mode on bridges and trouble spots 800-1000 lbs.
- Brine 80/20 (76%) 200 lbs of salt per lane mile.
- Brine additives – 10% calcium and 10% potato juice continuous operation with salt and brine applied.

Application Rates, Location of Application, and Cleaning

When asked on the application the rates of materials used for ice events, the following were the responses from regions 1 and 4:

- Rock Salt 300 lbs/lane mi. just before snow event.
- Salt Brine and $CaCl_2$ mixture 50 gal/lane mi. before snow event in pressurized system.
- Spread rate 250 lbs/lane mi., for salt brine and calcium chloride.
- Increase brine additives to 20% calcium and 20% potato juice.
- Lower travel speed to increase coverage
- Salt applied at Standard Operation Guideline rate.

The effective pre-storm treatments in various situations and their coverage rates reported are as follows:

- Salt Brine and strong $CaCl_2$ mixture 50gal/lane mi. before snow event in pressurized system.
- Standard brine with 10% calcium and 10% potato juice
- Depending on weather forecast sometimes spread light salt during pre-treatment"

The portion of the shoulder width paved with OGFC was reported as both full shoulder and portion of the shoulder depending on the project. When asked exactly what portion of the shoulder answers included before the rumble strip 6", past the rumble strip > 6", and at 4 feet. When asked if they pave OGFC over only 4 feet of the outside shoulder to allow the OGFC to drain onto the remaining paved 6-foot shoulder five answered yes and three answered no. A respondent from TDOT Region 1 added "this poses issues when employees are attempting to clean the shoulder area. It is difficult to clean, and the shoulder drop off will "pull" the vehicle when the tire is navigating the drop off. Therefore, the employee is constantly fighting this "pulling" effect while plowing."

When asked if they add extra salt to the outside OGFC shoulder to reduce blockage from frozen ice, the responses comprised of both no's and yes's. However, some participants gave additional information: (1) shoulders are treated like mainline, no extra salting, (3) work from the shoulder to the interior lanes to ensure water can escape from the treated surface, and (4) apply brine to shoulder continuously and if needed place salt at 250 lb/lane mile. To ensure that the full outside shoulder paved with OGFC is not blocked by soil or fine aggregates some participants use shoulder clipping while others place shoulder stone prior to placing OGFC.

Cleaning of OGFC roads in Tennessee is not common; few roads experience sporadic sweeping. The average life of OGFC roads in Tennessee is 10 years, ranging from 1 year to 14 years. Some of the participants consider maintenance of OGFC projects when designing, while others do not. Some participants exclude certain roads from OGFC, especially if they are on areas with high freezing like mountain roads, because OGFC maintenance is too difficult if the ice freezes. This is also the case on urban/high volume/low speed roads. Therefore, OGFC is preferred in areas with history of insignificant freezing and on Interstate lane miles.

Use of OGFC: Challenges and Successes

TDOT regions do not have any OGFC winter maintenance guidelines; they use TDOT's winter maintenance guidelines.

Challenges faced on districts/regions regarding OGFC maintenance are as follows:

- Removing of snow and ice and pretreating for snow and ice
- If OGFC pavement freezes then high concentration of calcium helps to break it up. This is not something preferred if it can be avoided. This results to spending more time in these areas to make sure the interstate stays open.
- Rutherford Co. has faced significant challenges regarding OGFC which are known to HQ (base failures, raveling). Marshall Co. is beginning to fight the OGFC on I-65 due to end of life cycle of the surface treatment.
- Most of Region 4's events are mixed events with a certain amount of ice prior to snowfall which is not necessarily normal to the rest of the state. They have adapted their approach to meet this expectation and therefore it may not be applicable to the other regions.

Successes highlighted on OGFC projects are:

- High concentrations of calcium help to break down frozen OGFC. This can be used only when necessary.
- Most of R4's events are mixed events with a certain amount of ice prior to snowfall which is not necessarily normal to the rest of the state. It is important for every district to come up with maintenance procedures that suit their situation.

Other comments regarding OGFC include:

- Region 3: "Good concept but needs more fine tuning before being placed on Tennessee roadways. Need to revisit the amount of water being allowed to drain beyond the OGFC. Need to revisit the specifications and ways of testing the OGFC at the plant prior to placement. Need to study the reasons of raveling at all joints."
- Region 3: "OGFC works well in keeping road spray down from passing cars. However, I do not think it is ideal for use in an area that experiences freezing temperatures."
- Region (4): "OGFC is harder to keep from freezing up resulting in more man-hours used for anti/de-icing operations. If a proper schedule could be developed for cleaning these projects, it might help with this by allowing it to drain faster."

Chapter 4 Results and Discussion

4.1 OGFC State of Practice

The objectives of this research project were to document the state of practice in OGFC winter maintenance technologies from TDOT Regions and other state DOTs and to identify appropriate de-icing agents and techniques for OGFC winter maintenance in Tennessee. The scope of this work is limited to literature review and state DOTs survey.

4.1.1. Advantages, Challenges, and Successes of OGFC

OGFC has been reported to have numerous benefits, such as providing safety to road users especially in wet conditions among other things. From the survey, it was determined that OGFC is mainly used on interstates and state routes or sections with heavy rains and sections that require noise reduction. In some states it is also used on parking lots and bike lanes. The advantages challenges and successes of OGFC, are as summarized from the survey as follows:

The advantages of OGFC includes:

- Increased road user safety especially on wet conditions,
- Reduced hydroplaning,
- Enhanced high speed and friction qualities,
- Decreased splash and spray,
- Improved visibility of pavement markings,
- Reduced noise levels by about 3 to 5 decibels,
- Increased pavement life and decreased long-term cost,
- OGFC is primarily used on higher volume roads in areas with higher rainfall. It has been very effective in reducing wet weather crashes.
- A study in Japan showed reduction in winter related accidents on porous pavement sections by 30% compared to densely graded pavement sections (Iwata et. al., 2002, Akin et. al., 2012).
- Reduced ice formation on wheel paths covered by snow due to surface permeability, and limitation of ice formation of wet surfaces due to good drainage and micro-texture (Houle, 2008) (Isenring, Koster, & Scazziga, 1990).

Challenges reported facing OGFC sections includes:

- Freezing roadways in cold seasons.
- Sensitivity to moisture and dirty aggregates.
- Premature surface raveling and tire damage in parking lots.
- If anti-icing is not performed adequately, it can be very challenging to keep wet pavements clean.
- Issues with OGFC pavement survival from snow plows as both plows and motor graders are used during winter storm response. The OGFC pavement surface is easily damaged by plows and motor grader blades and, additionally, blades wear faster.
- High usage of de-icing material to keep roads safe especially on inclines.
- Roadway tends to freeze sooner than other pavements.
- Snow and ice bonds more significantly to the OGFC pavements.

- Cannot use abrasives because they would clog up the voids.
- The performance of OGFC decreases at a faster rate relative to the number of winter operations performed.
- Shoulder cleanup during winter storms is challenging.
- Issues with brine treatment using stream nozzles; switched to fan spray to have effective coverage on OGFC.
- Studded tires affect the longevity of OGFC pavements.
- OGFC requires double the rates of de-icing liquids to deliver on the same application cycle time as densely graded pavement.
- Raveling at joints, transitions, and bridge ends and some base failures.

Successes experienced from winter maintenance of OGFC projects are as follows:

- Proper timing of pre-treating or anti-icing roadways has been successful for pavements with OGFC.
- Using salt brine prior to a storm. Having this material below the snow and ice has improved the ability to clear roadways faster.
- Training by venders on the usage of the materials is very effective in improving the performance and reducing cost.
- Moving to salt with pre-wet and keeping vehicle speeds at 35 mph and below has shown benefit.
- It is recommended to dedicate the equipment to stay on sections on steep mountain routes. Try not to extend the equipment that would cause the cycle time to be greater for the material being spread.

Other comments shared by participants are:

- Make sure that aggregates' water absorption does not exceed 2.5% and asphalt absorption does not exceed 1.0%. OGFC is very sensitive to moisture damage.
- From a winter perspective, OGFC is not preferred.
- OGFC has been primarily used on higher volume roads in areas with higher rainfall. It has been very effective in reducing wet weather crashes.

4.1.2 Winter Maintenance Techniques

The winter maintenance techniques evaluated through the survey include; anti-icing, pre-wetting, de-icing, snow-plowing, and sanding. Sanding is discouraged for use on OGFC sections because it clogs pores and defeats the drainage purpose of OGFC. If sanding is used, consider using larger sand particles or gravel to prevent clogging the pores. Cleaning should follow immediately after the winter event to open up the pores and reduce wind shield related accidents.

From the national survey, the most effective techniques are de-icing and snow plowing, followed by anti-icing and pre-wetting, while sanding is rarely used. In Tennessee, the most effective techniques reported are pre-wetting and snow plowing, followed by anti-icing and de-icing, and sanding is also rarely used.

Best Practices that Showed Success

- Apply salt brine prior to a storm. Having this material below the snow and ice has improved the ability to clear roadways faster.
- Training by venders on the usage of the materials is very effective in improving the performance and reducing cost.
- Moving to salt with pre-wet and keeping vehicle speeds at 35 mph and below has shown benefit.
- Snow operation vehicles should be dedicated troubled OGFC sections on adverse snow events.
- Other practices that have been used successfully or suggested by researchers as best winter management tools are

    1. Provide signage at transition between OGFC and densely graded pavement zones and alerting road users when unsafe conditions are present on OGFC sections (Noort, 1997).
    2. Concentrating traffic to one lane or reducing speed limits to increase traffic on OGFC pavements to encourage pumping of liquid deicers from the void spaces to the road surface (Hernandez & Verburg, 1997).

4.1.3 Winter Maintenance Materials

Materials used for winter maintenance reported by nationwide participants were solid rock (NaCl) (77%), salt brine (77%), abrasives (45%), calcium chloride ($CaCl_2$) (41%), and magnesium chloride ($MgCl_2$) (36%). Some specify $MgCl_2$ on higher elevation only, with much lower temperatures, while others use beet juice.

For TDOT, materials that are mainly used are solid rock salt (NaCl), salt brine, and salt brine with additives (calcium chloride ($CaCl_2$) and/or potato juice). A high dosage of $CaCl_2$ is required to break the ice if it freezes. Addition of light salt during pre-treatment, depending on the weather forecast, has improved winter maintenance of OGFC. Standard brine with 10% calcium chloride and 10% potato juice works better on lower temperatures.

In Texas, the binder is usually latex or tire rubber modified to provide more resistance to stripping and shelling/raveling. Furthermore, OGFC is sensitive to dirty aggregates and moisture. It is important to make sure that aggregates' water absorption does not exceed 2.5% and asphalt absorption does not exceed 1.0 %. OGFC is very sensitive to moisture damage.

Application Techniques Used/Not Used:

- Liquid solution and pressurized application systems are different between OGFC and densely graded asphalt pavement. On OGFC, nozzle sprays are switched to fan spray for effective coverage.
- Using a little "hotter" brine on OGFC helps.
- Heavier salt and brine applications for OGFC is expected.
- Heavier on pre-wet $CaCl_2$ application on OGFC.
- Continuous brine operation in addition to salt application needed on OGFC.
- Belly plows are not recommended on OGFC.

Application Rates on Snow Events:

- Rock Salt - 200 to 300 lb/lane mile just before snow event.
- Salt Brine and $CaCl_2$ mixture 40 – 50 gal/lane mile before snow event in pressurized system.
- Blast mode on bridges and trouble spots 800-1000 lb/lane mile.
- Brine (80/20) 200 lb/lane-mile. Brine additives – 10% calcium and 10% potato juice continuous operation with salt and brine applied.

Application Rates on Ice Events:

- Rock Salt - 300 lb/lane mile. just before snow event.
- Salt Brine and $CaCl_2$ mixture - 50 gal/lane mile before snow event in pressurized system.
- Spread rate - 250 lb/lane mile, for salt brine and calcium chloride.
- Blast mode on bridges and trouble spots - 800-1000 lb/lane mile.
- Increase brine additives to 20% calcium and 20% potato juice.
- Lower travel speed to increase coverage

Table 4-1 shows the comparison of winter maintenance materials in terms of cost, environment, and effectiveness. NaCl has the lowest cost per lane mile though it is not very effective on temperatures below 15^{o}F. Calcium magnesium acetate (CMA) and potassium acetate (Kac) have higher cost per lane mile. NaCl is toxic to plants on the road side while the rest of the agents are not toxic to vegetation. More information can be drawn from Table 4-1.

Table 4-1 Effectiveness of Winter Maintenance Techniques Used in Tennessee

Category	*Factor*	*NaCl*	$CaCl_2$	$MgCl_2$	*CMA*	*Kac*
COST	Cost per unit	$15-20 /ton	$225-229 /ton	$30-70 / gallon	$1000 /ton	$5/gallon
	Application rate per lane mile	100-400 lb	250-450 lb	40-50 gallon	200-400 lb	25 gallon pre-wet
	Cost per lane mile	$0.75-4	$29-66	$12-42	$100-200	$125
	Comment	Least expensive				Most expensive
ENVIROMENTAL IMPACT	Impact on animals	Non-toxic	Non-toxic	Non-toxic	Non-toxic	Non-toxic
	Impact on plants	Toxic	Plant nutrient	Nutrient	Non-toxic	Non-toxic
	Corrosion/Roads and structures	Spalling to concrete/ steal corrosion	Minimal spalling; steal corrosion	Minimal spalling; utility pole damage	Little corrosion	No steal corrosion
	Comment	Somewhat negative impact	Somewhat negative impact		Highly acceptable	Few negative impact
EFFECTIVENESS	Eutectic temperature	-6°F	-59°F	-28°F	-17.5°F	-76°F
	Lowest melting temperature	15°F	-25°F	5°F	20°F	-13°F
	Eutectic concentration	23.30%	30%	22%	32.50%	50%
	Thermodynamics	Absorbs heat when melting	Release heat when melting	Release heat when melting	Release heat when melting	Release heat when melting

According to FHWA Manual of Practice for an Effective Anti-Icing Program: A Guide for Highway Winter Maintenance Personnel; anti-icing procedures involve a combination of liquid, dry solid, and pre-wetted chemicals applied at the appropriate times, considering temperature, amount of moisture, and traffic conditions as shown in Table 4-2 (Estakhri et al., 2008; Ketcham, 1996). De-icing procedures are to be reserved for events where ice and snow have already bonded since this procedure requires more materials and do not maintain safe road condition as well as anti-icing procedures. and show a plan for anti-icing and de-icing operations recommended by the FHWA in a snow and black ice events, respectively (Estakhri et al., 2008; Ketcham, 1996).

Table 4-2 Weather Event: Light Snowstorm with Period(s) of Moderate or Heavy Snow (Ketcham, 1996)

Pavement Temperature range and trend	Pavement surface at the time of initial operation	I.O.*: Maintenance action	I.O.: Dry Chemical spread rate -Liquid, kg/lane-km (lb/lane-mi)	I.O.: Dry Chemical spread rate -Solids or Prewetted solid, kg/lane-km (lb/lane-mi)	S.O.**: Maintenance action	S.O.: Dry Chemical spread rate - Liquid, kg/lane-km (lb/lane-mi) for Light Snow	S.O.: Dry Chemical spread rate - Liquid, kg/lane-km (lb/lane-mi) for Heavy Snow	S.O.: Dry Chemical spread rate - Solids or Prewetted solids, kg/lane-km (lb/lane-mi) for Light snow	S.O.: Dry Chemical spread rate - Solids or Prewetted solids, kg/lane-km (lb/lane-mi) for Heavy snow	Comments
Above 0°C (32°F), steady or rising	Dry, wet, slush, or light snow cover	None, see comments			None, see comments					1) Monitor pavement temperature closely for drops toward 0°C (32°F) and below 2) Treat icy patches if needed with chemical at 28 kg/lane-km (100lb/lane-mi); plow if needed
Above 0°C (32°F), 0°C (32°F) or below is imminent.	Dry	Apply liquid or prewetted solid chemical	28 (100)	28 (100)	Plow as needed; reapply liquid or solid chemical when needed	28 (100)	55 (200)	28 (100)	55 (200)	1) Applications will need to be more frequent at lower temperatures and higher snowfall rates.
ALSO -4 to 0°C (25 to 32°F), remaining in range	Wet, slush, or light snow cover	Apply liquid or solid chemical	28 (100)	28 (100)	Same as above	28 (100)	55 (200)	28 (100)	55 (200)	2) Do not apply liquid chemicals onto heavy snow accumulation or packed snow 3) After heavier snow periods and during light snow fall, reduce chemical rate to 28 kg/lane-km (100 lb/lane-mi); continue to plow and apply chemicals as needed
-10 to -4°C (15 to 25°F), remaining in range.	Dry, wet, slush, or light snow cover	Apply prewetted solid chemical		55 (200)	Plow as needed; reapply prewetted solid chemical when needed			55 (200)	70 (250)	1) If sufficient moisture is present, solid chemical without prewetting can be applied 2) Reduce chemical rate to 55 kg/lane-km (200 lb/lane-mi) after heavier snow periods and during light snow fall; continue to plow and apply chemicals as needed
Below -10°C (15°F),	Dry or light snow cover	Plow as needed			Plow as needed					1) It is not recommended that chemicals be applied in this temperature range 2)

Pavement Tempera-ture range and trend	Pavement surface at the time of initial operation	I.O.*: Mainte-nance action	I.O.: Dry Chemical spread rate -Liquid, kg/lane-km (lb/lane-mi)	I.O.: Dry Chemical spread rate -Solids or Prewetted solid, kg/lane-km (lb/lane-mi)	S.O.**: Mainte-nance action	S.O.: Dry Chemical spread rate - Liquid, kg/lane-km (lb/lane-mi) for Light Snow	S.O.: Dry Chemical spread rate - Liquid, kg/lane-km (lb/lane-mi) for Heavy Snow	S.O.: Dry Chemical spread rate - Solids or Prewetted solids, kg/lane-km (lb/lane-mi) for Light snow	S.O.: Dry Chemical spread rate - Solids or Prewetted solids, kg/lane-km (lb/lane-mi) for Heavy snow	Comments
steady or falling										Abrasives can be applied to enhance traction

*I.O. = Initial Operation

**S.O. = Subsequent Operation

Notes CHEMICAL APPLICATIONS. (1) Time initial and subsequent chemical applications to prevent deteriorating conditions or development of packed and bonded snow. (2) Anticipate increases in snowfall intensity. Apply higher rate treatments prior to or at the beginning of heavier snowfall periods to prevent development of packed and bonded snow. (3) Apply chemical ahead of traffic rush periods occurring during storm. PLOWING. If needed, plow before chemical applications so that excess snow, slush, or ice is removed and pavement is wet, slushy, or lightly snow covered when treated.

Table 4-3 Weather Event: Frost or Black Ice (Ketcham, 1996)

Pavement Tempera-ture range and trend	Pavement surface at the time of initial operation	I.O.*: Mainte-nance action	I.O.: Dry Chemical spread rate -Liquid, kg/lane-km (lb/lane-mi)	I.O.: Dry Chemical spread rate - Solids or Prewetted solid, kg/lane-km (lb/lane-mi)	S.O.**: Maintenance action	S.O.: Dry Chemical spread rate - Liquid, kg/lane-km (lb/lane-mi)	S.O.: Dry Chemical spread rate - Solids or Prewetted solids kg/lane-km (lb/lane-mi)	Comments
Above 0ºC (32ºF), steady or rising	Any level	None, see comments	None	None	None, see comments	None	None	Monitor pavement temperature closely; begin treatment if temperature starts to fall to 0ºC (32ºF) or below and is at or below dew point
-2 to 2ºC (28 to 35ºF) remaining in range or falling to 0ºC (32ºF) or below and equal to or below dew point.	Traffic rate less than 100 vehicles per hr.	Apply Prewetted solid chemical	None	7 - 18 (25 – 65)	Reapply prewetted solid chemical as needed.	None	7-18 (25– 65)	1. If pavement becomes wet or if thin ice forms, reapply chemical at higher indicated rate. 2. Do not apply liquid chemical on the ice so thick that the pavement cannot be seen.
-2 to 2ºC (28 to 35ºF) remaining in range or falling to 0ºC (32ºF) or below and equal to or below dew point.	Traffic rate greater than 100 vehicles per hr.	Apply liquid or prewetted solid chemical	7 - 18 (25 – 65)	7 - 18 (25 – 65)	Reapply prewetted solid chemical as needed.	11 – 32 (40 – 115)	7 - 18 (25 – 65)	1. If pavement becomes wet or if thin ice forms, reapply chemical at higher indicated rate. 2. Do not apply liquid chemical on the ice so thick that the pavement cannot be seen.
-7 to -2ºC (20 to 28ºF) remaining in the range and equal to or below dew point	Any level	Apply liquid or prewetted solid chemical.	18-36 (65-130)	18-36 (65-130)	Reapply liquid or prewetted solid chemical when needed	18-36 (65-130)	18-36 (65-130)	1) Monitor pavement closely; if thin ice forms, reapply chemical at higher indicated rate 2) Applications will need to be more frequent at higher levels of condensation; if traffic volumes are not enough to disperse condensation, it may be necessary to increase frequency 3) It is not advisable to apply a liquid chemical at the indicated spread rate when pavement temperature drops below -5ºC (23ºF)
-10 to -7ºC (15 to 20ºF) remaining in the range and equal to or below dew point	Any level	Apply prewetted solid chemical.	None	36-55 (130-200)	Reapply prewetted solid chemical when needed	None	36-55 (130-200)	1) Monitor pavement closely; if thin ice forms, reapply chemical at higher indicated rate 2) Applications will need to be more frequent at higher levels of condensation; if traffic volumes are not enough to disperse condensation, it may be necessary to increase frequency
Below -10ºC (15ºF) Steady or falling.	Any level	Apply abrasives	None	None	Apply abrasives as needed	None	None	It is not recommended that chemicals be applied in this temperature range

*I.O. = Initial Operation

**S.O. = Subsequent Operation

Notes TIMING. (1) Conduct initial operation in advance of freezing. Apply liquid chemical up to 3 h in advance. Use longer advance times in this range to effect drying when traffic volume is low. Apply prewetted solid 1 to 2 h in advance. (2) In the absence of precipitation, liquid chemical at 21 kg/lane-km (75 lb/lane- mi) has been successful in preventing bridge deck icing when placed up to 4 days before freezing on higher volume roads and 7 days before on lower volume roads

4.2 Research Deliverables

Another objective of this study was to develop OGFC winter maintenance guidelines for the state of Tennessee. From the state survey, most state DOTs responded to the survey have general winter maintenance procedures for their state for all roads, not specific to OGFC pavements. The research team recommends that a chapter on winter maintenance of OGFC pavements should be added to the current winter maintenance procedures for TDOT.

4.2.1 Proposed Initial Winter Maintenance Guidelines for OGFC Pavements for the State of Tennessee

Introduction

Both the literature and the DOT survey results agree that there is a difference between OGFC and densely graded pavements in terms of accumulation of snow, formation of ice, and use of salts and de-icing chemicals. The surface temperature of OGFC is expected to be lower than that of densely graded because the higher voids lower the surface heat conduction (Yildirim Y., 2006). Ice and snow may accumulate faster, thaw slower, and freeze quicker on OGFC compared to densely graded surfaces. Because of its nature, more winter maintenance materials are expected to be used on OGFC than densely graded surfaces. Since the safety benefits, reduction of wet crashes, noise reduction and other benefits of OGFC are undeniable, it is beneficial to plan ahead for OGFC winter maintenance.

1. **Mix Design**

The scope of this work did not include the OGFC mix design, but it is important to mention findings from the survey. Overall, the OGFC mix design affects its performance. From the survey it was reported that the use of latex or tire rubber modified binder has shown to provide more resistance to stripping and shelling/raveling of OGFC surfaces. Furthermore, OGFC is very sensitive to dirty aggregates and moisture. It is important then, when selecting aggregates, to make sure that aggregates' water absorption does not exceed 2.5% and asphalt absorption does not exceed 1.0 %.

2. **Winter Maintenance Materials**

Winter maintenance materials that are used in the State of Tennessee are rock salts ($NaCl$), salt brine, pre-wetted salts, and brine additives ($CaCl_2$) with potato juice. Sanding is not commonly used on OGFC pavements in Tennessee. The use of rock salts is effective when the surfaces are wet, to trigger the salt solution. The Maintenance team must be ready to apply the rock salt immediately after sufficient rain, but before snow or ice formation. The liquid solutions can be sprayed faster and uniformly over the pavement surface. These include salt brine and brine with calcium Chloride ($CaCl_2$) or/and potato juice. Table 4-4 shows winter maintenance materials commonly used in Tennessee.

The voids in OGFC and its lower surface temperature lead to more usage of materials than on densely graded surfaces. This can be from slower speeds or an increased number of passes.

A recent study in Texas indicates that almost the same amount of materials can be used on OGFC as on densely graded surfaces especially with anti-icing procedures showing that larger salt grains may minimize draining away of materials (Yildirim Y., 2006). However, guidelines for reducing materials used will require further research before being implemented.

On densely graded surfaces, abrasives (mainly sand) are the most commonly used materials and are moderately effective. It provides good friction/traction but does not melt the ice or snow. When used on OGFC, the small sand particles penetrate into the pores and clog the pavement. Sand with larger particles or gravel/rock may be used to provide friction on OGFC pavements but must be cleaned immediately after the snow event.

Other materials reported by other states are not recommended at the moment. ***These materials are subject to further evaluation, trial implementation, then approval if they perform satisfactorily in Tennessee.*** Vender training is recommended for new materials.

Table 4-4 Proposed OGFC Winter Maintenance Materials for Tennessee

Materials	Advantages	Disadvantages
Rock Salts (NaCl)	Cost effective, melts ice	Corrosion, drains away (may need to use more materials), not very effective at temperatures below 15°F.
Salt Brine	Cost effective, uniform application easily achieved.	Need more material passes on OGFC surfaces, not very effective at temperatures below 15°F.
Brine additives ($CaCl_2$), potato juice	Effective on cold temperature up to -25°F.	More expensive
Pre-wetted salts	Better adhesion to the surface, more even distribution of material	Requires more materials

3. OGFC Winter Maintenance Techniques

Five winter maintenance techniques were considered on the survey. Anti-icing, pre-wetting, de-icing, snow plowing and sanding. The first four techniques are recommended on OGFC, while sanding is rarely recommended due to the clogging it causes. Anti-icing is recommended for faster removal of ice and snow, but proper timing is required. The advantages and disadvantages of each technique are as reported in Table 4-5.

Table 4-5 Proposed Winter Maintenance Techniques

Technique	Advantages	Disadvantages
Anti-icing	Proactive, maintains safe conditions, reduces/prevents ice and snow formation.	Precise timing is required.
Pre-wetted salts and chemicals	Improve effectiveness. spread more uniformly. better adhesion to road surface. Faster & longer-lasting effect. Increased spreading speed. Road surface may dry more quickly.	Precise timing is required
De-icing	Remove snow and ice bonded to the surface	Reactive, does not provide safe conditions, uses more materials and time than with anti-icing.
Snow plowing	Useful when there are snow accumulations.	Damages the OGFC surface. Wears out plough blades.
Sanding	Provides traction and increases friction.	Clogs voids in OGFC layer.

4. Decision on OGFC Snow and Ice Control Treatment

This recommendation if based on literature review and survey results. Every time a snow or ice treatment is being designed, the following information should be on hand or estimated as much as possible (Amsler, 2014):

- The level of service prescribed by local policy; TDOT for this case.
- Present pavement temperature and trend of the pavement temperature.
- The amount of snow or ice on the surface after plowing and prior to chemical treatment
- Is the remaining snow or ice bonded to the surface?
- Anticipated snow, ice, or water accumulations between treatments
- Traffic volume, speed, and timing.

Action decisions can be made according to the information on the items above. It is likely to have different treatments as the critical factors are always changing.

Step by Step

1. Determine the pavement temperature trends before treatment, at the time of treatment and the temperature trend after treatment. This will help in making decisions of the technique needed as it has been reported that proper timing of pre-treatment or anti-icing has been successful for cleaning OGFC pavements. It is recommended to use salt brine prior to a storm since it has shown that having this material below the snow and ice increases the ability to clear roadways faster.

2. Establish the appropriate chemical treatment required and the dilution potential

while considering what (1) a chemical treatment must endure before another treatment is made during a winter weather event, or (2) will Produce a satisfactory result in the absence of precipitation at the end of an event (Amsler, 2014). The establishment of dilution potential should consider precipitation trend, the presence of various wheel path area conditions, treatment cycle time, and traffic speed and volume.

3. Determine what technique is needed (such as anti-icing, de-icing or de-icing and plowing), amount of materials, number or passes and speed depending on temperature, pre-treatment, and event forecast, bearing in mind that OGFC pavements requires more material than densely graded pavement surfaces. Moving to salt with pre-wet and keeping vehicle speeds at 35 mph and below has shown benefit on OGFC pavements.

4. On steep mountain routes or troubled OGFC sections, it is recommended to dedicate specific equipment to stay on those sections. Avoid extending the equipment, because it would cause the cycle time to be greater for the material being spread.

5. An adjustment to the precipitation dilution potential may have to be made for OGFC pavements especially with traffic speeds greater than 35 mph and traffic volume greater than 125 vehicles per hour (vph), as needed.

6. Once some determination of the items above has been made, a decision on treatment can be made. It is likely that every treatment will be different as the critical factors are always changing.

Chapter 5 Conclusion

5.1 Conclusion

Open graded friction course (OGFC) pavements have been widely used because of the safety benefits they provide especially in wet conditions, noise reduction, reduction of hydroplaning, decreased water splashing, and improved visibility of pavement markings especially in wet conditions. The objectives of this study were to document the state of practice in OGFC winter maintenance technologies from other state DOTs; to identify appropriate de-icing agents and techniques for OGFC winter maintenance in Tennessee; and to develop OGFC winter maintenance guidelines for the state of Tennessee. The scope was limited to the literature review and state DOT survey. Further testing and/or research is necessary to solidify the guidance.

A survey was sent to all 50 states, 27 (54%) responded, out of them 59% are currently using OGFC and 41% are not currently using OGFC, out of which 22% never used OGFC in their states. Information was gathered on types of materials used for winter maintenance, application rates and winter maintenance techniques. The winter maintenance materials used in Tennessee are rock salts (NaCl), salt brine, pre-wetted salts, and brine additives ($CaCl_2$) with potato juice. Abrasives (sand) are rarely used and are not recommended on OGFC pavements because it clogs the pores and need to be cleaned immediately after the event. It was also determined that the use of NaCl before the snow events as anti-icing treatment has shown to improve the ability to clean OGFC roadways faster. The techniques commonly used are anti-icing, pre-wetted salts and chemicals, de-icing, and snow plowing. The application rates range depending on the snow event and type of material.

The research team was not able to obtain a winter maintenance manual for OGFC pavements from other states. Most states have winter maintenance manual for all pavements. TxDOT is working on the same type of document, and research documents were obtained online with some recommendations, but the document shared was a general winter maintenance manual. Arizona DOT also shared a document on OGFC, but it was more on the mix design and requirements and not winter maintenance of OGFC pavements. It is recommended that a chapter addition on OGFC winter maintenance considerations be made to the current TDOT winter maintenance manual. This manual may also be of use to other states as a result of the findings from the survey.

From this study, OGFC winter maintenance guidelines are proposed based on the survey results and literature review as given in section 4.2.1. The implementation of the guidelines will be possible as soon as they are approved. The recommended OGFC winter maintenance guidelines are already being used by TDOT regions; this study gathered the current best practices to be used throughout the state.

5.2 Benefits to TDOT

OGFC pavements are prevalent in Tennessee. Currently, TDOT lacks statewide winter maintenance guidelines for these pavements. Whereby, every district or TDOT Region have their own best practices on winter maintenance of OGFC pavements. This study has collected the information available on making an initial statewide procedure on winter maintenance of OGFC pavements. This will help TDOT with further documenting statewide winter maintenance guidelines, which will also help in proper planning for winter events knowing that OGFC sections require more effort and materials compared to densely graded surfaces. The implementation of the guidelines should be almost immediate after TDOT approval.

5.3 Recommendations

This study did not look at the mix design, but there was a recommendation to use of latex or tire rubber modified binder to provide more resistance to stripping and shelling/raveling of OGFC surfaces. Additionally, for a good performing OGFC mix moisture, absorption of aggregates should be limited to < 2.5% and asphalt binder absorption to < 1%. References to these recommendations can be found in the section covering the DOT survey responses.

The research team recommends that a chapter on winter maintenance of OGFC pavements should be added to the current winter maintenance procedures for TDOT. The initial guidelines, again, can be found in Section 4.2.1.

There are sections that were identified having challenges in Tennessee through the internal state survey, the following is recommended to address these issues:

- Sections CNP292 and CNL957 use increased material and manpower to remove snow/ice in winter events. This is a trouble section where planning is needed ahead of time and if possible, equipment should be dedicated to these sections to provide safe driving conditions.
- Several sections were identified with either pavement coming up, complete base failure or raveling at transition joints and bridge ends. These include I 275 and downtown 40, CNM342, CNN327 CNP075, CNP282, CNQ362, CNQ376, CNR304. A study is recommended on how to improve joints between OGFC and bridge ends or at transitions. Drainage layer is also necessary to reduce base layer failures.

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Appendices Summarized Survey Response

Appendix A: External Survey Response

The survey was sent to all 50 state DOTs, twenty-eight state DOT's (or 56%) responded to the surveys as shown in Figure A-1. From the respondents sixteen participants (57 %) currently use OGFC pavements in their states, while twelve participants (43 %) are currently not using OGFC pavements. A follow-up question was asked if OGFC was used in the past, 23 participants responded, nineteen (83 %) with yes and four (17 %) responded with no, meaning never used OGFC in the past. Figure A-1 below displays the surveyed states in terms of OGFC use.

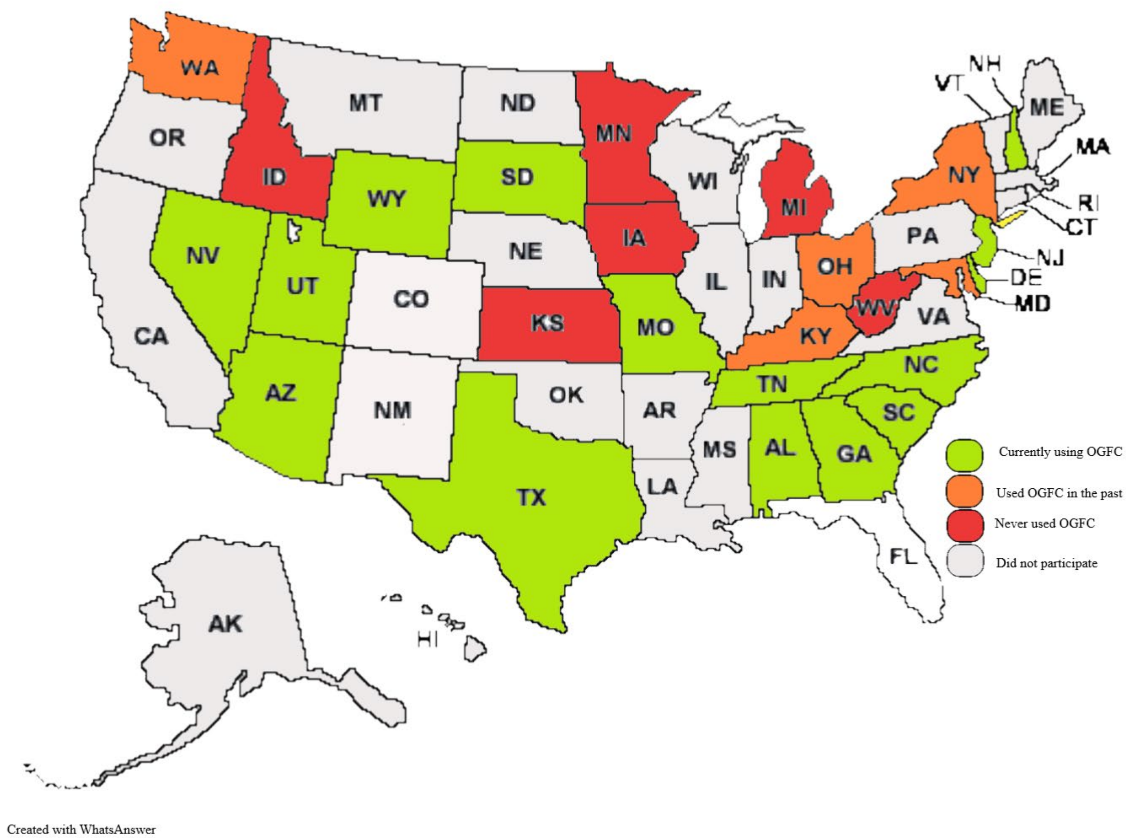

Figure A-1 Map of USA Indicating State DOT's Participation on Survey

Table A-1 Response from the Survey

SN	STATE	Date Responded	Using OGFC	Used in the past?	# Responded
1	Tennessee	3/15/2020	Yes	n/a	8
2	Missouri	3/16/2020	Yes	n/a	1
3	Utah	3/16/2020	Yes	n/a	1
4	KYTC	3/16/2020	No	Yes	1
5	New Jersey	3/16/2020	Yes	n/a	1
6	Wyoming	3/16/2020	Yes	n/a	2
7	Kansas	3/16/2020	No	No	1
8	Washington State	3/17/2020 & 7/30	No	Yes	2
9	New Hampshire DOT	3/17/2020	Yes	n/a	1
10	Iowa	3/17/2020	No	No	1
11	Nevada	3/17/2020	Yes	n/a	1
12	Maryland State Highway Admn.	3/18/2020	No	Yes	1
13	Arizona	3/19/2020	Yes	n/a	1
14	Michigan	3/24/2020	No	No	1
15	MN DOT	3/26/2020	No	No	1
16	Texas	3/27/2020 & 7/25	Yes	n/a	2
17	West Virginia	7/29/2020	No	No	1
18	South Carolina	7/29/2020 &7/30	Yes	n/a	1
19	Delaware	7/30/2020	Yes	n/a	1
20	South Dakota	7/30/2020	Yes	n/a	2
21	NY DOT	8/4/2020	No	Yes	1
22	IDAHO	8/4/2020	No	No	1
23	Alabama	8/4/2020	Yes	n/a	1
24	Ohio	8/31/2020	No	Yes	1
25	North Carolina	9/3/2020	Yes	n/a	1
26	Oklahoma	9/5/2020	Yes	n/a	1
27	Georgia	9/8/2020	Yes	n/a	1
00	Total	Not applicable	16	5	38

When asked on what types of roads OGFC is used, 23 participants responded: interstates (83 %), state routes (87 %), and 13 % indicated the use of OGFC on parking lots, bike routes and where noise reduction is needed. When asked if there are different considerations on winter maintenance between OGFC and densely graded pavements, the answer was 52% "yes" and 48% "no". Moreover, responses indicated that OGFC,

- requires heavier application rates of de-icing and anti-icing;
- requires more salt due to additional passes;
- requires the use fan spray nozzles instead of stream spray for liquid anti icing;
- cannot have sand/gravel applied;
- is generally avoided where ice events are difficult to manage. Some Northern districts in Texas do not use OGFC surfaces at all.

Some reported use of same techniques on all roads. Furthermore, it depends on storm events, intensity and road characteristics.

Important Questions and Answers from the Survey

Q6. Are there different considerations on winter maintenance between OGFC and densely graded pavements?

Twenty-three participants answered this question; twelve responded with 'YES' and eleven with 'NO'.

Q7. Please give examples for the previous question. Please answer with a Yes or No and an explanation.

Nineteen participants responded to this question, 11 provided needed information tabulated below in Table A.2.

Table A-2 Deference on Winter Maintenance between OGFC and Densely Graded Pavements

State	Types of Chemicals:	Application Rate:	Triple coverage	Technique	Comments
Tennessee	Clorox	gal/hr	n/a	manual	n/a
Missouri	Brine and Beet juice	50 gal per lane mile	n/a	Heavier application rates of de-icing and anti-icing.	n/a
Wyoming	liquids, brine, mag chloride, and beet juice added to brine.	50-60 gal per lane mile, double the usual rate.	n/a	Depends on storm events characteristics.	n/a
Washington State	1. Solid Salt and/or sand pre-wet with CaCl 2. Sand-Salt mix (50/50) with calcium and salt.	1. 200-400 lb/lane mile with 10 gal per ton CaCl 2. 400 lbs/ln mi., Calcium at 20 gal/ln.	n/a	Plow and apply deicer.	n/a

State	Types of Chemicals:	Application Rate:	Triple coverage	Technique	Comments
Texas DOT Austin District	1. Brine solution and Magnesium Chloride granular products. Which dissolve in and evaporates. No build up. No sand or chat rock. 2. Salt Brine	1. Do not differ from pavement types 2. 50 gpm	no	1. Same as other roads 2. Use fan spray nozzles instead of stream spray for liquid anti-icing.	OGFC are generally avoided where ice events are difficult to manage. Some Northern district s do not use OGFC surfaces at all.
South Carolina	No	Yes. Application rates are approximately doubled on OGFC pavements.	no	n/a	n/a
South Dakota	No. Use the same materials.	No. Use same application rate	no	No. Use the same technique.	n/a
Alabama	No difference	No difference	no	No sand/gravel on OGFC	n/a
North Carolina	No difference	No difference	no	Requires more salt through additional passes.	n/a
Oklahoma	No	yes	no	n/a	n/a
Georgia	Yes, Granular Salt & Liquid brine @23%, liquid calcium is placed at 20% with the brine as needed. Some granular calcium may be added to our salt spreaders.	Granular Salt varies depending on storm 50lbs and up. Brine is 40 gal per lane mile.	We do make multiple passes with brine and granular salt if the storm impacts require it.	Same techniques to all roads	We also add 89 stone to the granular mixture at a ratio of 3:1 stone to salt for friction.

Q8. what winter maintenance techniques(s) do you or did you adopt? (Select all that apply)

Twenty-one participants responded to this question. 15 participants use anti-icing, 19 participants use De-icing, 15 participants use pre-wetting, 19 participants use snow plowing, 9 participants apply sanding, and 1 reported other methods, which is all above products using $MgCl_2$ that dilutes in ice and provides good ride quality. Figure A-2 below displays the answers.

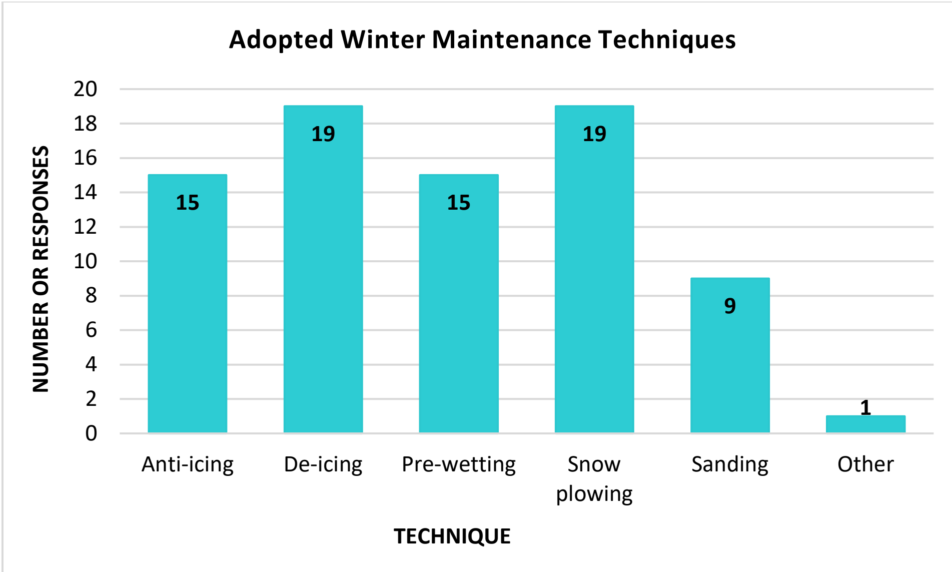

Figure A-2 Adopted Winter Maintenance Techniques

Q9. On a scale of 0 - 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness of the anti-icing on OGFC pavements?

Twenty-one participants rated this technique, out of whom three don't use the technique. The answers ranged from 1 to 5 with a median rating of 3.56.

Q10. On a scale of 0 - 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness of de-icing on OGFC pavements?

Twenty-four participants rated this technique. The answers ranged from 1 to 5 with a median rating of 3.75. Five (5) participants do not use the technique.

Q11. On a scale of 0 - 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness of pre-wetting on OGFC pavements?

Twenty-two participants rated this technique. The answers ranged from 1 to 5 with a median rating of 3.85. Seven (7) participants do not use the technique.

Q12. On a scale of 0 - 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness of snow - plowing on OGFC pavements?

Twenty-four participants rated this technique. The answers ranged from 1 to 5 with a median rating of 4.0. Five (5) participants do not use the technique.

Q13 On a scale of 0 - 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness sanding on OGFC pavements?

Twenty-one participants rated this technique. The answers ranged from 1 to 5 with a median rating of 2.7. Nine (9) participants do not use the technique.

The Table A.3 below displays the summary of answers to questions Q9 to Q13. The states are presented alphabetically.

Table A-3 Summary of Winter Maintenance Technique Rating by State

State	Anti-icing	De-icing	Pre-wetting	Snowplowing	Sanding
Alabama	4	5	5	5	0
Arizona	5	5	5	4	0
Delaware	4	4	4	4	0
Georgia	5	5	0	5	0
Missouri	4.6	4	1	1.5	0
Nevada	2.5	2.6	2.7	4.3	3.5
New Jersey	1	1	1	3.5	0
North Carolina	2.5	3.8	0	3	0
Oklahoma	3.7	2.4	4.2	4.4	2.7
South Carolina	2.7	2.8	2.8	1.6	0
South Dakota	0	4.4	4	5	0
Texas	3.7	4.2	0	1	0
Utah	1.3	2.1	2.5	3.4	2.5
Washington	4.4	4.4	4.5	4.2	0
Wyoming	1.6	3.6	2.2	4.1	2.5
Alabama	4	5	5	5	0

Figure A-3 below illustrates the effectiveness of the adopted techniques as reported by the surveyed states. Fifteen states provided this information, four states indicated not using the techniques. Each colored bar represents a winter maintenance technique as illustrated in the graph legend. The vertical axis indicates the rating of the adopted technique on a scale of 5, 1 being not effective and 5 being very effective. Figure A-4 shows that De-icing and snow plowing are the most used techniques, followed by anti-icing, then pre-wetting. Sanding is not commonly used as it results in the clogging of OGFC surfaces.

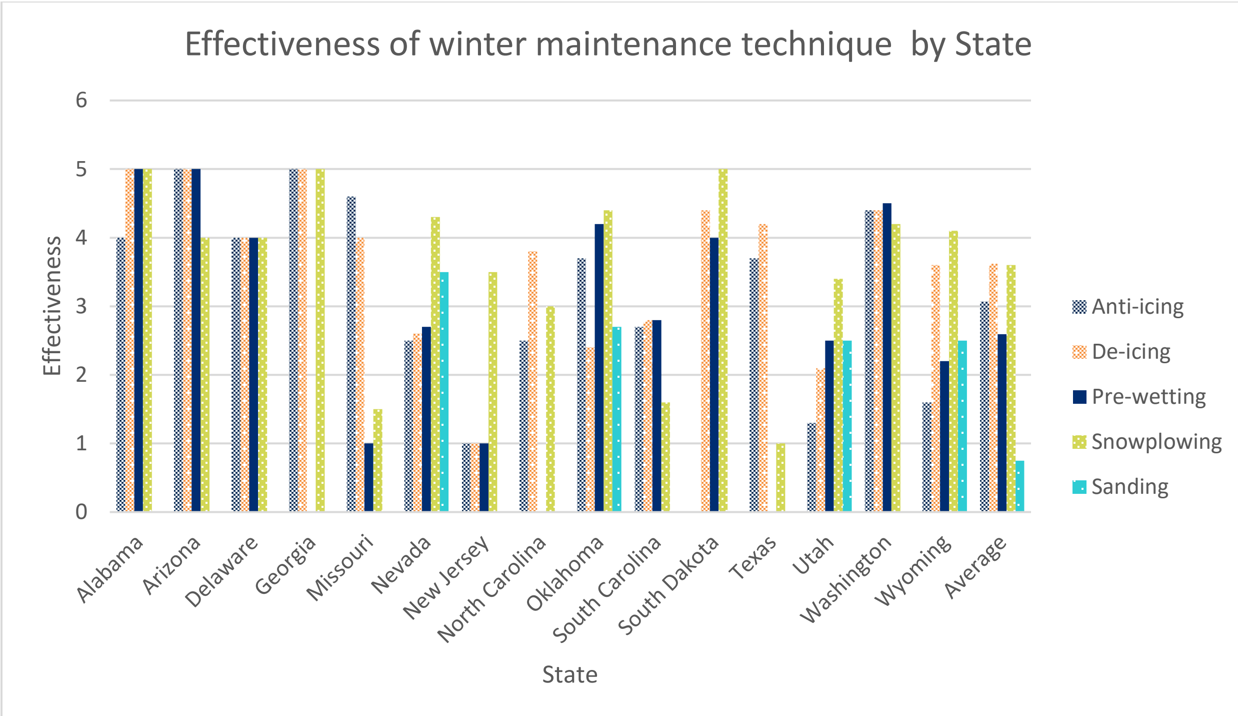

Figure A-1 Effective Winter Maintenance Techniques Rated by State

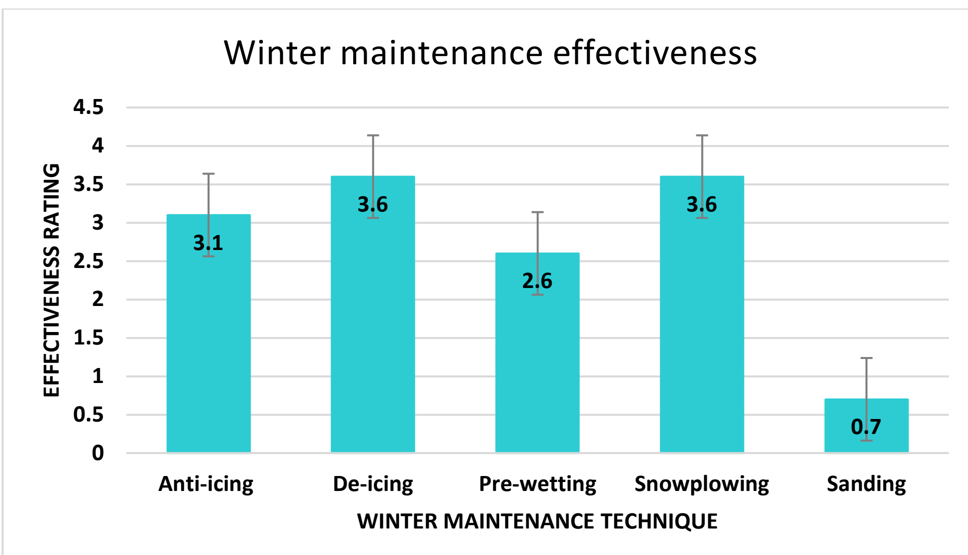

Figure A-2 Effectiveness Rating of Winter Maintenance Techniques

Q14. What winter maintenance materials do you use? (Select all that apply)

Twenty-two participants responded to this question, ten (45%) use abrasives, seventeen (77%) use solid rock (NaCl), seventeen (77%) use salt brine, nine (41%) use calcium chloride ($CaCl_2$), and eight (36%) use magnesium chloride ($MgCl_2$). Two responded with "other"; one reported using $MgCl_2$ on higher elevations only and the other respondent reported using beet juice. Figure A-5 below shows the different winter materials used by the surveyed states. The horizontal axis represents the number of states using the specified winter maintenance material.

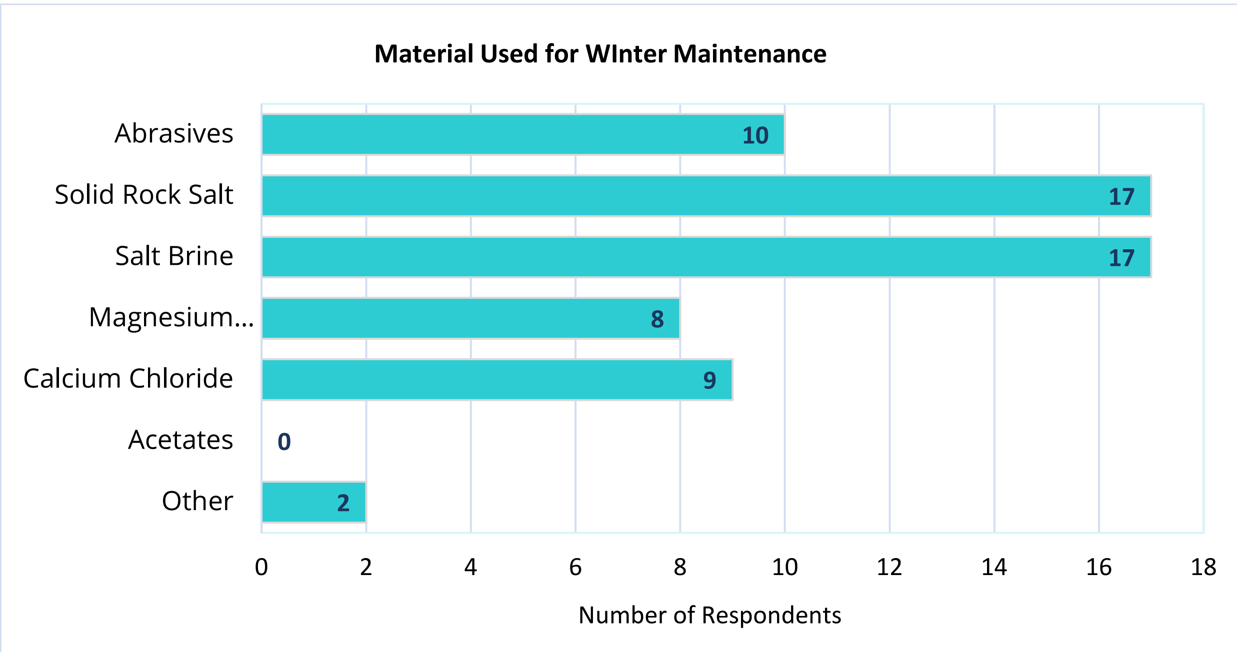

Figure A-5 Effectiveness of Winter Maintenance Techniques

Q15. What salt brine (listed in question 14 or other materials) treatment rates and times are being applied to OGFC for SNOW? (List material/ application rate/ time in which it was applied)

Sixteen participants responded to this question. The Table A.4 below displays the response of each state alphabetically.

Table A-4 Salt Brine Treatment Rates and Application Times for Snow Events

STATE	Salt brine treatment rates and times for SNOW
Alabama	Liquids are 30 Gal/Mile. Solids are 500#/Ln. Mile
Delaware	100gal/lane mi every hour and half
Georgia	Brine is applied at 40 gal per lane mile 24 hrs. ahead of the storm or rain. This operation continues throughout the storm for Metro Atlanta. Salt is applied 24 hrs. ahead of a storm if it is raining and we cannot put brine down. Salt is normally applied at ratio of 3:1. 3 parts abrasives to 1 granular salt. This begins at the onset of the snow/icing. Salt poundage and ratio may be adjusted due to the severity and impacts of the storm.
Maryland SHA	For the pilot projects (very small amount of OGFC) it would be 60 Gal/Ln. Mi.
Missouri	50 gallons per lane mile brine, 30 gallons per lane mile beet juice
New Jersey	Salt brine prior to storm with the right conditions.
North Carolina	NaCl/40-45 gal/lane mile/up to 48 hrs. prior, throughout event
Oklahoma	Salt Brine/30-40 gal/lane mile before the storm
South Carolina	The treatment rates are the same. The frequency of application is approximately doubled on OGFC. Additionally, the intensity of the storm leads to more frequent application rates as well.
South Dakota	Pre-wetting of applied salt @ 30 gallons per mile
South Dakota	50 gals per lane mile when temp is above 23 degrees surface temp.
Texas	50 gal per mile.
Utah	23% Concentration rate for Brine - 30 Gallons per mile For De-Icing Materials (Salts) we use 250 Lb/Lane Mile - Proposed Maximum Anti-Icing (Salts) we use 250 lb/ lane mile. Anti-Icing Liquids - 24 -48 hours before a storm is forecast - 30 gal/lane mile
WA State DOT	solid salt/sand mix prewet with CaCl2 as needed. CaCl2 treatment as anti-icer at 20 gallons per lane mile as needed prior to event
WYDOT	50-60 gal per lane mile
Wyoming	50-60 gal per lane mile. During daylight hours temperature not during high winds over 20 mph

Q16. What salt brine (listed in question 14 or other materials) treatment rates and times are being applied to OGFC for ICE? (List material/ application rate/ time in which it was applied).

Twelve participants responded to this question. The answers are displayed in the Table A.5 below.

Table A-5 Salt Brine Treatment Rates and Application Times for Ice Events

STATE	Salt brine treatment rates and times for Ice
Alabama	Liquids are 30 gal/mile. Solids are 500 lb/Ln. Mi.
Delaware	100 gal/lane mile. times vary on effectiveness
Georgia	when ice is present we will add 20% liquid calcium and apply a rate of 40 gal per lane mile or if the severity is bad enough it may be increased to 80 gal per lane mile.
Maryland	For the pilot projects (very small amount of OGFC) it would be 80 GPLM.
Missouri	salt brine - 50 gallons per lane mile beet juice - 30 gallons per lane mile
North Carolina	NaCl/40-45 gal/lane mile/up to 48 hrs prior, throughout event
Oklahoma	salt brine/30-40 gal/lane mile/before the storm
South Carolina	The rate is not adjusted as much as the frequency of application. Additionally, if we have icy conditions, we try to apply salt in addition to the brine to help melt the ice. If it is very cold, prewet the salt with calcium chloride too.
South Dakota	60 gal per lane mile in the morning if the sun is out and temp will get above 23 degrees
Texas	50 gal. per mile.
Utah	Our maximum amount of De-Icing materials that we suggest is 500 lb/mile. We have different categories of alt that our folks are able to use based on the situation - We have a time release and a fast acting that are more effective at lower temps.
Wyoming	50-60 gal per lane mile

Q17. What alternative pre-storm treatments have been most effective in various situations? At what concentration and coverage rates? (Ex. potato juice, beet juice, calcium, etc.) (List product/ concentration/ coverage rate).

Fourteen participants responded to this question; five have not tried any other pre-storm treatments. The answers are shown in the Table A.6 below.

Table A-6 Alternative Pre-Storm Treatments

STATE	Effective alternative pre-storm treatments
Alabama	N/A
Delaware	no other products tested
Georgia	23% brine solution at 40 gal per lane mile. 80lbs of salt if raining per lane mile.
KYTC	Liquid salt brine (10% calcium chloride) for anti-icing and de-icing. We use liquid Magnesium Chloride at a concentration of 25%
Maryland SHA	We only use salt brine due to our temperatures. However, when it does become extremely cold (very rare) we will mix an 80/20 blend of brine/liquid mag.
Missouri	Beet juice at 30 gallons per lane mile
New Jersey	beet juice mixed with brine
North Carolina	N/A
Oklahoma	N/A
South Carolina	The most effective pre-storm treatment that we have found is the application of brine. We have been successful with multiple applications of brine before adverse conditions start. In some cases, we may begin days ahead of the actual storm. The water evaporates leaving a salt residue on the pavement and in the voids that helps prevent an ice bond. The biggest problem with this issue is applying brine under high-speed conditions when the public is not necessarily expecting to see slower moving chemical application equipment on the interstates.
South Dakota	Have not tried any
Utah	Brine we stick with our concentration rate of 23%. Liquid Calcium Chloride we use at concentration rate of 25%
Washington State	Calcium (31%, applied at 20 gal/ln mi
Wyoming	30-70 beet juice to brine mix

Q18. On open-graded paving projects; is the full shoulder width typically paved with OGFC, or is only a portion of the shoulder width paved with OGFC?

Twenty participants responded to this question. While eight of them reported 'paving the full shoulder', Six participants reported paving the 'roadway only', and eight participants reported paving a 'portion of the shoulder'. Figure A-6 below demonstrates the different practices used by the surveyed states on paving the shoulder with OGFC.

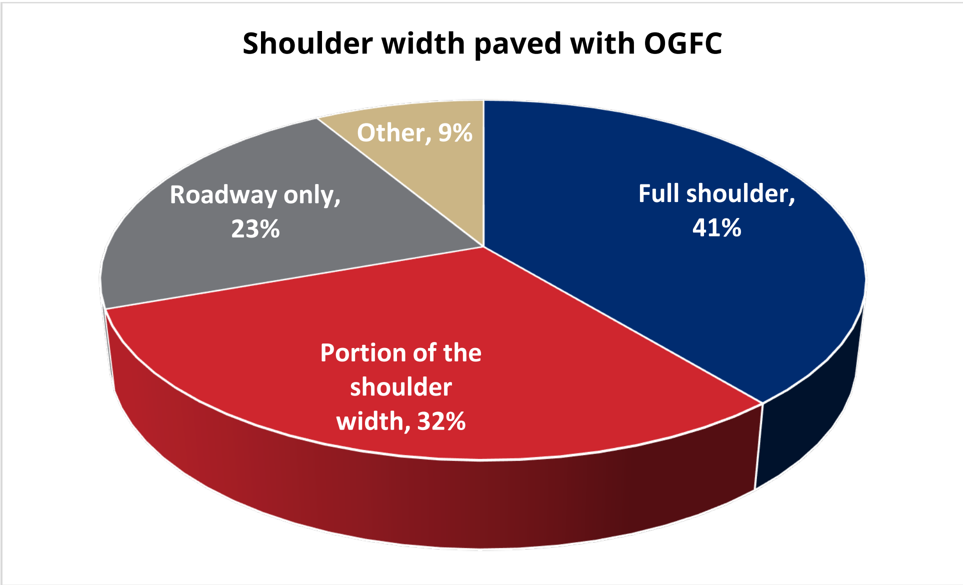

Figure A-6 Shoulder Width Paved with OGFC

Q19. If only a portion of the shoulder width is paved with OGFC, how much?

Thirteen participants responded to this question, five of them answered with "*Past the rumble strip >6"*,' two answered with "*Before the rumble strip 6"*,' and the remaining six answered with paving more than 1 foot past the joint as shown on Table A.7.

Table A-7 Portion of the Shoulder Paved with OGFC

Shoulder portion with OGFC	Responded
Before rumble strip 6"	2
Past the rumble strip >6"	5
Exactly what width	6
12 inches	1
18 inches	1
24 inches	2
Full width	2

Q20. Does your agency pave OGFC over only 4 feet of the outside shoulder to allow the OGFC to drain onto the remaining paved 6-foot shoulder?

Twenty participants responded to this question, fifteen of them answered with 'NO' and only five participants responded with 'YES'. The participants responded with yes answered the question of how do you plow the bi-level shoulder? By:" (1) We normally send a plow truck down the shoulder and they will run their blade down the edge of the OGFC. (2) We normally don't plow our shoulders until our lanes are clear and (3) We plough as best as we can, but there is much less concern with a little snow being left on the shoulder".

Q21. Do you add extra salt to the outside OGFC shoulder to reduce blockage from frozen ice?

Twenty-one participants responded to this question, while twenty of them answered with 'NO', one participant (Utah) responded by saying: "Depends upon the situation that we encounter. Typically, due to the nature of our spreaders and natural traffic kicking the salt onto the shoulders the need for additional salt is not necessary."

Q22. If full outside shoulder is paved with OGFC, how do you ensure that the OGFC drainage is not blocked by soil and/or fine aggregate at the edge of the shoulder?

Eight participants answered this question. The answers are as shown on Table A.8 below.

Table A-8 Response on OGFC Shoulder Drainage

STATE	Shoulder not paved with OGFC
Alabama	Berm control.
Maryland SHA	Do not consider drainage function for OGFC
Nevada	OGFC is full depth so the water drains through the pavement into the underlying base courses
New Hampshire DOT	Typically, the outside sluff of the OGFC ties in with the sluff of the asphalt pavement lift below. The topsoil on the shoulder only comes to the bottom of the sluff allowing the water to runoff the surfacing.
South Dakota	Have not encountered this issue
Texas	We recess our catch basin lids below the level of the OGFC so that we can capture the drainage.
Utah	There is enough moisture to flush the porous material
WYDOT	Nature takes its course
Wyoming	Shoulder not paved with OGFC

Q23. Apart from winter maintenance, are OGFC pavements in your state cleaned?

Twenty-one participants answered this question, seventeen answered with 'NO' and four with 'YES'. Majority of states (81%) do not clean OGFC pavements.

Q24. If answer to question 23 is yes, what method is used to clean? (Select all that apply)

Five participants answered this question. While all five participants agreed in the use of 'Sweeping' as the main method of pavement cleaning, one participant (Texas) added vacuuming as another means of cleaning OGFC roads. Moreover, the participant from South Carolina responded with: "There may be some sweeping of some OGFC pavements, but it would be done to remove some of the loose rock from pavement raveling in an effort to minimize damage claims and broken windshields."

Q25. A bout how long (in years) do OGFC pavements last in your state?

Eighteen participants responded to this question. The answers ranged from 3 to 20 years with an average minimum of 8 years and average maximum of 11 years. New Hampshire plans on 20 years for shoulders and parking lots.

Q26. Is winter maintenance considered when designing OGFC projects in your state?

Twenty-one participants responded to this question. Ninety (90%) of them answered with 'NO' and two (10%) with 'YES'.

Q27. Do you exclude certain roads from using OGFC?

Twenty-one participants responded to this question. Six (29 %) of them answered with 'NO' and fifteen (71 %) with 'YES'. Some of the participants who answered with yes elaborated in their answers by mentioning what types of roads OGFC are used or excluded. Most states use OGFC on interstates or high volume with high number of wet weather crushes. Table A.9 below reports all the mentioned exclusions.

Table A-9 Exclusions on the use of OGFC

STATE	OGFC Exclusions
Alabama	OGFC is typically only used on Interstates and limited multi-lane highways (Ex. 6 or more lanes), and areas with high numbers of wet weather crashes.
Maryland SHA	Yes, we normally pave OGFC on Interstate and High traffic volume multi-lane state routes.
Nevada	OGFC is only used for full depth porous applications for parking lots (Park and Rides) and Interstate shoulder applications. There are only two applications for each that I am aware of. It is considered for all park and rides, but the underlying soil conditions determine if it is ultimately feasible.
New Hampshire	Cost, Volume of traffic
South Dakota	There is currently a push to transition interstate pavement to a dense pavement due to the relatively short life span of OGFC and the inability to afford to replace it as quickly as it is needed.
Texas	Traffic volumes
Utah	Due to the expense, OGFC are used in highways with higher volume of traffic. Other roads have an asphalt surface treatment (chip seal) installed.
WYDOT	OGFCs are generally avoided where ice events are difficult to manage. Some Northern districts do not use OGFC surfaces at all. Do not use on urban sections with turning and stopping motions. Do not use on roadways with curb and gutter for in mill and inlay operations. PFC/OGFC is sometimes discouraged in order to meet environmental requirements, since quality of storm water runoff can be lost over the life of the surface course.
Wyoming	low volume roads and non-NHS

Q28. Do you have a design procedure/consideration for OGFC layer thickness and shoulder width?

Twenty participants responded to this question; nine answered with 'YES' and eleven with 'NO'.

Q29. If the answer to number 28 is YES, can you share the document? Please upload it on the next question or email it to ogfcresearch@gmail.com. Please kindly provide a summary of the OGFC winter maintenance plan adopted in your State

Only one participant (Texas) provided an answer to this question, which was: "In addition to conventional preservation measures, OGFCs may also be cleaned by washing or vacuuming periodically. Texas is wary of damage ice can cause OGFCs, so they are not favored in areas with frequent freeze/thaw cycles. Also, the binder is usually latex, or tire rubber modified to provide more resistance to stripping and shelling/raveling. Each TXDOT District is responsible for the continued maintenance of their OGFCs and use different maintenance and ice control strategies."

Q30. File upload for previous question.

Only one participant (Arizona) responded to this question by uploading a file that is provided to TDOT separately.

Q31. Would you recommend the above winter maintenance plan statewide?

From the fourteen participants who answered this question seven states responded with 'YES', and seven participants answered with 'NO'. Furthermore, one participant (Wyoming) replied with "WYDOT uses these methods statewide." The participant from the state of Georgia answered with: "It works for the state of Georgia. If your impacts are similar this plan will work."

Q32. Please kindly highlight any challenges your state face regarding OGFC winter maintenance and pavement performance.

Sixteen participants responded to this question. Table A.10 below displays the answers.

Table A-10 Winter Maintenance and Pavement Performance Challenges

STATE	Winter maintenance and pavement performance challenges
Alabama	In Alabama, same as other pavement types - Freezing roadways due to our climate. We don't usually have snow-only events. It's typically snow and ice or snow melt and re-freeze.
Arizona	Sensitive to moisture and dirty aggregates.
Georgia	None at this time. We do have a current research project that is looking at the impacts of salt on our roadways.
Maryland SHA	Not sure of any as our pilot projects are new.
Missouri	If anti-icing isn't performed adequately, it can be very challenging to reach our objective of a clean wet pavement.
Nevada	survive from snow plow
New Hampshire	Have seen some premature surface raveling and tire damage in parking lots

STATE	Winter maintenance and pavement performance challenges
New Jersey	Mostly on inclines. We have to use a lot of de-icing material to try and keep the road safe
North Carolina	OGFC roadway tends to freeze sooner than other pavements. Snow and Ice bonds more significantly Blades wear faster Can't use abrasives on account they would "clog" up the voids
Oklahoma	The performance of our OGFC decreases at a faster rate relative to how many winter operations are performed.
South Carolina	OGFC is an issue for winter maintenance because it freezes so quickly. Additionally, SCDOT utilizes both plows and motor graders during winter storm response. The pavement surface of the OGFC is easily damaged by plows and motor grader blades.
South Dakota	None other than shoulder cleanup during winter storms.
Texas	Issues with brine treatment using stream nozzles, switched to fan spray to have effective coverage.
Utah	The timing of pre-treating or anti-icing has been found to be successful for pavements with OGFC.
WA State DOT	Our main challenge is related to studded tires and longevity.
Wyoming	Having the value of liquids to deliver double the rate. Then stay on the same application cycle time.

Q33 Please share any success you have experienced with winter maintenance on any projects in your state. Things that we can learn from your winter maintenance program.

Shared below in Table A.11 are responses to this question provided by participants.

Table A-11 Winter Maintenance Experiences

STATE	Shared winter maintenance experiences
Arizona	I am not aware of our state winter maintenance program.
Georgia	Our RWIS program affects our program along with the forecast on our next steps as we work through a storm.
Maryland SHA	Not sure of any as our pilot projects are new.
Oklahoma	We have begun using salt brine throughout the state prior to a storm. Having this material below the snow and ice has improved our ability to clear our roadways faster.
Texas	Active pretreatment with brine has been very effective
Utah	Pre-Anti-Icing, has been helpful. Knowing our materials and having the vendors provide specific training to our sheds on how to deal with different conditions has also helped our guys to get a better understanding of what and how they should be operating to minimize costs but to maximize benefits.

STATE	Shared winter maintenance experiences
WA State DOT	Training is key to success from a performance and budget standpoint. We have recently refocused and are experiencing clear benefits.
Washington State	Moving to salt with pre-wet and keeping vehicle speeds at 35 MPH and below has shown benefit.
Wyoming	If you have a steep mountain route it would be good to dedicate the equipment to stay on that section of the route. Try not to extend the equipment that would cause the cycle time to be to great for the material being spread.

Q34 Please provide any other comments or recommendations you may have regarding OGFC.

Eight participants responded to this question as shown in Table A.12 below.

Table A-12 Comments and Recommendations Regarding OGFC

STATE	Comments & recommendations
Arizona	Please make sure your water absorption does not exceed 2.5% and Asphalt absorption does not exceed 1.0 %. OGFC is very sensitive to moisture damage.
Kansas	Please send me results of survey or research project
KYTC	The state of Kentucky has not applied any OGFC pavements since about 1984. Many of these questions I can't answer concerning OGFC.
Maryland SHA	Not sure of any as our pilot projects are new.
New Hampshire	We do not use OGFC as wearing course for travel lanes.
New Jersey	From a winter perspective, we do not like OGFC.
Ohio	Ohio has used OGFC but they rarely last. The last one we attempted on a lower volume experimental road needed to be repaved the following year. FHWA has suggested that we do not use OGFC and have since removed it from our specifications. There is probably very little maintenance documents that we have. I do know more salt was used versus typical dense-graded mixes.
Texas	OGFC has been primarily used on higher volume roads in areas with higher rainfall. It has been very effective in reducing wet weather crashes.
Utah	Our pavement division would also be a better source of information on project related criteria for roads with OGFC
Washington State	OGFC was initially placed as test sections in Washington State to measure noise reduction. Because the noise characteristics were reduced for a short time, OGFC is not used.
WYDOT	Understanding the Chemical and Mechanical Performance of Snow and Ice Control Agents on Porous or Permeable Pavements (January 2018) Clearroads.org has done research on OGFC. Please review the document.
Wyoming	Works great for 4 months of the year.

Q35 Do you have OGFC winter maintenance procedures documented?

All the eighteen participants responded to this question answered with 'NO', while two responded 'YES', Arizona uploaded it on question 30, Alabama did not upload.

Q36 File upload for previous question.

No file was uploaded in response to this question. All participants skipped the answer.

Appendix B Internal survey questions and results

Q1 Region/District

Eight districts from twelve TDOT's four regions have responded to the survey. Three districts from region (1) including 1/17 west and 1/18 west (the third participant from region (1) did not identify their district), one participant from region 2 district 2/29, three participants from region (3) district 3/39, and one participant from region (4) who also did not identify their district. Figure B-1 below displays a map of TDOT's four regions. Region 1 Districts 17, 18, 19; Region 2 district 27, 28 and 29 Region 3 37, 38 and 38 and District 4 47, 48 and 49

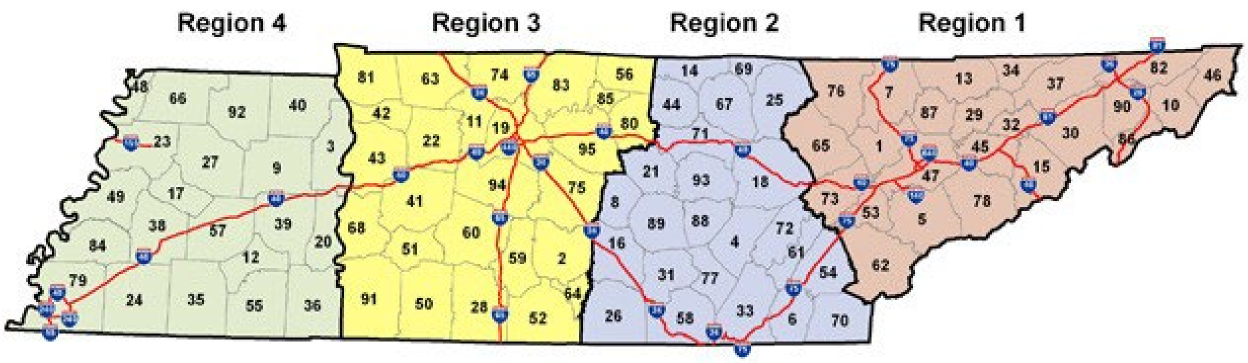

Figure B-1 The TDOT four regions

Q2 Contact Information

All the contact information of the survey participants has been sorted and logged in a separate register file.

Q3 Are there pavement sections with OGFC in your region/district?

All the survey participants responded with 'YES' to this question.

Q4 On what road types (classes) is OGFC applied (used)? (Select all that apply)

All the survey participants responded with 'Interstates' to this question.

Q5 The list of OGFC projects is provided in the appendix. Please add any projects in your region/district that are not listed. This appendix is sent as an excel file attached to the email containing this survey. Please upload amended file here.

Three participants answered this question, one from region (1) and two from region (3). Answers are saved in a separate file to be compared with the projects list provided by TDOT HQ.

Q6 Out of the sections listed in the appendix, which sections have posed a maintenance challenge? List the project number and the challenges you faced.

Five participants responded to this question, two from region (1) and three from region (3). The answers as shown in the Table B.1 below.

Table B-1 Winter Maintenance Challenges Faced by TDOT Regions

District	Maintenance challenges
Region (1), District 1/17 West	CNP292 – Increased material and manpower to remove snow/ice from roadway when compared to other asphalt surfaces CNL957 – Increased material and manpower to remove snow/ice from roadway when compared to other asphalt surfaces
Region (1), District 1/18 west	1 I-275 and downtown 40, pavement coming up
Region (3), District 3 / 39	(1) CNM342 – Raveling at Joints, Incomplete Shoulder Paving (2) CNN327 – Raveling at Transitions, Joints, and Bridge Ends (3) CNP075 – Raveling at Bridge Ends, Bridge End Settlement (4) CNP282 – Raveling at Bridge Ends, Base Failures (5) CNQ362 – Massive Base Failures throughout project (6) CNQ376 – Raveling at Bridge Ends and Joints (7) CNR304 – Base Failures
Region (3), District 3 / 39	CNM342, Shoulders were not paved out full width, hard to plow

Q7 Are there different considerations on winter maintenance between OGFC and densely graded pavements as far as type of chemical, application rate or triple coverage are concerned?

All the eight participants answered this question with 'YES'

Q8 Please give examples for the previous question. Please answer with a Yes or No and an explanation.

The Table B.2 below displays the answers of the participants to this question.

For Q8 other: Lower travelling speeds and shorter intervals between applications

Table B-2 Examples for Winter Maintenance and Pavement Performance Challenges

Region/ District	Region (1), District 1/17 West	Region (1)	Region (1), District 1/18 west	Region (2), District 2 / 29	Region (3), District 3 / 39	Region (3), District 3 / 39	Region 4
Techniques:	Yes - Liquid solution and pressurized application system	Try using a little "hotter" brine	Yes, heavier salt applications and bribe applications for OGFC	Yes	Yes - Heavier on pre-wet CaCl application	Yes-unable to use belly plows	continuous brine operation in addition to salt application
Types of Chemicals:	Yes - Cacl		No	Yes	No - Use of Brine, Salt, and CaCl regardless of surface	No	salt brine, calcium chloride, magic salt (potato juice), salt
Application Rate:	Throughout the event the OGFC sections tend to receive more material		Yes, more since it's a thicker porous material	No	Heavier application (increased spread rates)	No	use standard rates for salt and brine application per Standard Operation Guideline
Adopted winter maintenance techniques	Anti - Icing, De - Icing, Pre - Wetting, Snow - Plowing	Anti - Icing, De - Icing, Pre - Wetting, Snow - Plowing	Anti - Icing, De - Icing, Pre - Wetting, Snow - Plowing	Anti - Icing, Pre - Wetting, Snow - Plowing	Anti - Icing, De - Icing, Pre - Wetting, Snow - Plowing	Anti - Icing, De - Icing, Pre - Wetting, Snow - Plowing	Anti - Icing, De - Icing, Pre - Wetting, Snow - Plowing,

Q9 What winter maintenance techniques(s) do you adopt? (Select all that apply)

Seven participants responded to this question. All the answers included Anti–Icing, De–Icing, Pre–Wetting, and Snow Plowing, except for Region (2). They didn't include De-icing their answer. Other answer(s): spreading salt then applying brine on top.

Q10 On a scale of 1 – 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness of anti-icing on OGFC pavements in your region/district?

Seven participants responded to this question. The answers ranged from 0 to 5 with an average rating of 3.8

Q11 On a scale of 1 – 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness of de-icing on OGFC pavements in your region/district?

Eight participants responded to this question. The answers ranged from 0 to 5 with an average rating of 3.4

Q12 On a scale of 1 – 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness of pre – wetting on OGFC pavements in your region/district?

Eight participants responded to this question. The answers ranged from 0 to 5 with an average rating of 3.9

Q13 On a scale of 1 – 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness of snow plowing on OGFC pavements in your region/district?

Eight participants responded to this question. The answers ranged from 0 to 5 with an average rating of 3.9

Q14 On a scale of 1 – 5 (0 if not used the technique, 1 being not effective at all and 5 being very effective), how would you rate the effectiveness of sanding on OGFC pavements in your region/district?

All participant responded with 0 to this technique implying it is not commonly used in Tennessee.

The Table B.3 below displays the answers to the questions Q10 to Q14 (Numbers are rounded to a nearest 0.5)

Table B-3 Effectiveness Rating of OGFC by TDOT Regions

Region/ District	Region (1), District 1/17 West	Region (1)	Region (1), District 1/18 west	Region (2), District 2 / 29	Region (3), District 3 / 39	Region (3), District 3 / 39	Region (3), District 3 / 39	Region 4
Anti-icing	1.8	3.8	1.8	4	0	3.8	5	3.8
De-icing	1.8	3.8	1.4	0	4	3.8	5	3
Pre-wetting	2.5	5	2.5	4.4	4	3.8	3.8	4.3
Snow-Plowing	3.5	4.3	1.3	3.8	4.5	4	4.5	3.8
Sanding	0	0	2.1	0	0	0	0	0

Figure B-2 below displays the reported effectiveness of the adopted winter maintenance techniques. Each colored bar represents a winter maintenance technique as illustrated in the graph legend. The 'y' axis indicates the rating of the adopted technique from scale of 5.

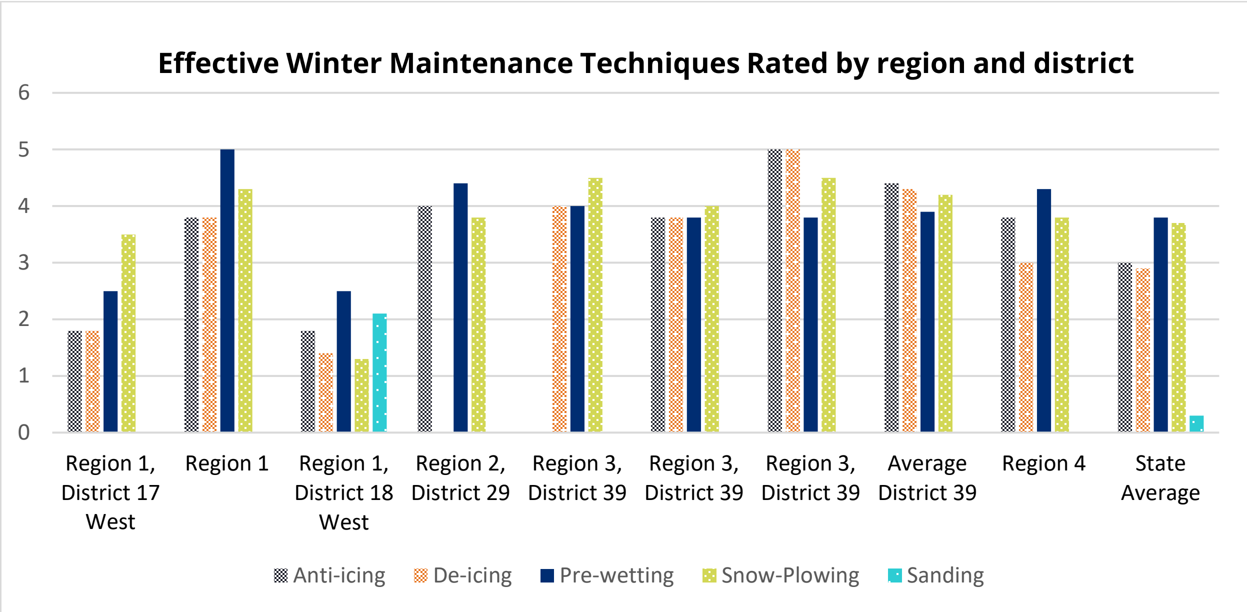

Figure B-2 Effective Winter Maintenance Techniques Rated by TDOT Region and District

Q15 What winter maintenance materials do you use? (Select all that apply)

All eight participants responded to this question, and the answers included solid rock salt (NaCl), salt brine, and calcium chloride ($CaCl_2$). Figure B-3 below displays the reported answers. The 'Y' axis represents the number of region/districts using the specified material. The answers are shown graphically in Figure B-3 below.

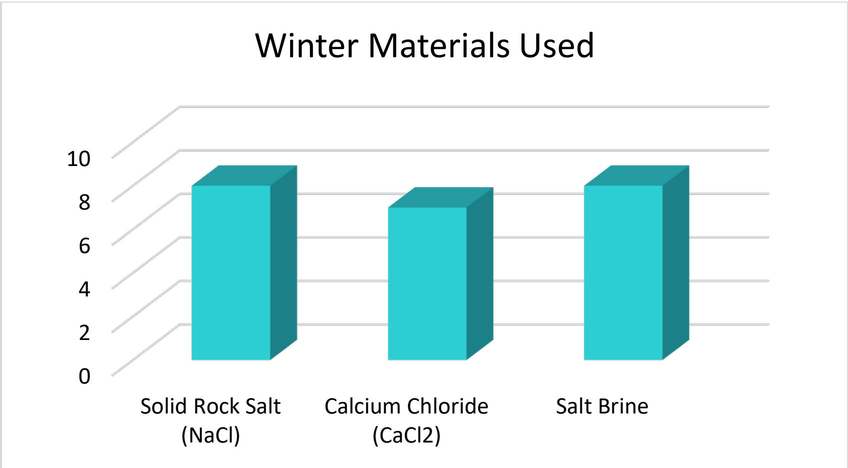

Figure B-3 Winter Maintenance Materials Used

Q16 What salt brine (Abrasives, Magnesium Chloride (MgCl2), Solid Rock Salt (NaCl), Calcium Chloride (CaCl2) Salt Brine, Acetates, or other materials) treatment rates and times are being applied to OGFC for SNOW? (List material/ application rate/ application times that produce best results)

Four participants responded to this question and their answers are as shown in the Table B.4 below.

Table B-4 Treatment Rates and Times Applied to OGFC for Snow

Region/District	Treatment Rates for Snow
Region (1), District 1/17 West	(1) Rock Salt/300#perLM/Just before snow event (2) Salt Brine and $CaCl_2$ mixture/50galperLM/Before snow event in pressurized system
Region (1)	(1) Spread Rate 200-250lb/lane mile (2) Blast Mode on Bridges and Trouble Spots 800-1000 lb (3) Brine 80/20 (76%)
Region (1), District 1/18 west	200 lb per lane mile of salt
Region (4)	(1) rock salt – 250 lb/lane mile (2) brine – 40 gallons per mile (3) brine additives – 10% calcium and 10% potato juice (4) continuous operation with salt and brine applied

Q17 What salt brine (Abrasives, Magnesium Chloride (MgCl2), Solid Rock Salt (NaCl), Calcium Chloride (CaCl2) Salt Brine, Acetates, or other materials) treatment rates and times are being applied to OGFC for ICE? (List material/ application rate/ application times that produce best results)

Four participants replied to this question and their answers are as shown in the Table B.5 below

Table B-5 Treatment Rates and Times Applied to OGFC for Ice

Region/District	Treatment Rates for Ice
Region (1), District 1/17 West	(1) Rock Salt/300#perLM/Just before snow event (2) Salt Brine and Strong CaCl2 mixture/50galperLM/Before snow event in pressurized system
Region (1)	Salt Brine and Calcium Chloride

Region/District	Treatment Rates for Ice
Region (1), District 1/18 west	250 lbs per lane mile
Region (4)	(1) Increase brine additives to 20% calcium and 20% potato juice (2) lower travel speed to increase coverage (3) salt applied at Standard Operation Guideline rate

Q18 What alternative pre-storm treatments have been most effective in various situations? At what concentration and coverage rates? (Ex. Potato juice, beet juice, calcium, etc.) List product/ concentration/ coverage rate.

Two valid responses were given to this question.

1- Region (1): "Salt Brine and Strong CaCl2 mixture/50galperLM/Before snow event in pressurized system."
2- Region (4): "1- standard brine with 10% calcium and 10% potato juice 2- depending on weather forecast sometimes spread light salt during pretreatment"

Q19 On open-graded paving projects; is the full shoulder width typically paved with OGFC mix, or is only a portion of the shoulder width paved with OGFC mix?

All eight participants responded to this question. Three of them answered with 'full shoulder width', three with 'portion of the shoulder,' and two regions reported the combined use of both practices depending on the project.

Q20 If only a portion of the shoulder width is paved with OGFC, how much?

Six participants responded to this question and their answers are shown in the Table B.6 below

Table B-6 Portions of the Shoulder Paved with OGFC by TDOT Regions

Region/District	Portion Paved
Region (1), District 1/17 West	Before the rumble strip, 6"
Region (1)	Full 10-12 feet shoulder
Region (1), District 1/18 west	Past the rumble strip, >6"
Region (3), District 3 / 39	Past the rumble strip, >6"
Region (3), District 3 / 39	4
Region (4)	4 feet

Q21 Does your region/district pave OGFC over only 4 feet of the outside shoulder to allow the OGFC to drain onto the remaining paved 6-foot shoulder?

All the eight participants responded to this question; five of them answered with 'NO', and three with 'YES'. Moreover, the participant from Region (1) replied with "This poses issues when employees are attempting to clean the shoulder area. It is difficult to clean, and the shoulder drop off will "pull" the vehicle when the tire is navigating the drop off. Therefore, the employee is constantly fighting this "pulling" effect while plowing.”

Q22 Do you add extra salt to the outside OGFC shoulder to reduce blockage from frozen ice?

Seven participants answered this question, two of them answered with ‘YES’, two with ‘NO’, and the remaining three participants gave extensive answers. A participant from Region (1) answered with “We salt shoulder but not necessarily extra.” Another participant from Region (3) replied to this question with “Treat the shoulders as main line. Work from the shoulder to the interior lanes to ensure water can escape from the treated surface.” And the participant from region (4) responded with “apply brine to shoulder continuously and if needed place salt at 250 lbs/lane mile”

Q23 If full outside shoulder is paved with OGFC, how do you ensure that the OGFC drainage is not blocked by soil and/or fine aggregate at the edge of the shoulder?

Four participants gave valid answers to this question, three participants answered with ‘shoulder clipping’, and one participant from Region (3) replied with “Place shoulder stone prior to placing OGFC”

Q24 Apart from winter maintenance, are OGFC pavements in your region/district cleaned? How? (Select all that apply)

All the eight participants replied to this question, seven of them replied with ‘Not cleaned’ and a participant from Region (1) answered with ‘Sporadic Sweeping’

Q25 About how long (years) do OGFC pavements last in your region/district?

Seven participants answered this question and the answers ranged from 1 to 14 years with an average answer of 10 years.

Q26 Is winter maintenance considered when designing OGFC projects in your region/district?

Seven participants responded to this question, four answered with ’NO’ and three with ‘YES’

Q27 Do you exclude certain roads from using OGFC?

Six participants responded to this question. While only one participant - Region (1) answered with ‘NO’, two participants replied with ‘YES’, and the remaining three gave extensive answers. A participant from Region (2) responded with “Area with high freezing like mountain roads. OGFC is a pain if the ice freezes. So, it is used in areas the historically doesn't freeze as much as others.” Another participant from Region (3) answered with “Interstate lane miles only.” And the participant from Region (4) replied with “Urban/high volume/low speed roads.”

Q28 Please provide a summary of the OGFC winter maintenance plan adopted in your region/district. If you have a winter maintenance document, we will appreciate if you can share it with us (file upload available on next question).

The only valid answer to this question was a reference to TDOT’s Winter Maintenance Standard Operation Guideline.

Q29 File upload for previous question.

All the participants skipped the answering this question.

Q30 Would you recommend the above winter maintenance plan statewide?

Three participants answered this question; two answered with 'NO' and one with 'YES'

Q31 Please provide a highlight of any challenges your region/district face regarding OGFC winter maintenance and pavement performance.

Five participants responded to this question and their answers are as shown in the Table B.7 below.

Table B-7 Highlight of Challenges TDOT Region/District Face Regarding OGFC

Region/District	OGFC Challenges
Region (1), District 1/17 West	Removing of snow and ice and pretreating for snow and ice
Region (1), District 1/18 west	Honestly, we haven't had bad winters since it has been installed so I don't have a lot of input.
Region (2), District 2 / 29	If it freezes then you have to use high concentration of calcium to help break it up. This isn't something we like to do if we can help it. So, we end up spending more time in these area to make sure the interstate stays open.
Region (3), District 3 / 39	Rutherford Co. has faced significant challenges regarding OGFC which are known to HQ (base failures, raveling) Marshall Co. is beginning to fight the OGFC on I-65 due to end of lift cycle of the surface treatment.
Region 4	Most of R4's events are mixed events with a certain amount of ice prior to snowfall which is not necessarily normal to the rest of the state. we have adapted our approach to meet this expectation and therefore it may not be applicable to the other regions

Q32 Please share any success you have experienced with winter maintenance on any projects in your region/district.

Three valid responses were given to this question

1- Region (2), District 2 / 29: "If it freezes then you have to use high concentration of calcium to help break it up. This isn't something we like to do if we can help it. So, we end up spending more time in these areas to make sure the interstate stays open."

2- Region (3), District 3 / 39: “Rutherford Co. has faced significant challenges regarding OGFC which are known to HQ (base failures, raveling). Marshall Co. is beginning to fight the OGFC on I-65 due to end-of-life cycle of the surface treatment.”
3- Region (4): “Most of R4's events are mixed events with a certain amount of ice prior to snowfall which is not necessarily normal to the rest of the state. We have adapted our approach to meet this expectation and therefore it may not be applicable to the other regions”.

Q33 Please provide any other comments or recommendations you may have regarding OGFC.

Three valid responses were given to this question.

1- Region (3): “Good concept but needs more fine tuning before being placed on Tennessee roadways. Need to revisit the amount of water being allowed to drain beyond the OGFC. Need to revisit the specifications and ways of testing the OGFC at the plant prior to placement. Need to study the reasons of raveling at all joints.”
2- Region (3): “OGFC works well in keeping road spray down from passing cars. However, I do not think it is ideal for use in an area that experiences freezing temperatures.”
3- Region (4): “OGFC is harder to keep form freezing up resulting in more man-hours used for anti/de-icing operations. If a proper schedule could be developed for cleaning these projects, it might help with this by allowing it to drain faster.”