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16. Abstract (Limit: 250 words)

Porous and permeable pavements (PPPs) have been successfully used by many transportation agencies as a wearing surface to help reduce water splash and spray, increase friction, reduce potential for hydroplaning, and reduce noise. Despite their inherent advantages, when used in colder climates PPPs tend to freeze more rapidly, appear whiter and "snowier" longer, and need greater and more frequent applications of deicers than traditional dense graded pavements (DGPs). Laboratory tests were conducted on DGP pavement samples, new and old open graded friction course pavements, and ultrathin friction course samples in a walk-in cold lab at 28°F with snow, compaction equipment, and a trafficking device. Snow–pavement bond strength and static friction were measured to determine the effectiveness of anti-icing with salt brine and deicing with dry and prewet solid salt. Compacted snow bonds more strongly to PPPs, yet friction of PPPs was significantly greater than DGPs after snow removal, even without the use of salt. The PPPs appeared more white and snowy, and this appearance may be contributing to unnecessarily high application rates of salt. Even when snow is trapped in PPPs, friction tends to be higher than DGPs treated for snow and ice control, owing to the overall greater frictional properties of open graded, ultrathin and permeable friction courses. Field testing is recommended to better understand the frictional behavior of PPPs during a variety of winter storm conditions and deicer application strategies.

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# WINTER MAINTENANCE, FRICTION AND SNOW–PAVEMENT BOND ON PERMEABLE FRICTION SURFACES

## DRAFT FINAL REPORT

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# TABLE OF CONTENTS

## LIST OF FIGURES

## LIST OF TABLES

# EXECUTIVE SUMMARY

Porous and permeable pavements have been successfully used by many transportation agencies in several countries as a wearing surface to help reduce water splash and spray, increase friction, reduce potential for hydroplaning, and reduce noise.  Despite their inherent advantages, when used in colder climates PPPs may tend to freeze more rapidly, transport deicing chemicals from the road surface, clog from sands and other debris, and retain snow and ice for a longer period of time.  Most of the reported difficulties with PPPs were at near-freezing temperatures (28–35°F).  A literature review, interviews and laboratory tests were conducted to provide recommendations for winter maintenance practices on PPPs.  A summary of findings regarding porous and permeable pavements compared to traditional dense graded pavements (DGPs) from the literature review and interviews includes:

- Good drainage and macrotexture limit ice formation on wet pavements
- Friction values are generally the same or better
- Pavement surface cools faster and remains frozen longer
- Snow and ice tend to stick to sooner
- Surface remains wet longer, dries slower
- Pavement appears white or snowy for longer
- May require higher deicer application rates, more frequent application rates, or applications for a longer duration

Laboratory tests were conducted using samples of traditional dense graded pavement, cores from new and old open graded friction course pavements from Massachusetts, and ultrathin friction course samples made from hot mix from New York and Missouri.  The tests were conducted in a walk-in cold lab at 28°F with snow, compaction equipment, and a trafficking device.  Snow–pavement bond strength and static friction were measured to determine the effectiveness of anti-icing with salt brine and deicing with dry and prewet solid salt.  A summary of findings regarding PPPs in comparison to DGPs from the laboratory testing includes:

- Snow bond is generally stronger on PPPs than DGPs.
- PPPs appear more snow-covered after scraping snow from the surface.
- Anti-icing generally provides the greater reduction in snow bond.
- Friction on PPPs is significantly greater than on DGP.
- Friction on PPPs was only slightly greater when salt was applied during tests compared to control tests.

Compacted snow bonds more strongly to PPPs, yet friction of PPPs was significantly greater than traditional dense graded pavements (DGPs) after snow removal, even without the use of salt.  ***The PPPs appeared more white and snowy, and this appearance may be contributing to unnecessarily high application rates of salt.***  Even when snow is trapped in PPPs, friction tends to be higher than DGPs treated for snow and ice control, owing to the overall greater frictional properties of open graded,

ultrathin and permeable friction courses. Field testing is recommended to better understand the frictional behavior of PPPs during a variety of winter storm conditions and deicer application strategies.

# CHAPTER 1: INTRODUCTION

Porous and permeable pavements (PPPs) offer several safety and environmental benefits, including improved wet-weather skid resistance, reduced splash and spray, reduced potential for hydroplaning, reduced light reflection, reduced tire/pavement noise, improved pavement smoothness, reduced contribution to urban heat island effect and potential use of waste materials (Cooley et al., 2009). Notable improvements in materials specifications and design have contributed to an increased use of permeable friction surfaces after unsatisfactory experiences in the 1970s and 1980s, particularly draindown, raveling, and other early distresses that shortened life expectancy. Significant challenges of winter maintenance on PPP surfaces have been reported, indicating that PPPs freeze more quickly, accumulate snow faster, require greater deicer application rates, require deicer applications for longer duration, and stay wet longer (dry slower) than traditional dense graded pavements (DGPs). Despite these challenges, their many benefits have ensured broader support, acceptance and use. Therefore, there is a need for DOTs to learn 1) what to expect from these pavements during snowstorms, freezing rain, high humidity–cold temperature conditions, etc., and 2) how to maintain safe driving conditions on these pavements during winter.

In this report the term "porous and permeable pavement" refers to pavement surfaces with a porous, permeable or high macrotexture. Terminology for these various types of pavement surfaces varies regionally, particularly across domestic and international borders, and includes open graded friction course, open graded surface course, porous European mix, ultra-thin friction course, ultrathin bonded asphalt wearing course, paver placed surface treatment, and other names. Full-depth porous asphalt or porous concrete pavements, which have limited implementation on highways and interstates, are not included in this project.

# CHAPTER 2: LITERATURE REVIEW

This literature review provides information about the use and specifications of porous and permeable pavements in the US. Research and documented winter maintenance practices on these types of pavements are thoroughly discussed – including a significant portion of information about European practices to supplement the limited information currently documented in domestic sources.

## 2.1 PAVEMENT MATERIALS, DESIGN, AND CONSTRUCTION

The two primary constituents in most asphaltic pavements are aggregate and an asphalt binder. Stabilizing additives are also frequently incorporated into the mix design to improve strength and durability. Differences in pavement properties are generally due to different aggregate gradations, additives, and mix proportions. The aggregates, binder, and mix undergo various performance and durability tests. Today, a typical DOT-specified asphalt pavement is a Superpave mix of dense graded aggregate and performance grade (PG) asphalt binder and may be referred to simply as hot mix asphalt (HMA) or dense graded HMA (Figure 1a). A common gap graded pavement used more in Europe than the US is stone matrix asphalt (SMA) that provides high resistance to studded tire wear because of good contact between large aggregate and sufficient fines to fill the voids (Figure 1b). A typical open graded HMA used in Europe and the US also contains large and small aggregates (thus, gap graded), but are proportioned such that significant void space exists to drain water and improve wet-weather performance (Figure 1c).

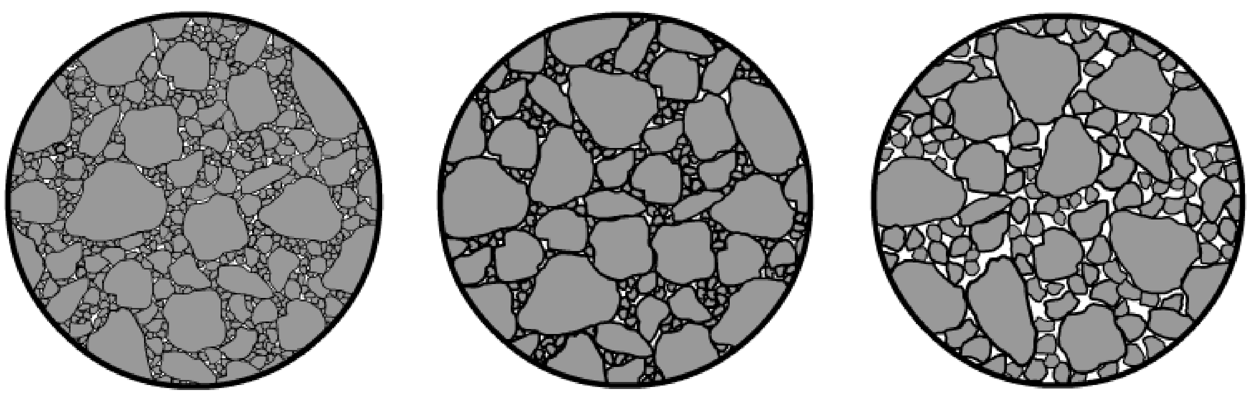


**Figure 1: Cross section view of several types of pavements: a) dense graded HMA, b) stone matrix asphalt, and c) open graded HMA (Pavement Interactive, 2010).**

### 2.1.1 Aggregates

Aggregates make up the largest proportion of pavement materials and provide the primary structural support. Aggregate gradation plays a significant role in various pavement properties, including porosity. Traditional dense graded pavements tend to have well graded aggregates that include all sizes and are generally impermeable. Gap graded and uniformly graded aggregates tend to produce more permeable pavements because void spaces usually exist around particles that are not filled with smaller particles. However, as shown in Figure 1b, gap graded pavements are not necessarily permeable. Pavements are generally classified by aggregate gradation and nominal maximum aggregate size (NMAS), which is the sieve size that retains less than 10 percent of particles (maximum aggregate size is the smallest sieve size in which 100 percent of particles pass through and is usually one size larger than NMAS). Dense graded HMA pavements range in NMAS from 1.5 to 0.75 in (37.5 to 9.5 mm) with larger sizes generally used on roads with high-volume or heavy traffic loads. The most common aggregate gradation for domestic and European open graded friction courses (a common type of PPP) are gap graded near the No. 4 sieve (a gap at No. 8 is the next most common) with a NMAS of 0.75 in (19 mm). A few mixes exist with 1 in (25 mm) NMAS and 0.5 in (12.5 mm) NMAS (Cooley et al., 2009).

- *Aggregate gradation and size affects the porosity of pavements.*
- *Open graded porous pavements have gap graded aggregates*
- *Dense graded impermeable pavements have well graded aggregates.*

### 2.1.2 Asphalt Binder

Bituminous asphalt cement is added to pavement mixes to bind the aggregates into a stable mass. Most PPPs use a polymer modified asphalt binder because a high stiffness is generally needed to prevent draindown and short-term raveling, and improve strength and durability. Draindown is when asphalt binder drains through the aggregate under the influence of gravity during storage and transport or after placement on the road. Draindown contributes to short-term raveling (the progressive loss of aggregate from the road surface) because of a lack of asphalt binder to bind the aggregates together. In the US the Superpave PG system is the most common grading system for asphalt binders, but some agencies still utilize a viscosity grading system. The PG binder selection is primarily based on pavement temperatures at the project site and anticipated traffic volume. Typical polymer modifiers in both the US and Europe are styrene butadiene styrene (SBS) and ethylene vinyl acetate (EVA) (Cooley et al., 2009).

### 2.1.3 Stabilizing Additives

In addition to using a polymer-modified asphalt binder, fibers are commonly added to PPPs as stabilizing additives to prevent draindown, increase strength, and improve durability. Stabilizing additives were notably absent in the open graded pavements used in the US in the 1970s and 80s and are largely responsible for the improved performance and increased use of open graded pavements. Typical dosage ranges from 0.1–0.2% by total mix mass. In the US cellulose and mineral fibers are the most common. Other options include asbestos, polypropylene, polyacrylonitrile, glass, and acrylic fibers. Hydrated lime is also commonly added to permeable pavements (and even dense graded HMA) as an anti-stripping agent to improve the bond between aggregates and the asphalt binder (Cooley et al., 2009, ASTM D7064). Other mineral fillers include fly ash, baghouse fines, and Type 1 Portland cement (Russell et al., 2008a).

### 2.1.4 Mix Design

The process of determining proper aggregate gradation and optimal asphalt and additive content is the mix design process – often considering durability, draindown, and target air void content (e.g., Superpave method, or more rarely, Hveem and Marshall methods). The most common test used to assess durability in Europe is the Cantabro Abrasion test in which compacted specimens are placed in the L.A. Abrasion machine (ASTM C131) without the steel charge and subject to 300 revolutions at 30–33 revolutions per minute. The percent abrasion loss is reported as the percent difference between the initial and final mass (ASTM D7064). Most agencies specify a maximum Cantabro loss of 15–25% for open graded mixes (Cooley et al., 2009). A recent ASTM standard for assessing draindown (ASTM D6390) is based on a method developed by the National Center for Asphalt Technology in which a sample of uncompacted pavement mix is placed in a wire basket in an oven for 1 hour and the amount of binder/additives/fines that leach from the basket into a container is weighed. The maximum permitted draindown is usually about 0.3% (ASTM D7064). Target air void content for traditional dense graded HMA is usually about 4% for design and 6–8% for construction. Porous and permeable open graded mixes generally have air voids of 15–20% (Cooley et al., 2009).

### 2.1.5 Construction

Most PPPs constructed in the US are between 1.25 and 2 in thick, where thickness is often based on experience rather than a mechanistic-empirical design process. A rational method of determining minimum lift thickness of open graded pavements was proposed by Cooley et al. (2009) based on pavement permeability, geometry, and rain intensity and duration. Conventional static steel drum rollers should be used to compact open graded mixes. Vibratory rollers generally should not be used (exceptions are at transverse joints and occasionally longitudinal joints, but only if necessary). Pneumatic tire rollers should also not be used.

### 2.1.6 Pavement Maintenance

Similar to traditional dense graded HMA, PPPs usually receive both preventive and corrective surface maintenance during their useful life. Unlike HMAs, however, they may also need to be cleaned to prevent clogging or restore permeability. Preventive maintenance includes sealing/rejuvenating the asphalt surface, crack sealing, and patching. Surface seals can reduce permeability and friction initially, but it is generally restored after sufficient trafficking. Longitudinal crack seals and large patches can impede the lateral movement of water within the PPPs. More intensive maintenance activities include seal coats, milling, overlays, etc., which may affect the porosity of the surface. Clogged PPPs can be cleaned with a fire hose, high-pressure cleaner, or a specially manufactured washing/vacuuming vehicle (used in Switzerland, Austria, and Japan) (Cooley et al., 2009). Sweeping can also be performed, although washing and vacuuming generally provide better restoration of permeability (Kinter, 2010). Winter maintenance of PPPs is discussed extensively in Section 4.

## 2.2 TYPES OF POROUS AND PERMEABLE PAVEMENTS

This section contains information about pavement types with a porous, permeable, or highly frictional surface. A typical traditional dense graded pavement is presented for comparison purposes.

### 2.2.1 Traditional Dense Graded Pavement

Traditional dense graded pavements (DGP) are commonly constructed throughout the US for surface courses, overlays, or full-depth pavement applications. A typical DGP contains about 6–8% air voids during construction and about 4% air voids while in service. DGPs are generally considered impermeable if well designed and constructed. Asphalt binder content typically ranges from 4–6% and aggregates make up about 86–90% of the total mix (NJDOT, 2009). Superpave mixes vary from ⅜ to 1½ in. (9.5 to 37.5 mm) NMAS, with ¾ in. (19 mm) being one of the more common mixes used.

### 2.2.2 Stone Matrix Asphalt

Stone matrix asphalt (SMA), also referred to as stone mastic asphalt, was developed in Europe as a wearing course with high resistance to rutting and studded tire wear. This technology is not commonly used in the US due to higher costs and lack of experienced contractors, although when properly constructed the higher cost is expected to be more than offset by the increased performance (Brown et al., 1997). SMA pavements are generally more appropriate for high volume roads. The gap graded mixture provides strong stone-to-stone contact and requires more durable aggregates and slightly higher asphalt binder content than traditional DGPs. Polymer modified binders and fibers are also commonly used. SMA mixtures are usually more permeable than DGPs because of the gap graded aggregate skeleton (refer to Figure 1b). To reduce permeability, the compacted air void content is usually kept low at 5–6%. Thus, SMA pavements are generally designed and constructed to provide an impermeable surface. However, the coarse surface texture improves wet weather friction and reduces tire noise (NJDOT, 2009; Pavement Interactive, 2009; Brown & Cooley, 1999). New generation SMAs with air void contents of 5–10% are more permeable, but little additional information was found for these pavements (PIARC, 2013). Notes from a SMA task force meeting between Colorado DOT and Colorado Asphalt Pavement Association indicated SMA pavements receive the same winter maintenance treatments as DGP (CTC & Associates, 2009). South Dakota has noted the pores in their SMA pavements hold liquid deicers instead of losing it as runoff (Sorensen, 2011).

### 2.2.3 Open Graded Friction Course

An open graded friction course (OGFC) can be placed as a wearing course in new construction or rehabilitation, or be installed as an overlay for preventive maintenance of the pavement structure.

OGFCs allow water to drain through the upper portion of the pavement where it is then directed laterally to the pavement edge. This improves the wet-weather performance of roads by reducing the potential for hydroplaning, reducing splash and spray, and improving skid resistance. According to a 2009 survey, states that use OGFC pavements generally use them on urban freeways and rural interstates and primarily because of policy and traffic volume considerations (Cooley et al., 2009). OGFCs don't usually contribute heavily to the structural capacity of the pavement system, but are generally used as a sacrificial wearing course or overlay to improve wet-weather performance and prevent age-hardening of the underlying DGP (Caltrans, 2006). Issues and best practices of winter maintenance on OGFCs are discussed in Section 2.3 .

There are several variations of OGFC pavements – some of which are simply different nomenclature based on regional preference – and some of which incorporate different types of materials that may or may not affect pavement properties. OGFCs use a wide variety of aggregate sizes and porosity. Five examples of OGFC pavements used by various states are listed in Table 1 and elaborated on below.

**Table 1: Examples of OGFC Pavements in the US**

| Name | Thickness (in.) | Nominal Maximum Aggregate Size (in.) | Porosity (%) |
|---|---|---|---|
| Asphalt Rubber Friction Course | 0.5–0.75 | ⅜ or ½ | 11–19 |
| Porous European Mix | 1.25 | ¾ | 20–24 |
| Type F, ¾ inch OGFC | 2–3 | ¾ | 13.5–16 |
| Modified Class D HMA | 1.8 | ¾ | * |
| Open Graded Surface Course | 1.0 | ⅜ | * |

*porosity not found in literature

**Asphalt Rubber Friction Course**

Asphalt rubber friction course is primarily used in Arizona and Texas and occasionally in California, although other states have experimented with its application as well (Smith, 2013; Alvarez et al., 2012; ADOT, 2011; Muench et al., 2011; Anderson, 1997). It is similar to a conventional OGFC, but contains a crumb rubber modifier recycled from automobile or truck tires in addition to an asphalt binder. An asphalt rubber friction course typically has higher total asphalt content than typical OGFCs (7–10%). Air voids and permeability may be similar, greater or less than conventional OGFCs. There are two common gap graded mixes with a maximum aggregate size of 0.375 in (9.5 mm) and 0.5 in (12.5 mm).

**Porous European Mix (Georgia DOT)**

All interstates and state routes with average daily traffic (ADT) ≥ 25,000 (two-way) and ≥ 55 mph speed limit in Georgia are required to have an OGFC surface. Georgia DOT (GDOT) has two approved 0.5-in (12.5 mm) NMAS mixes, one with 18–20% air voids placed at 0.75 in (19 mm) thick and the other referred to as porous European mix (PEM) with 20–24% air voids placed with a 1.25-in (37.5 mm) lift thickness. Fibers, hydrated lime, and a polymer modified asphalt binder are used to prevent draindown and stripping and improve durability. According to Muench et al. (2011) several southern states use gradation bands similar to Georgia's PEM which yield a greater porosity than most OGFCs.

**¾-inch Open Graded Mix or Type F Mix (Oregon DOT)**

Similar to Georgia, Oregon Department of Transportation (ODOT) has a long history of using OGFC with significant research and development when many states abandoned their use after poor experiences in the 70s and 80s. An OGFC long referred to as Type F mix with a NMAS of 0.75 in (19 mm) is now referred to as ¾-in open-graded mix (Muench et al., 2011 and ODOT, 2008). The mix utilizes a polymer modified asphalt binder and has 13.5–16% air voids and is generally placed as a 2–3-in overlay. However, a recent analysis of the performance of ODOT's OGFCs recommends discontinuing their use because of a shorter service life compared to DGPs and uncertain and unquantified safety benefits (Muench et al., 2011).

**Modified Class D HMA (Washington State DOT)**

Washington State DOT (WSDOT) began using OGFCs (referred to as Class D HMA) which consisted of a gap graded mix with a NMAS of 0.375 in (9.5 mm) for overlays with a thickness of 1 in. (25 mm) or less. In the early 1990s the mix was modified (referred to as Modified Class D HMA) based partially on Oregon DOT's practices by incorporating a polymer modified asphalt binder, 0.75 in (19 mm) NMAS and a minimum lift thickness of 1.8 in. (46 mm). Modified Class D HMA is typically used on roads with ADT <10,000 though the mix is also appropriate for higher ADT roads as well. A study of these pavements constructed between 1993 and 2005 in South Central and Eastern Washington indicated a slightly shorter service life than DGP and did not recommend OGFC pavements as an alternative to DGP (Russell et al., 2008a).

**Open Graded Surface Course (Utah DOT)**

Utah DOT's open graded pavement, referred to as "open-graded surface course," is 1 in (25 mm) thick and has a NMAS of 0.375 in (9.5 mm) (UDOT, 2007 and UDOT, 2009). The mix includes hydrated lime to reduce stripping. Information on porosity was not available except for a single reference indicating they are designed with a high percentage of air voids to be water permeable (UDOT, 2009).

### 2.2.4 Ultra-Thin Overlays

Ultra-thin overlays are typically about the thickness of the maximum aggregate size and are most often used to seal the pavement surface to minimize weathering, raveling and oxidation. They generally provide a smooth surface with high frictional resistance, but do not contribute to the structural capacity of the pavement system; they are used for pavement preservation. Chip seal and NovaChip are two common examples of ultra-thin overlays.

**Chip Seal**

A chip seal is an application of asphalt emulsion followed by a layer of aggregate (typically one stone thick), which is then rolled into the asphalt (Gransberg & James, 2005). A chip seal protects pavement from ultraviolet rays and moisture infiltration. Double chip seals are also used in which a second chip seal is placed immediately over the first. In this application, the first chip seal uses more asphalt and larger aggregate than the second overlying chip seal. A double chip seal provides a quieter and smoother riding surface and is better suited for pavements in poor condition, in which cases a single seal coat may not be as effective (Johnson, 2000). Chip seals may consist of uniformly or gap graded aggregates having a maximum aggregate size of about 0.375 in (9.5 mm). Chip seals don't provide as much drainage as an OGFC and the only concern regarding winter maintenance on chip seals was that they can be more susceptible to damage by aggressive snowplowing.

**NovaChip**

NovaChip is a proprietary ultra-thin, bonded, gap-graded wearing course placed by a specialized machine in one pass. Two passes of a double drum static roller sufficiently seats and compacts the aggregate after placement. NovaChip was developed in France in the 1980s and first introduced to the US in the 1990s in Alabama, Mississippi and Texas. Since then, many other states have implemented NovaChip (Russell et al., 2008b). Nonproprietary versions of NovaChip have been established with a variety of names:

- Ultrathin friction course (NJ),
- Paver placed surface treatment (NY),
- Ultrathin bonded asphalt wearing surface (MO), and
- Ultrathin bonded asphalt surface (KS).

According to the World Road Association (PIARC, 2013) the texture and porosity of a NovaChip surface is similar to porous asphalt concrete with about 20% air voids. However, other sources indicate 5–13% air voids (NJDOT, 2009; Uhlmeyer et al., 2003; Cooper & Mohammad, 2004). Winter maintenance issues on NovaChip pavements are discussed in Section 2.3 .

### 2.2.5 Summary of Porous and Permeable Pavement Types

Several types of pavement overlays and surface courses can be used to create a porous or permeable surface. Most are referred to as OGFC, although other similar terms exist (e.g., open graded wearing course, open graded surface course, porous European mix, etc.). Most highly permeable open graded pavements use gap graded aggregates, although some gap graded pavements (e.g., SMA) can have permeability between open graded and dense graded pavements. Based on the findings from the literature search, the porosity of PPPs has a wide range, from 5–25% air voids. Traditional DGPs usually have air voids in the range of 4–8%. A summary table of the characteristics and implementation of various pavement types is shown in Table 2.

Table 2: Summary of PPP Pavement Characteristics

| Pavement Type | Uses | | | Thickness | Aggregates | | | | Porosity (% air voids) |
|---|---|---|---|---|---|---|---|---|---|
| | Overlay | Surface (Wearing) Course | Full Depth | | Uniformly graded | Gap graded | Well graded | NMAS | |
| Traditional Dense Graded Pavement (DGP) | ☑ | ☑ | ☑ | 1–3 in | ☐ | ☐ | ☑ | 0.375 – 1.5 in | 4 |
| Stone Matrix Asphalt (SMA) | ☐ | ☑ | ☐ | 2.5 – 3 times NMAS | ☐ | ☑ | ☐ | No. 4 – 1 in | 5 – 6 |
| Open Graded Friction Course (OGFC) | ☑ | ☑ | ☐ | 0.5 – 3 in | ☐ | ☑ | ☐ | 0.375 – 1 in | 11 – 25 |
| Chip Seal | ☑ | ☐ | ☐ | 1.5 times NMAS | ☑ | ☑ | ☐ | 0.375 – 0.5 in | 6 – 8 |
| NovaChip | ☑ | ☐ | ☐ | 1.5 times NMAS | ☐ | ☑ | ☐ | 0.5 – 0.75 in | 5 – 20 |

Uniformly graded full-depth porous asphalt or concrete pavements have been constructed in the US, but these types of pavements are primarily found in parking lots and urban streets.  A few highway applications exist (shoulders in Nevada, a highway median in New Jersey, test cells in Minnesota's MnROAD facility), but due to the relatively scarce application of these types of pavements to highway environments they were not included in this this project.

## 2.3 WINTER MAINTENANCE ON PPPS

There is currently no consensus on winter maintenance operations specific to porous and permeable pavements (Cooley et al., 2009).  Nevertheless, as use of these types of pavements increased many of the basic strategies and understanding regarding winter maintenance of PPPs steadily developed, including the general practice of increasing deicing chemicals and how these pavement types behave with regard to ice formation when compared to traditional DGPs (Lefebvre, 1993; Bishop & Oliver, 2001).  Work completed by Bishop & Oliver (2001) in British Columbia documented that an adjusted approach to winter maintenance of PPPs is needed, but the slightly higher winter maintenance costs are offset by the improved performance during rain events and corresponding reduction in accidents.  The general consensus regarding winter maintenance of PPPs is that a quick response is needed, but also the response methods need to be flexible depending on different weather and road conditions (Litzka, 2002).  A survey completed for the Ministry of Transport in the Netherlands identified the following situations which may require close monitoring during winter conditions on PPPs (Noort, 1996):

- roads with low traffic volume,
- roads on an incline,

- roads with limited super-elevation,
- hard shoulders,
- warm temperatures following cold conditions,
- snow remaining on the road surface,
- slipperiness caused by condensation or freezing rain, and
- transition zones between PPP and DGP.

### 2.3.1 Role of Weather and Traffic

- *Porous pavements are generally about 2 to 4°F colder, can freeze quicker, and remain colder longer than dense pavements.*
- *The most critical temperature range for PPPs is just below freezing.*

Winter weather conditions (temperature, precipitation, etc.) dictate the behavior and effectiveness of deicers on PPPs and can be used to select an appropriate treatment strategy. Pavement temperature and humidity within the void space of PPPs contribute to the differences between PPPs and DGPs during winter conditions according to Noort (1996). PPPs have a lower thermal conductivity than DGPs which causes the road surface temperature to drop below freezing sooner (Greibe, 2002). The insulating effect of PPPs inhibits heat transfer from the subgrade and can result in a frozen surface when an adjacent DGP remains above freezing. Generally the greatest pavement temperature differences between PPPs and DGPs occur during clear sky conditions with no wind (Huber, 2000). The additional surface area of PPPs also contributes to the difference in temperature behavior between PPPs and DGPs (Dibbs et al., 2005). PPP surfaces have been found to be 2 to 4°F (1 to 2°C) colder and behave differently than DGP at temperatures ranging from 23 to 32°F (-5 to 0°C) (Lefebrve, 1993; Dibbs et al., 2005) (Figure 2). According to Bishop & Oliver (2001) the most critical temperature range requiring closer attention by winter maintenance personnel is 27–32°F (-3–0°C). The surface temperature can stay below the freezing point longer than DGP surfaces even as air temperatures are rising above freezing (Greibe, 2002). Daytime pavement surface temperatures have been shown to be higher for DGPs while nighttime time pavement surface temperatures have been shown to be higher for PPPs due to the insulating effect of the air voids in PPPs. During snowfall the temperatures of PPPs tends to be slightly lower (0.4°F, 0.2°C) than DGP surfaces (Iwata et al., 2002).

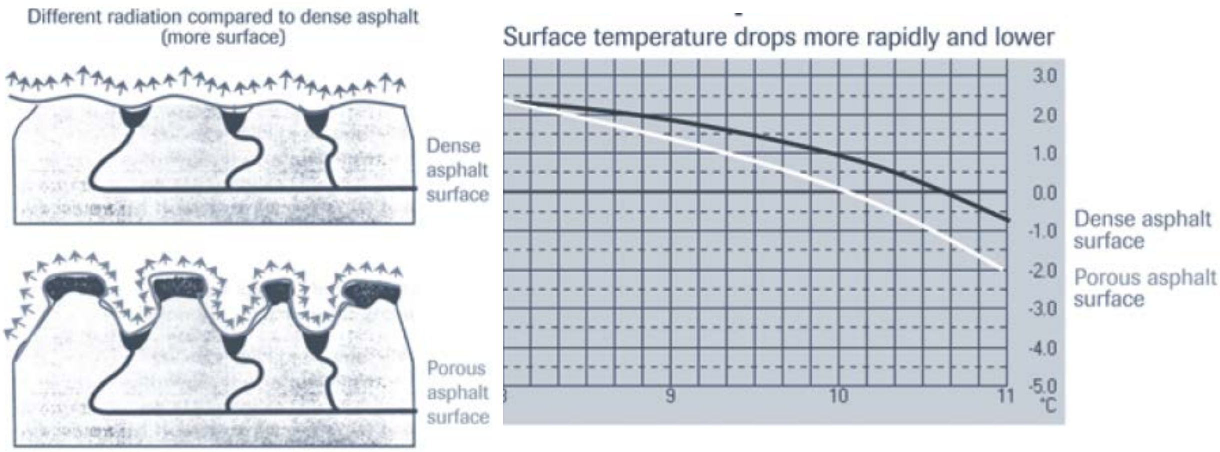



**Figure 2: Comparison of a) surface radiation and b) temperature in PPPs versus DGPs (Dibbs et al., 2005).**

The purpose of void space in PPPs is to drain water, and the presence of liquid water in the voids during drainage contributes to increased water vapor (humidity) that remains in the voids after the liquid water has left the void space. In winter, PPPs dry slower because traffic brings moisture back to the road surface, caused by "air pumping" from vehicle tires. This moisture can contribute to icing in freezing temperatures (Noort, 1996; Greibe, 2002). Liquid or solid deicing products applied to porous pavements can initially appear to be lost in the pore spaces; however, heavy traffic has been shown to "pump" the deicing solutions from the pore spaces up to the road surface. Road managers have attempted to encourage this phenomenon by redirecting traffic into one lane or reducing the speed limit (Hernandez and Verburg, 1997). If slushy conditions are present on porous asphalt, the performance may take longer to recover than on DGPs because snowplows may tend to press the slush into the voids where it may have the tendency to reemerge over time under the influence of traffic (Litzka, 2002).

PPPs do offer a couple benefits even during winter conditions because of their ability to drain water. Rain falling on unfrozen pavements will drain and prevent ice formation if the temperature drops below freezing. The high macrotexture of PPPs can also help break up thin ice while trafficked (Isenring et al., 1990). The removal of melt water from the surface of PPPs is generally better than on DGPs, so dilution of deicers is less likely on these types of surfaces (Houle, 2008). If insufficient deicers are present, however, any remaining water that may have become trapped in the porous structure of the PPP may freeze and cause surface distresses or pavement damage (Cooper, 2010).

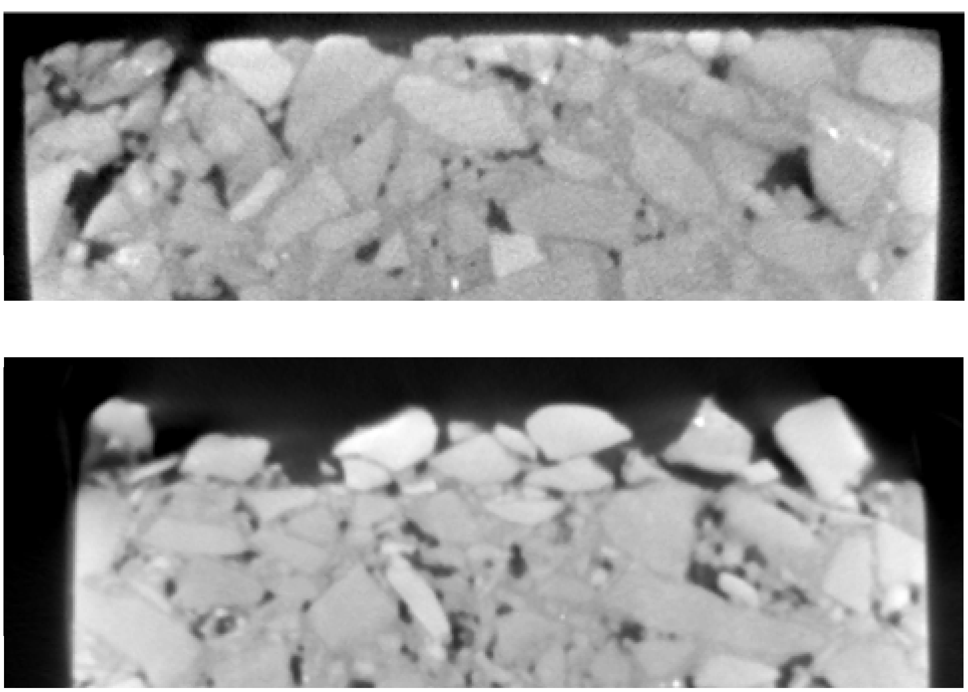
Critical times to treat PPPs are at the beginning of snowfall and in certain cases during the thaw period (Isenring et al., 1990). Three winter conditions that require particular diligence when managing porous pavements are:

1. Freezing fog/hoar frost – at certain temperature and humidity conditions, ice can form on the pavement surface through condensation and freezing (Lefebvre, 1993). Because ice forms sooner on PPPs, freezing fog/hoar frost can occur more often and last for a longer duration. Generally, this is only a problem when traffic volumes are low. In these instances, increased application of deicing products may be necessary (Hernandez and Verburg, 1997).

2. Frozen wet surfaces (rain on snow or ice) – ice buildup due to glazed frost or rain on frozen PPPs should not be treated with liquids, and prior anti-icing is ineffective because the porous structure will quickly drain the deicing products from the surface (Lefebvre, 1993). An increased application of solid salt can be used treat this condition. If snow is present it should be plowed off, and additional salting may be necessary (Hernandez and Verburg, 1997).
3. Snow or sleet/hail – for these conditions, anti-icing is less effective on PPPs. Under these conditions, traffic will press snow into the voids, and the pavement will appear snow covered sooner and for a longer period of time. More frequent salting is needed to melt through the packed snow. Application of too much salt can lead to ice formation on the porous asphalt surface due to an endothermic reaction (Lefebvre, 1993).

### 2.3.2 Plowing

The removal of a bonded ice layer on a PPP surface is more difficult than on a DGP surface (Litzka, 2002). The greatest problem Slovenia reported at a workshop with PPPs was the clearing of packed snow (Litzka, 2002). Research conducted at Montana State University demonstrated that increased efforts in removing snow and ice from more porous surfaces (e.g., porous pavements) is directly related to mechanical "keying" between the two substrates (Figure 3, Edens & Adams, 2001). Because of the open surface and high texture of PPPs, keying likely promotes a stronger bond with ice than on DGPs, whose surfaces tend to be smoother. This could explain the additional effort (quantity of deicers and multiple applications) required to remove snow and ice from PPPs, as reported by Litzka (2002).



**a)** **b)**

**Figure 3: Mechanical keying a) CT image of DGP, b) CT image of DGP with chip seal.**

Snow plows can gouge and damage pavement surfaces during routine winter maintenance activities. PPPs generally exhibit higher rates of surface distress from snowplow activity (Moore et al., 2001; Rogge, 2002). Plow blades can also damage or remove raised markers and bounce along the surface causing a "chatter" or plow marks in the surface layer (Huber, 2000). Cahill (2012) suggests setting the plow blade slightly higher than usual, about 1 in above the pavement, to avoid excessive damage to PPPs. Others suggest waiting to plow porous pavements until at least 2 in of snow has accumulated (Stormwater Fact Sheet, 2013). Steel plow blades are generally not recommended for use on PPPs (Rogge & Hunt, 1999; Moore et al., 2001). Mountainous snow zones in Oregon stopped using PPPs in 2001 because of their vulnerability to plow damage and tire chains (Moore et al., 2001; Rogge, 2002).

### 2.3.3 Sanding, Deicing and Anti-icing

Sanding, deicing and anti-icing are strategies commonly used in response to winter storms. Because snow and ice removal can be more difficult on PPPs due to quicker freezing and additional deicing requirements, winter maintenance crews should respond quickly and be flexible to varying weather and road conditions (Litzka, 2002). Weather forecasting and RWIS can be helpful in planning a response to PPPs, similar to how these tools are used for winter maintenance of DGPs. An important issue for winter maintenance of PPPs is treatment of the transition zones between PPPs and DGPs. PPPs are frequently sandwiched between sections of DGPs and therefore tend to receive the same winter maintenance strategies, despite their differences (Lefebvre, 1993).

A survey of Oregon DOT winter maintenance personnel found that the two most commonly used winter maintenance techniques for OGFCs were 1) sanding and 2) liquid deicers/anti-icers (Rogge, 2002). Magnesium chloride, calcium magnesium acetate and potassium acetate were specifically mentioned several times as the preferred chemical treatment, as was use of heavier application rates on OGFCs than DGPs. Rogge (2002) suggested conducting field trials using more viscous organic deicers to assess whether they offered improved retention and performance. Rogge (2002), however, noted some conflicting comments from the survey participants about the timing of application, such as, a) apply material 60 minutes before the storm, and b) do not pre-treat; it is not effective; the material goes down into the asphalt. In general, conflicting information regarding appropriate winter maintenance of PPPs was prevalent in the literature. Thus this review attempts to identify and present the general consensus regarding sanding, deicing, and anti-icing, which are discussed in more detail below.

**Sanding**

While sanding of PPPs is still commonly used out of convenience, it is generally not recommended. Information reviewed as part of this synthesis revealed conflicting recommendations as the standard practice of sanding PPPs.

In the survey conducted by Rogge (2002) it was reported that sanding was the most commonly used practice to treat winter conditions on roads by Oregon DOT on ¾-inch OGFCs; however, respondents also stated that sanding should be used as a last resort because it can clog the pavement, is less successful than deicing, and that cinders (finely crushed volcanic rock) work the best as they seem to migrate through the pores more easily.

It is highly recommended that abrasives such as sand not be used on porous pavement types for any reasons including friction enhancement on snow and ice because the porous structure of the pavement surface will become clogged and the benefits (water drainage, noise reduction, etc.) of the porous pavement will be lost (Isenring et al., 1990; Noort, 1996). Laboratory testing of 12-in wide, 24-in long, and 6-in thick samples cast during construction of a porous concrete parking lot in Vermont resulted in a 96 percent reduction in surface infiltration capacity after six repeated applications of a 2:1 salt–sand mix applied at 10,000 lb/LM followed by simulated plowing. A 12 percent reduction in surface infiltration capacity was found when only plowing was simulated and a 10 percent reduction when rock salt and plowing was used (McCain & Dewoolkar, 2010).

**Deicing/Prewet Solids**

Deicing treatments are suggested during and after storms on porous pavements to control compacted snow and ice not removed by plowing (Stormwater Fact Sheet, 2013). PPPs generally require more frequent application of deicers, but not necessarily higher application rates. Litzka (2002) acknowledges that PPPs may require a greater number of passes by winter maintenance service vehicles, and recommends applying smaller quantities of deicers on each pass than applied on DGPs to improve performance and limit the overall quantity of deicers used. Oregon DOT maintenance staff noted that OGFCs may require a greater quantity of deicer, because they may need to be applied earlier, more frequently, and over a longer period of time (Rogge, 2002).

According to research conducted in the Netherlands by Van Doorn (2002), the use of too much deicing salts on PPPs during dry conditions can lead to slippery conditions. At temperatures below 5°F (-15°C), melted salt brine can refreeze. It is recommended that a liquid product with a colder eutectic point be used at these colder temperatures instead.

As reported by Litzka (2002) regarding Austria's experience with PPPs, a wet salt application (salt/brine ratio of 2:1) provided the best results and limited the overall increase of salt use on PPPs compared to DGPs to only 10–15 percent more. Lefebvre (1993) found that many countries are increasingly using prewet rock salt instead of dry salt by adding $CaCl_2$ brine or NaCl brine in varying proportions (5 to 30 percent, or up to 0.5 gallon of brine to 11 lb dry NaCl).

**Anti-icing**

Reports on the effectiveness of anti-icing PPPs are also conflicting as demonstrated by the following recommendations from various sources.

- Generally speaking, brines are not recommended for use on porous pavements (Lefebvre, 1993).

- New Jersey Garden State Parkway pre-treats PPPs with liquid magnesium chloride to avoid icing, and has found that this makes the pavement surface manageable and plowable (on par with DGPs) (Bennert et al., 2005).
- On PPPs, immediate and continued applications of anti-icing materials are required (Litzka, 2002).

PPPs can make anti-icing operations difficult and expensive, and have been found to require 30 percent more anti-icing material to achieve the same level of service (LOS) as DGPs (Giuliani, 2002). This could be due to the additional surface area from the open nature and high texture of the pavement surface. Preventative treatments should be carried out sooner on porous pavements because they freeze sooner than DGP (Lefebvre, 1993).

**Products Commonly Used**

Special local adjustments to salt spreading strategies may be necessary due to the unique behavior of salt on PPPs (Greibe, 2002). Several recommendations for deicing products on PPPs are available from international sources. Heystraeten and Diericx (2002) of Belgium suggest using a mixture of ⅓ $CaCl_2$ flakes plus ⅔ coarse NaCl grain up to mesh No. 4. In Austria, a wet application of salt–brine (mixed at a 2:1 ratio) provides the best results on PPPs (Litzka 2002). Lefebvre (1993) of Belgium summarized the various types and forms of deicers used in Europe and Japan and found solid NaCl and solid $CaCl_2$ flake to be the most widely used deicing agents (Table 3).

**Table 3: Types of salt used in Europe and Japan on PPPs (adapted from Lefebvre, 1993)**

| | Austria | Belgium | Denmark | France | Germany | Italy | Japan | Netherlands | Sweden | Switzerland | United Kingdom |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Solid NaCl | VC | VC | VC | VC | VC | VC | VC | VC | VC | VC | VC |
| NaCl brine | RE | | | RE | | RE | VC | | RE | | |
| $CaCl_2$ flakes | | VC | | RE | RE | VC | VC | | | LC | |
| $CaCl_2$ brine | | RE | | | | VC | VC | | | | |
| NaCl/$CaCl_2$ solid mix | LC | | | LC | | RE | | | | VC | |
| Solid NaCl + $CaCl_2$ brine | VC | RE | | LC | VC | RE | | VC | | LC | RE |
| Solid NaCl + NaCl brine | LC | | VC | | | | | LC | VC | RE | RE |

Key: VC = very commonly used, LC = less commonly used, RE = rather exceptionally used, Blank = never used

Oregon DOT reportedly uses magnesium chloride, calcium magnesium acetate (CMA), and potassium acetate on PPPs, with $MgCl_2$ generally favored as the best except for the use of CMA during frost conditions (Rogge, 2002).

In developing recommendations for porous parking lots (asphalt or concrete) for California, Cahill Associates (2012) reported that light snow accumulation is generally not problematic, but during heavy snow they recommended the use of 1) dry rock salt, 2) a $MgCl_2$-based liquid, or 3) salt prewet with liquid $MgCl_2$.

**Application Rates**

Once applied, solid salt dissolves and little salt solution remains on the road surface, with most of the liquid flowing into the porous voids of the pavement. Iwata (2002) noticed it can take about 20 minutes longer for salt to dissolve on PPPs than DGPs because there is less water available on the pavement surface. However, despite the apparent "loss" of dissolved salt into the pores of PPPs, the salt solution in the voids can be transported back to the road surface by the "air pumping" effect of tire traffic, if sufficient traffic is present (Noort, 1996). In general, a driver may not notice any difference between a PPP and DGP surface as long as sufficient traffic is present. Winter maintenance field personnel and researchers show mixed recommendations for using deicers for snow and ice prevention and removal on PPPs. Most of the literature indicates greater application rates are needed on PPPs than DGPs, but there were several sources that indicate similar or lower application rates can be used. A summary of application rates found for several international sources is presented in Table 4.

- *PPPs generally require more frequent application of deicers and for a longer duration*
- *Application rates may be need to be greater for PPPs*

NCHRP Report 526 states that heavily textured pavement surfaces (e.g., open-graded, gap-graded, and porous fiction courses) require an unspecified increase in chemical application rates (Blackburn et al., 2004). The Netherlands use two applications of prewetted salt at 90 lb/LM each for preventive treatment of PPPs, whereas only a single application of 90 lb/LM is needed on DGP (Burns Cooley Dennis, Inc., 2009). In a survey conducted by Cooley et al. (2009), Austria reportedly uses 20 to 50 percent more product on PPPs than on DGPs. Litzka (2002) of Austria found that long stretches of PPPs generally need 25 to 50 percent more deicing agent, while roadways with alternating surface types (including sections of PPPs) may need as much as 50 to 100 percent greater application rates. While road salt use can be as high as triple or quadruple on porous asphalt, these application rates are generally isolated to extreme situations that last for only brief periods and occur once or twice per year. For instance, greater application rates or more frequent application of deicers (immediately after plowing) are necessary during slushy conditions (Litzka, 2002). PPPs may require an increase in the frequency of salt applications and require different timing of application than DGPs (Lefebvre, 1993). A survey response from Oregon DOT mentioned the use of a triple-stream nozzle for PPPs and a single-stream nozzle for DGPs, although whether the application rate was three times greater was not specified (Cooley et al., 2009). An earlier survey of Oregon DOT winter maintenance personnel found magnesium chloride to be the most effective deicer on OGFC, but that it needed to be applied "twice as heavy" (Rogge, 2002). Testing during a FHWA study of PPPs in Utah found that new OGFC pavement required more salt and cleared at a slower rate than DGPs. However, testing on an older OGFC pavement (age not specified) did not exhibit the same differences between OGFC and DGP (Besselievre, 1977).

**Table 4: Application Rates for Various Deicers from International Sources**

| Location | Product | Application Rate (lb/LM) | Condition | Information Source |
|---|---|---|---|---|
| **Germany** | Salt, solid | 130–260 | Normal Treatment | Litzka (2002), Lefebvre (1993) |
| | Salt, solid | 260–520 | Problem areas | |
| **Italy** | Salt, solid | 130–260 | Preventive Treatment | Litzka (2002), Lefebvre (1993) |
| | Salt, solid | 130–390 | Normal Treatment | Litzka (2002), Lefebvre (1993) |
| | $CaCl_2$ flakes | 130–260 | Normal Treatment | Lefebvre (1993) |
| | $CaCl_2$ flakes | 65–130 | Preventive Treatment | Lefebvre (1993) |
| **Belgium** | Salt, solid | 260–390 | Normal Treatment | Lefebvre (1993) |
| | $CaCl_2$ flakes | 260–390 | Normal Treatment | |
| | $CaCl_2$ flakes | 90–260 | Preventive Treatment | |
| **Denmark** | Salt, solid | >130 | Normal Treatment | Lefebvre (1993) |
| | Salt, solid | 65–130 | Preventive Treatment | |
| **France** | Salt, solid | 260–390 | Normal Treatment | Lefebvre (1993) |
| | Salt, solid | 130–195 | Preventive Treatment | |
| | $CaCl_2$ flakes | 260–390 | Normal Treatment | |
| **Japan** | Salt, solid | <1300 | Normal Treatment | Lefebvre (1993) |
| | Salt, solid | >130 | Preventive Treatment | |
| | $CaCl_2$ flakes | 130–650 | Normal and Preventive Treatment | |
| **Netherlands** | Salt, solid | 65–260 | Normal Treatment | Lefebvre (1993) |
| | $CaCl_2$ liquid | 16% prewet to solid salt | Not specified | Hernandez & Verburg (1997) |

| | | | | |
|---|---|---|---|---|
| **United Kingdom** | Salt, solid | 260–520 | Normal Treatment | Lefebvre (1993) |
| | Salt, solid | 130–260 | Preventive Treatment | |
| **Sweden** | Salt, solid | 260 | Normal Treatment | Lefebvre (1993) |
| | Salt, solid | 65–130 | Preventive Treatment | |
| **Switzerland** | Salt, solid | 195–260 | Normal Treatment | Lefebvre (1993) |
| | Salt, solid | 130–195 | Preventive Treatment | |
| | $CaCl_2$ flakes | 195–520 | Normal Treatment | |
| | $CaCl_2$ flakes | 195–390 | Preventive Treatment | |

Kentucky DOT reported using the same application rate on PPPs as they use on DGPs (Cooley et al., 2009). A four-state FHWA study of deicers on PPPs reported that Michigan and Vermont needed less salt on OGFC pavements than on DGPs, Maine found similar application rates were needed, and Utah found that only newer OGFC pavement needed higher application rates (Besselievre, 1979). Research on a full-depth porous asphalt parking lot in New Hampshire over two winters found as little as 25 percent of the standard application rate of salt (standard rate was 190 lb/LM) yielded the same snow and ice cover and friction improvement as a typical dense grade asphalt parking lot treated at the standard salting rate. Black ice due to lack of drainage of melt water on the standard parking lot was a consistent problem for several days after a storm, but the drainage provided by the porous pavement meant repeated salt applications were not needed (Houle, 2008). The applicability of this information to highways, however, is unknown.

**Retention of anti-icing chemicals**

Anti-icing salts have been shown to remain in the void space of PPPs and be available for frost prevention and ice melting considerably longer than salt on the surface of DGPs because over time traffic can remove the dry salt (applied as a solid, or evaporated from a brine application) from the surface (Noort, 1996; Greibe, 2002). South Dakota DOT has indicated SMA pavements retain liquid deicing agents in the pore space (Sorensen, 2011). Colorado DOT has found NovaChip pavements retain residual liquid deicers as well and caution against applying too much to avoid slickness issues (CTC & Associates, 2009). The retention of excess salt in a porous asphalt parking lot has been shown to reduce snow and ice buildup in subsequent events (Houle, 2008). Research conducted in the Minneapolis–St. Paul area found that porous surfaces generally inhibit refreezing of the pavement and promote snow melt (MacDonald, 2006). Research investigating chloride runoff through porous asphalt, porous concrete, and porous interlocking concrete pavers found that chloride flushed through the porous asphalt at the slowest rate and the researchers hypothesized this was due to the smaller pore spaces in porous asphalt relative to porous concrete and porous interlocking concrete pavers (Borst & Brown, 2013). Because chloride had the slowest release rate from the porous asphalt surface, it persisted at the higher concentrations in runoff later in the season

**Summary of International Experience**

A comprehensive scan tour of Europe provided the following input on PPPs and winter maintenance (Dibbs et al., 2005).

**Denmark** – The Danish Road Institute (DRI) reported using a wetted salt solution, where water is added to the salt at the back of the truck, for snow and ice control. DRI noted that black ice formation can be an issue, but that the wetted salt seems to work well and has the added benefit of leaving the top dry with a white coating, which seems to slow drivers. DRI also uses calcium chloride and wetted salt because they provide a more even distribution and prevent ice hats (surface freezing due to loss of salt into the porous pavement). They are looking into using larger grain salt to minimize this problem. DRI also noted that PPPs require 50 percent more salt and require more maintenance. DRI also noted that short sections of PPPs should be avoided as the zones can "spook" drivers.

**Netherlands –** The Dutch use signage, the news, weather reports, lane closures (direct two lanes onto one to assist in ice break-up), and anti-icing to manage PPPs during winter. About 50 percent more salt is required on PPPs. Black ice formation in the eastern part of the country has presented a challenge. They commonly use prewetted salt and apply it as the pavement begins to freeze.

**France –** France has had problems with PPPs freezing during the winter and generally do not use porous mixes east of Paris' meridian and at altitudes above 2,000 ft. France has observed black ice on PPPs and ultra-thin asphalt overlays. PPP surfaces have been found to fall below the frost point 30 minutes sooner than dense pavements. France uses a combination of dry salt, wet salt, wet salt enhanced with $CaCl_2$, and $CaCl_2$ brine depending on the pavement condition and preventive versus reactive maintenance.

**Italy –** The Italians reported up to a 50 percent increase in salt use for porous pavements in winter. Typically, a combination of $MgCl_2$ and $CaCl_2$ is used. It was noted that in Italy, the salt brine runoff is an environmental concern.

**United Kingdom –** The UK prefers to use thin, noise-reducing surfacing rather than PPPs because of clogging issues, raveling, short life span, and increased winter salt requirements.

### 2.3.4 Friction and Safety

Most friction testing on PPPs has primarily been conducted on dry or wet pavements, although some testing has also been conducted on PPPs during snow and ice conditions. PPPs generally have equal or better friction values than DGPs (Huber, 2000). Immediately after construction, PPPs tend to have slightly lower friction that quickly increases after the thin asphalt binder film on the surface is worn down by traffic. Continued trafficking can tend to reduce friction over several years due to polishing and abrasion of the exposed aggregate. This trend in friction has been observed by several researchers (Lefebvre, 1993; Isenring et al., 1990; Bishop & Oliver, 2001; Griebe, 2002). The results of long term skid resistance measurements (from 1973 to 1983) made on PPPs in the Netherlands are presented in Figure 4 as an example of this trend. PPPs generally have higher friction than DGPs at high speeds due to the pavement macrotexture, but friction may be lower at low speeds due to a lack of microtexture (Isenring et al., 1990).

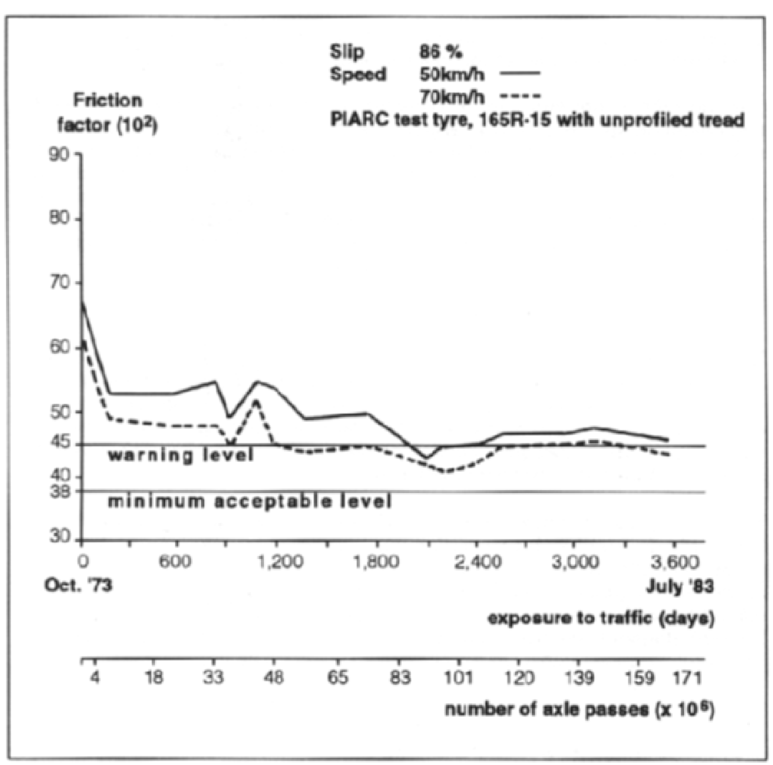



**Figure 4: An example of the decrease in skid resistance of a PPP over of time (Lefebvre, 1993).**

Friction testing in Oregon and Arizona on PPPs treated with anti-icers prior to a winter storm found no reduction in friction due to the anti-icers and the skid resistance was comparable to or greater than DGPs also treated with anti-icers (Martinez and Poecker, 2006). During their review of literature completed in 2006, Martinez & Poecker (2006) found no study conclusively linked anti-icing to reduced friction. A section of open graded pavement installed by Colorado DOT was thought to be responsible for increased winter accidents. And while an investigation revealed that the open graded pavement was reported to show a greater tendency to freeze than nearby DGPs, no accidents were specifically associated with the application of deicer on the open graded asphalt (Martinez & Poecker, 2006).

A few notable studies have evaluated friction of PPPs during winter conditions. Friction tests with a Skiddometer BV8 during winters from 1981 to 1986 in Switzerland found that skid values on PPPs are generally within the same range as DGPs. Isenring et al. (1990) found that other factors contributed to skid resistance more than pavement type, including microclimate, roadside vegetation, wind exposure, road width, altitude, and shading. Friction testing during two winter storms in February 2005 in New Jersey was conducted on two pavement types: 1) a ¾-in thick OGFC overlay constructed in 2001 with ½-in NMAS and 23% air voids, and 2) a ½-in thick NovaChip overlay constructed in 2000 with ½-in NMAS and 12% air voids (Bennert & Cooley, 2006; Bennert et al., 2005). These pavements were in the same vicinity with similar traffic and weather. During the storms they were treated with 350 lb/LM of rock salt prewet with $CaCl_2$ brine. The two pavements generally performed similarly; however, the NovaChip pavement had a slightly lower friction during the storm than the OGFC pavement. On both pavements, the lane with greater traffic volume showed less decrease in friction than the less trafficked lane. Friction measurements were correlated to both traffic (greater traffic → higher friction) and snow accumulation (more snow → lower friction). Limited testing also occurred on a typical DGP, which showed a much more significant reduction in friction than both the OGFC and NovaChip pavements. Interestingly, the DGP was also treated with salt brine in addition to the prewet rock salt, but as suggested by Bennert & Cooley (2006), the DGP may have had lower traffic volumes.

Porous pavements generally have higher friction values than dense pavements except when:

- The voids of porous asphalt are filled and permeability is reduced to 0.26 gal/min. In this case porous pavements were found to behave the same as dense asphalt with similar surface texture (Isenring et al., 1990).
- Porous pavement is covered with compacted snow. In this case, skid numbers were similar to dense pavement when also snow covered (Iwata et al., 2002; Bennert & Cooley, 2006).

The safety of PPPs in winter conditions can be maintained if they are appropriately treated (Lefebvre, 1993). In Japan, a comparison of traffic accidents on a road section with DGP that was later replaced with a PPP showed that the number of traffic accidents on icy or snow covered surfaces was lower by 34 percent for the PPP surface (Iwata et al., 2002). The following practices have been used successfully or have been suggested by researchers as best management tools to improve safety on PPPs.

- Providing signage for drivers at the transition zones between PPPs and DGPs (Noort, 1996).
- Alerting the media when unsafe conditions are present on PPPs so that the public can be informed (Noort, 1996)
- Passing out informational pamphlets on PPPs at border crossings (Noort, 1996).
- Providing frequent and timely road weather updates to maintenance agencies and the public (Litzka, 2002).
- Modifying speed limits and temporarily closing roads during severe weather on PPPs (Litzka, 2002).
- Using ice warning systems on PPPs (specifically related to humidity issues on porous pavements) (Greibe, 2002).
- Concentrating traffic to one lane or reducing speed limits to increase traffic on PPPs to encourage the pumping of liquid deicers from the void spaces to the road surface (Hernandez & Verburg, 1997).

### 2.3.5 Summary of Winter Maintenance on PPPs

Porous and permeable pavements present challenges and some advantages compared to DGPs during winter conditions, as summarized in Table 5. While there is some consensus regarding the behavior of PPPs during various winter conditions, recommendations regarding best winter maintenance practices are not clear and generally not quantified. Thus, there is a need for additional research in order to understand how deicers behave on PPPs and how that behavior affects various winter maintenance strategies.

**Table 5: Advantages and Disadvantages of PPPs during Winter Conditions**

| Advantages | Information Source |
|---|---|
| • Good drainage and macrotexture limit ice formation on wet surfaces | Houle (2008), Isenring et al. (1990) |
| • Ice formation within wheel paths covered in snow is reduced due to the macrotexture and permeability | Isenring et al., 1990 |
| • Friction values are generally the same or better than DGPs | Bennert & Cooley (2006), Huber (2000) |
| • Improved surface drainage, reduce glare and spray during wet conditions | Cooley et al. (2009), Bishop & Oliver (2001), Lefebvre (1993) |
| **Disadvantages** | |
| • Freezes sooner and for a longer period of time than DGPs | Greibe (2002), Noort (1996), Lefebvre (1993) |
| • Surface dries slower due to moisture trapped in the voids that is "pumped" to the surface by traffic, which can lead to icing when adjacent DGPs are dry | Greibe (2002), Noort (1996) |
| • Sanding is not recommended to improve friction because of the potential to clog PPPs | McCain & Dewoolker (2010), Noort (1996), Isenring et al. (1990) |
| • May require higher application rates of deicers or more frequent application of deicing chemicals | Cooley et al. (2009), Dibbs et al. (2005), Blackburn et al. (2004), Litzka (2002), Lefebvre (1993) |
| • May required more frequent application of deicers and for a longer duration than DGPs | Burns Cooley Dennis Inc (2009), Rogge (2002), Noort (1996), Lefebvre (1993) |
| • Snow and ice tend to stick to PPPs sooner because the surface is generally cooler and snow and ice remain longer because salts have dissipated from the pavement surface | Isenring et al. (1990) |
| • Preventative salting (anti-icing) is not as beneficial because the salt penetrates into the void structure; however, this is less problematic in highly trafficked areas or if larger salt grains are used | Noort (1996), Isenring et al. (1990) |
| • Icing problems can occur in the transition zones between PPPs and DGPs due to a lack of deicers being carried over by traffic | Noort (1996), Lefebvre (1993), Isenring et al. (1990) |

## 2.4 SUMMARY OF LITERATURE REVIEW

Porous and permeable pavements have been successfully used by multiple transportation agencies in several countries as a wearing surface to help reduce water splash and spray, increase friction, reduce potential for hydroplaning, and reduce noise. Despite their inherent advantages, when used in colder climates PPPs may tend to freeze more rapidly, transport deicing chemicals from the road surface, clog from sands and other debris, and retain snow and ice for a longer period of time. Porosity and texture tend to be the leading material properties of PPPs that affect their behavior in winter conditions and have been noted to be the primary causes of differences between PPPs and DGPs in winter conditions. Infiltration of water and deicing chemicals through the pores and pumping of water and salts to the surface from traffic are a direct result of the porosity of PPPs. The use of sand as a friction enhancement is not recommended because they tend to clog the pores and create additional and costly maintenance to restore the desired porosity of the pavement. The behavior of PPPs at lower temperatures is different than traditional DGPs because of the different thermodynamic properties associated with the pore space in these mixes. The coarser surface texture of PPPs can provide temporary storage of ice and snow on the surface during a storm, and if frozen, ice and snow become integrally keyed to the pavement surface making it more difficult to remove these deposits. PPPs have a longer history in Europe, and domestic sources of information on these types of pavements as they relate to winter maintenance is scarce and oftentimes conflicting. A more comprehensive and successful approach to the effective and economical winter maintenance of PPPs in the US is needed.

# CHAPTER 3: INTERVIEWS

Porous and permeable pavements (PPPs) often respond differently to winter conditions and snow and ice control treatment than dense graded pavements (DGPs). As noted in the CHAPTER 2: literature review, PPPs may tend to freeze more rapidly, clog from sand and other debris, retain snow and ice for a longer period of time, and require more frequent applications and higher application rates of deicers. While general information about winter maintenance of PPPs was available in the literature, there was a notable lack of detailed information regarding successful treatment strategies, particularly in the United States. Thus interviews were conducted with DOT personnel to determine the types of PPPs in use, problems with PPPs during winter conditions, and successful treatment strategies for dealing with snow and ice.

Interviews were sought with states that have PPPs and experience winter conditions. An email invitation was distributed to Clear Roads members and most interviews were conducted during July, August and September. Interviews with ten states were documented and are individually summarized below.

## 3.1 US STATES

### 3.1.1 Colorado

From September 2003 to 2005, Colorado DOT had a 0.5-mile section of open graded friction course in Denver that covered three lanes and adjacent shoulders. This section was located on a curve with an uphill slope and poor snow storage. Snow would accumulate on the shoulders, and pavement not in direct sunlight would oftentimes freeze. Snow accumulations on the shoulders would melt and flow across traffic lanes through the open graded friction course creating black ice. Accident rates on this section of roadway increased significantly (2.5 times higher (Schiebel, 2005)) leading to a temporary emergency placement of an overlay to cover the OGFC in December 2004 and then milling and paving with a dense graded Superpave mix in summer 2005. The issues with the OGFC pavement were primarily due to melting snow and icing; there were never issues with fresh snow on the road. Typical winter maintenance operations for this pavement included applications of 20 to 100 gal/LM of magnesium chloride, depending on conditions, which was the same application rate used on adjacent DGPs.

### 3.1.2 Kansas

Kansas DOT maintains about 1300 center line miles of UBAS (Ultra-thin Bonded Asphalt Surface), and about 15 miles of open graded pavement sections near Garden City and Pittsburg. Kansas has been using UBASs for about 10 years. Three target aggregate gradations are specified for UBAS, all with NMAS of ⅝ in., with Type B being the most common. Type A has less coarse aggregate and is used in District 4 due to a lack of materials for Type B or C. Original specifications for these mixes allowed the aggregate to consist entirely of limestone; however, polishing and decreased surface friction required modifications to the aggregate specification to include a minimum percentage of "durable stone."

Winter maintenance operations on the UBAS and open graded pavements include anti-icing, plowing and deicing using salt, salt brine, prewet sand, and sand/salt mixtures. Kansas DOT generally uses the same or similar treatments for all pavement types; however, they modify their approach to improve winter maintenance strategies on their open graded pavements. For example, winter maintenance personnel apply the initial pretreatment of salt brine at a higher application rate for open graded surfaces. To accomplish this, Kansas DOT uses different nozzle types for varying pavement surfaces. Flood nozzles are used on the UBAS to get more brine down into the pavement and to provide more surface coverage, while stream nozzles are used on regular asphalt surfaces. When the stream nozzles were used on the UBAS there was less spreading and tracking of the product because it quickly drained into the porous structure of the open graded surface. The general strategy of Kansas DOT is to use the FHWA Manual of Practice for Anti-icing (Ketcham et al., 1996) as a general guideline to determine initial application rates, but to increase these rates until adequate performance is attained.

Comments from Kansas DOT field staff indicated that it takes longer to remove ice from open graded surfaces, for two reasons. One, the bond between the snow/ice and pavement is stronger, and two, the deicing liquids infiltrate into the pavement surface leaving less chemical to help break or weaken these bonds. However, they have noticed that residual chemicals in the pavement pores help weaken ice–pavement bonds for subsequent storms. Kansas DOT indicated that the UBAS pavements yield good overall structural performance and have good life-cycle costs, but indicated that they are dissatisfied with its behavior with respect to snow and ice removal. In areas where UBAS is used to overlay the driving lanes and chip seals are used on the shoulders, differences in elevation between the two surfaces (up to ⅝ in.) can cause non-uniform plow blade wear due to the harder aggregates in the UBAS (blade wear in general is also worse on UBAS roads). Differences in shoulder elevation also make it more difficult to clear snow from the shoulder, and on super elevated curves water can accumulate and freeze or flow through the open graded pavement and resurface in the travel lanes.

### 3.1.3 Massachusetts

Massachusetts DOT has OGFC pavements on almost 60 percent of their interstates and limited access highways. OGFC mix designs use a NMAS of ⅜ in. and an estimated porosity of about 15–17 percent. A latex modified Superpave binder is used, typically at 6.3 percent by weight for the pavement mix. The thickness of the wearing surface is currently 1 in. MassDOT also uses ultra-thin bonded wearing courses on sections of several interstates, and indicated that these overlays behave similar to OGFC. An informal crash analysis conducted by a state pavement engineer, based on different types of pavements, found that crash rates were lower on the OGFC surfaces. This result was thought to be attributed to drivers traveling slower on OGFC pavements because it appears to be snow covered longer—that is, the voids are packed with snow but the pavement macrotexture protrudes and provides traction. The OGFC wearing course typically lasts about 14–15 years, although some areas have failed at 10 years and others lasted as long as 22 years. OGFC pavements in Massachusetts are not cleaned and partial clogging does occur, although they generally still perform well (shed water and are quieter than DGPs). However, observations of a 24-mile section on I-95 milled after a service life of 12 years showed significant winter sand trapped within the pavement matrix, thought to be purposefully heavily applied with the intent of clogging the pavement to make snow and ice control easier.

### 3.1.4 Minnesota

MnDOT has evaluated the performance of porous pavements in its Low Volume Road segment of the MnROAD facility that is trafficked by a five axle loaded semi-truck. Sections of full-depth porous asphalt pavement, full-depth pervious concrete pavement, and a 4-in-thick porous concrete overlay over an existing PCC pavement have been constructed and monitored. The objective of the research was to determine the performance of porous pavements on low volume roads for potential deployment in urban environments – not for higher traffic volume applications (e.g., highway).

The MnRoad sections were not really a good test of winter maintenance performance and activities. The test sections do not experience typical traffic and do not receive typical snow and ice control treatments; however, temperature profile information and information on clogging and vacuuming practices were obtained and reported by Izevbekhai & Akkari (2011) and Lebens & Troyer (2012). The porous pavements with a granular subgrade are performing better than the ones over cohesive subgrade. There is currently a project funded through Minnesota's Local Road Research Board and contracted to Lev Khazanovich of the University of Minnesota to develop a user guide for pervious pavements with regard to hydrology and pavement design.

### 3.1.5 Missouri

Missouri DOT's most common PPP is a nonproprietary NovaChip referred to as UBAWS (ultrathin bonded asphalt wearing surface). A permeable diamond-grooved asphalt pavement also exists, but is not commonly used. UBAWS is used as a preventive maintenance treatment to help extend the life of pavements less than 10 years old in good condition but are beginning to crack. Three aggregate gradations are specified (Types A, B, and C with NMAS of ½, ⅝, and ¾ in., respectively) with Type A being the most costly and least used, and Type C the most commonly implemented. In urban areas, UBAWS pavements are placed on the entire shoulder; in rural areas only 2 ft of the shoulder is paved with UBAWS (the rest of the shoulder may be chip sealed). Cracks at seams have been reported with large pieces becoming dislodged from traffic and moisture. An underseal has been shown to effectively mitigate cracking at the joints.

UBAWS pavements perform very well in rainy conditions by effectively moving water off the road surface and research on a test plot showed a reduction in accidents. The rougher surface offers some benefits during winter, but problems have been reported. Snow and ice tends to melt quickly but it can refreeze quickly. Water reportedly gets trapped in the pores of the pavement and tends to dilute the salt, contributing to refreeze. More accidents have been observed at the transition zones between DGPs and UBAWS pavements. UBAWSs also reportedly result in increased plow blade wear when compared to DGPs.

Generally, Missouri DOT pretreats the pavement before storms using a sand/gravel/salt/cinders mixture with a salt concentration of less than 50 percent. The application rate depends on pavement temperature and weather conditions. For example, for temperatures below freezing an application rate of 250 lbs/LM is used but as temperatures decrease application rates up to 350 lbs/LM prewet with Geomelt may be used. Some Missouri DOT personnel have reported increased application rates and more frequent applications are required on UBAWS overlays, especially for new pavement and high speed roads; however, after three to five years or on low speed roads application rates and numbers of applications are more similar to DGPs.

### 3.1.6 New Jersey

New Jersey has OGFC pavements located sporadically throughout the state. Three aggregate gradation specifications exist, a ½ in NMAS with 15% air voids, a ¾ in NMAS with 20% air voids, and a ½ in NMAS with 18% air voids.

According to NJDOT winter maintenance personnel, OGFC pavements require greater anti-icing application rates and significant issues have been observed on newly constructed OGFCs, which have been attributed to the open structure and high air void content. During snow and ice events OGFC pavements appear to remain colder and stay snow covered longer than DGPs; however, friction measurements have indicated that the surface friction was satisfactory. Winter maintenance staff treat new OGFC pavements with sand/abrasives during the first couple years to purposefully decrease the void space and have noticed that by the third year OGFCs tend to perform similarly to DGPs during winter storms. Even with the reduced porosity the OGFC pavements continue to offer drainage and noise-reducing benefits, and winter maintenance staff suggest reducing the target air void requirements to improve winter maintenance without sacrificing drainage performance. Typical winter maintenance products used by NJDOT include salt brine, salt and calcium chloride brine blend, and sand. They have also tried adding more viscous ag-based deicers to their liquids, hoping it would stay on the road surface better but the results were inconclusive. They might try adding pine tar/pitch for the same reason based on a presentation at the Winter Maintenance Peer Exchange regarding this issue.

### 3.1.7 New York

New York DOT has a generic specification for a NovaChip type of pavement referred to as paver placed surface treatment (PPST). Three specifications exist, Type A, B, and C with NMAS of ⅜, ½, and ¾ in, respectively. About four to five projects each year use the PPST (about 30–40 lane miles total). Types B and C are the most common, but NYDOT is increasing their use of Type A.

NYDOT does not have pavement-specific guidelines for winter maintenance. They typically anti-ice with salt brine and follow up with applications of road salt. Sanding and deicing with liquids is generally avoided. While NYDOT is generally trying to reduce application rates across the state, the PPST tends to require a greater amount of salt than DGP during its first year.

Increased vehicle accidents on PPST sections were noted during dry, cool humid days on areas with salt residue. Even with the large amount of salt residue, moisture was freezing on the surface and decreasing surface friction. In fact, a NYDOT employee slipped and fell after getting out of the vehicle during a routine inspection, even though the road surface appeared dry.

### 3.1.8 Virginia

Virginia DOT has OGFC and other gap-graded pavements. The ⅜ and ½ in NMAS porous friction courses have a minimum of 16 percent air voids. Some projects incorporate asphalt rubber for better noise-reducing benefits. Standard winter maintenance includes anti-icing with salt brine at 36 gal/LM and deicing with solid salt at 325 to 600 lb/LM depending on snow depth, regardless of pavement type. However, VDOT noticed frequent icing problems with porous pavements and noted that snow frequently bonds to the pavement even after anti-icing activities. It was presumed that liquid deicers drained through the pavement and they have started trials with ChemShield a resinous (pine tar/sap) product that may help anti-icers adhere to the road surface better. During preliminary trials ChemShield was mixed with calcium chloride and sodium chloride and found that deicers stay on the road for 7–14 days longer; however, there have been issues with blending, bursting hoses, and nozzle flow rates. Additionally, ChemShield is expensive (~$500 for 30 gallons) and can only be applied during daylight hours because it is activated by sunlight.

### 3.1.9 Washington

Washington State DOT has a very limited amount of permeable pavements. A 10-yr old section of NovaChip has performed well, but does not require snow and ice control. OGFC has been implemented on a limited basis and has generally been plagued with problems related to poor compaction and surface wear. Anecdotal evidence indicates ice formation in OGFCs and greater applications of deicing chemicals are required.

### 3.1.10 Wyoming

Wyoming DOT uses an open graded plant mix wearing coarse on most two-lane roads. The NMAS of the crushed aggregate in the wearing coarse is ⅜ in and the porosity is not measured. Wyoming also has a few sections of NovaChip. Winter maintenance on the permeable pavements is the same as DGP and generally consists of plowing, sanding and deicer applications. Anti-icing at 35 gal/LM with salt brine or 60 percent salt brine/40 percent Geomelt during cold months is performed to delay snow accumulation and allow for better clearing after the storm. During and post storm sand applications contain 10 percent salt and may be prewet at 4–6 gal/ton with salt brine or salt brine/Geomelt. No difference has been observed between the permeable pavements and DGP during winter conditions. Wyoming DOT has also not observed a noticeable loss of liquid product while anti-icing, and also no problems with drainage/pavement performance during wet weather despite the heavy use of sand in the winter. The gradation specification for abrasive sands is broad (100% passing ⅜ in., 95–100% passing No. 4, and 0–12% passing No. 200) and Wyoming DOT has several different sources stockpiled. Material from riverbed sources tends to be good quality sand with less than 10 percent finer than the No. 50 sieve; however, they frequently get sand from bench pits and hopper reject that tends to be dusty and can have more than 30 percent finer than the No. 50 sieve. They suspect this dusty sand is able to pass right through the open graded wearing coarse and not clog the pores.

## 3.2 INTERNATIONAL INTERVIEWS

Interviews via email and LinkedIn were conducted with people from Italy, Japan, Norway and Sweden to determine current winter maintenance practices on PPPs internationally.

### 3.2.1 Italy

A LinkedIn communication regarding liquid calcium chloride, at 25–27% $CaCl_2$, on porous pavements indicates in Italy application rates are increased by 30–50 percent on PPPs because of drainage. Translation inaccuracies make additional details difficult to understand, but seem to indicate that on impermeable roads the lowest application rates are needed for preventive treatments, and they are tripled to remove snow and quintupled to remove ice. These rates are increased by 30–50 percent if the road surface promotes drainage, as is the case for PPPs.

### 3.2.2 Japan

Japan has a network of expressways with a significant portion of PPPs, up to 70 percent coverage in some areas. PPP surfaces were implemented to improve skid resistance on wet road surfaces. The interviewee is familiar with concerns about the durability of PPPs in cold regions and suggests the highly viscous bitumen used in Japan with Styrene Butadiene Styrene rubber (SBS rubber or SBR) contents of at least 8 percent improves the pavement's resistance to stripping. This is in contrast to the lower amounts used in the US (e.g., 3 percent in Massachusetts' OGFC). In response to inquiries about winter maintenance on PPPs, the interviewee directed our attention to a 2002 conference paper (Iwata et al., 2002) that addresses several concerns about PPPs. While already included in the literature review, the following are worth reiterating regarding PPPs (with about 20 percent porosity) and conventional dense graded pavements (DGPs) in Japan:

- surface temperature is about 0.4°F cooler on PPPs than conventional dense pavement during snowfall, although the temperature difference is more pronounced above 34°F,
- road condition during snowfall is not significantly different between PPPs and DGPs,
- the skid resistance of PPPs is greater than DGPs, even with the presence of frost on the PPP surface, and
- increased quantities of anti-icers are needed on PPPs, according to some road administrators.

### 3.2.3 Norway

Norway has two types of porous asphalt pavement with maximum aggregate size of 16 mm (similar to the ⅝ in mix common in the US) and 11 mm (somewhere between the ⅜ and ½ in mixes used in the US).

The PPPs reduce noise, although it is considered a temporary benefit because clogging causes an increase in noise levels and widespread use of studded tires increases wear and contributes to clogging. Generally porous asphalt is considered to be beneficial with regard to winter friction, at the same time, requiring greater application rates of salt when it is applied.

### 3.2.4 Sweden

Whereas sand is used in Sweden on snow-covered pavements during long-lasting cold temperatures, it is generally not applied on porous asphalt because of the potential to clog the pavement. Increased application rates are needed, though not quantifiably known.

## 3.3 SUMMARY OF INTERVIEWS

Most states that were interviewed have noticed that PPPs perform differently during winter than traditional DGPs, excepting Wyoming. This could be due to Wyoming's consistently cold temperatures and relatively dry climate, whereas locations that experience frequent freezing/thawing cycles or temperatures that often remain near freezing notice problems with drainage and icing of melt water. Problems with PPPs identified during the interviews include:

- ice formation on pavement and in the pores;
- pavement remaining/appearing snow-covered longer than DGPs;
- increased anti-icing and deicing application rates, most notably with newer pavements; and
- increased wear to plow blades.

A summary of the findings of the interviews is shown in Table 6. Two strategies identified during the interviews for improving the performance of liquid deicers include using different nozzles for liquid applications (flood nozzles instead of stream nozzles) and using a resinous anti-icer adherent (e.g., ChemShield). While the literature review found sanding was generally not recommended, gradations with more fine sand may limit clogging. Within a few years of placement PPPs tend to behave similarly to DGPs during winter, potentially due to reduced porosity. Thus constructing PPPs with less air voids may mitigate difficulties with winter maintenance without sacrificing the documented benefits of PPPs during rain events.

**Table 6: Summary of Findings from Interviews**

| State | Pavement Type | Observations or Problems | Actions or Solutions |
|---|---|---|---|
| CO | OGFC | • Refreeze of meltwater<br>• Increased accidents | • Milled and replaced with DGP |
| KS | UBAS<br>OGFC | • Anti-icers infiltrating<br>• Stronger ice–pavement bond<br>• Meltwater flow<br>• Increased plow blade wear | • Increased anti-icing application rate<br>• Used flood nozzles |
| MA | OGFC | • Appears snow-covered longer<br>• Lower accident rates | |
| MO | UBAWS | • Refreeze of meltwater<br>• Increased plow blade wear<br>• More accidents at transition zones | • Increased deicer application rates<br>• More frequent applications |
| NJ | OGFC | • Remains colder longer<br>• Remains snow-covered longer | • Treated new pavements with sand to decrease porosity<br>• Want to try ChemShield |
| NY | PPST | • Icing (even without precipitation, on cool humid days) | • Increased salt applications during first year |
| VA | OGFC | • Frequent icing<br>• Ineffective anti-icing | • Used ChemShield with anti-icers |
| WA | OGFC | • Ice formation | • Greater applications of deicers |
| WY | OGFC<br>NovaChip | • No differences observed | • Some winter sand sources are finer—may pass through without clogging |
| Italy | Porous | • Drainage of liquid $CaCl_2$ | • Increase application rate by 30–50% |
| Japan | Porous | • Cooler surface temperature<br>• Higher skid resistance | • Increased anti-icer application rates |
| Norway | Porous | • Quieter pavement<br>• Higher winter friction | • Increased salt application rates |
| Sweden | Porous | • Can't use sand | • Increased chemical application rates |

# CHAPTER 4:  LABORATORY TESTING

Porous and permeable pavements (PPPs) often respond differently to winter conditions and snow and ice control treatment than dense graded pavements (DGPs).  Key findings from the literature review and telephone interviews were used to design a laboratory test to compare the effectiveness of snow and ice control chemicals using a DGP made in Montana and several PPPs (from Missouri, New York and Massachusetts).  The laboratory test methodology (equipment, steps) are described, followed by results and a statistical analysis of the data.

## 4.1 LAB TEST METHODS AND RESULTS

Laboratory tests were conducted at the Subzero Science and Engineering Research Facility (SSERF) at Montana State University, in the *Cold Structures Testing Chamber* at a temperature of 28°F.  Information gathered in literature and from interviews indicated PPPs are more problematic at temperatures just below freezing (27–32°F).

### 4.1.1 Pavements

A series of laboratory tests were conducted on samples of DGPs and PPPs to simulate winter storms and determine the effectiveness of salt in reducing or preventing the snow–pavement bond and improving the friction of the road surface.  The DGP (referred to as DGP-mt) was made at a field site in Montana.  Two ultrathin friction course (UTFC) pavements were made in a laboratory from pavement mix supplied by New York and Missouri (referred to as UTFC-ny50i because it utilized 0.5 in aggregate and UTFC-mo75i because it utilized 0.75 in aggregate).  Two open-graded friction course (OGFC) pavements were made from cores of in-service pavements in Massachusetts (referred to as OGFC-ma5 and OGFC-ma2 because the pavements had service lives of 4-5 years and 1-2 years, respectively).  All pavement samples were permanently mounted with epoxy onto a rigid aluminum plate to ensure stability during cleaning and storage at warmer temperatures.  A summary of the pavement samples used for laboratory testing is in Table 7.

**Table 7: Pavement Specimens Used in Lab Tests**

| Pavement ID | Number of replicate samples | Source of Pavement Mix | Pavement type | Age | Size (in) |
|---|---|---|---|---|---|
| DGP-mt | 2 | MT | Dense-graded pavement | Old* (>4 yrs) | 9 x 19 x 1 |
| UTFC-ny50i | 2 | NY | Ultrathin friction course | New | 6 x 17 x 0.75 |
| UTFC-mo75i | 2 | MO | Ultrathin friction course | New | 6 x 17 x 0.75 |
| OGFC-ma5y | 1 | MA | Open-graded friction course | Old (>4 yrs) | 8.1 x 20 x 1.25 |
| OGFC-ma2y | 1 | MA | Open-graded friction course | New (< 2 yrs) | 8.1 x 20 x 1.25 |

* Pavement was newly made, but “aged” by lightly abrading the surface.

The DGP-mt pavement samples were made in Belgrade, Montana at a hot mix asphalt batch plant (Knife River Corporation – Belgrade Division). A large wood form with a depth of 1 inch was made by WTI staff and set up near the batch plant. Knife River produced, placed and compacted the hot mix asphalt (Figure 5, left). The asphalt mix had a nominal maximum aggregate size of ⅜ inch (some states refer to this as a 9.5 mm Superpave HMA), PG 58-28 asphalt binder, and air void content of 4.2%. A mix with ⅜ inch aggregate is common for 1-inch overlays (a very common pavement maintenance strategy), whereas 1½ and 2 inch overlays typically use asphalt mixes with aggregates up to ⅝ or ¾ inch. The pavement mix was compacted with a steel drum roller, without vibration. Samples measuring 9 inches by 19 inches were cut from the pad (Figure 5, right) and "aged" by lightly abrading the pavement surface with an angle grinder to expose the aggregate and make surface roughness and texture similar for all pavement samples (Figure 6).

**Figure 5: DGP compacted in wood form (left) and cutting samples (right).**

**Figure 6: DGPmt pavement specimen after surface grinding.**

The ultra-thin friction course pavements were made at the Highway Sustainability Research Center (HSRC) at the University of Massachusetts Dartmouth with a PReSBOX Asphalt Prism Shearbox Compactor using asphalt pavement mix collected from construction sites in Missouri and New York. Hot mix asphalt from these two sites was collected and shipped to HSRC for reheating and compaction. The PReSBOX compacts a pavement mixture that is 6 inches wide, 17.7 inches long, and 6 inches thick. From this, two samples were cut with “virgin” surfaces (the top and bottom of the beam) that were 6 x 17 x ¾ inches. The New York (UTFC-ny50i) hot mix was collected from a paving site on Rte 394 in Chautauqua County during September 2013 (Figure 7, left). The NovaChip Type B mix has a maximum aggregate size of ½ inch. The Missouri hot mix (UTFC-mo75i) was collected from a paving site on US 61 near St. Charles, MO (Figure 7, right). The ultrathin bonded asphalt wearing surface (UBAWS) Type C mix has a maximum aggregate size of ¾ inch.

**Figure 7: Ultrathin friction course pavements made with pavement mix from New York with ½ inch max aggregate (left) and Missouri with ¾ inch max aggregate (right).**

The open-graded friction course pavements were made from cores of two in-service pavements in Massachusetts. Ten 6-in diameter cores were collected from each site during April 2016. The pavement sample named OGFC-ma2y was from I-93 near Braintree, MA and had been in-service for 1.5 years (Figure 8). The pavement sample named OGFC-ma5y was harvested from I-95 near Woburn, MA and had been in-service for 4.5 years (Figure 9). The 4-in thick cores were shipped to WTI where they were sliced to a uniform depth of 1.25 in and the edges trimmed to form squares with 4 in sides. Ten of these squares were epoxied onto an aluminum plate to provide a level 8 x 20 x 1¼ in pavement specimen.

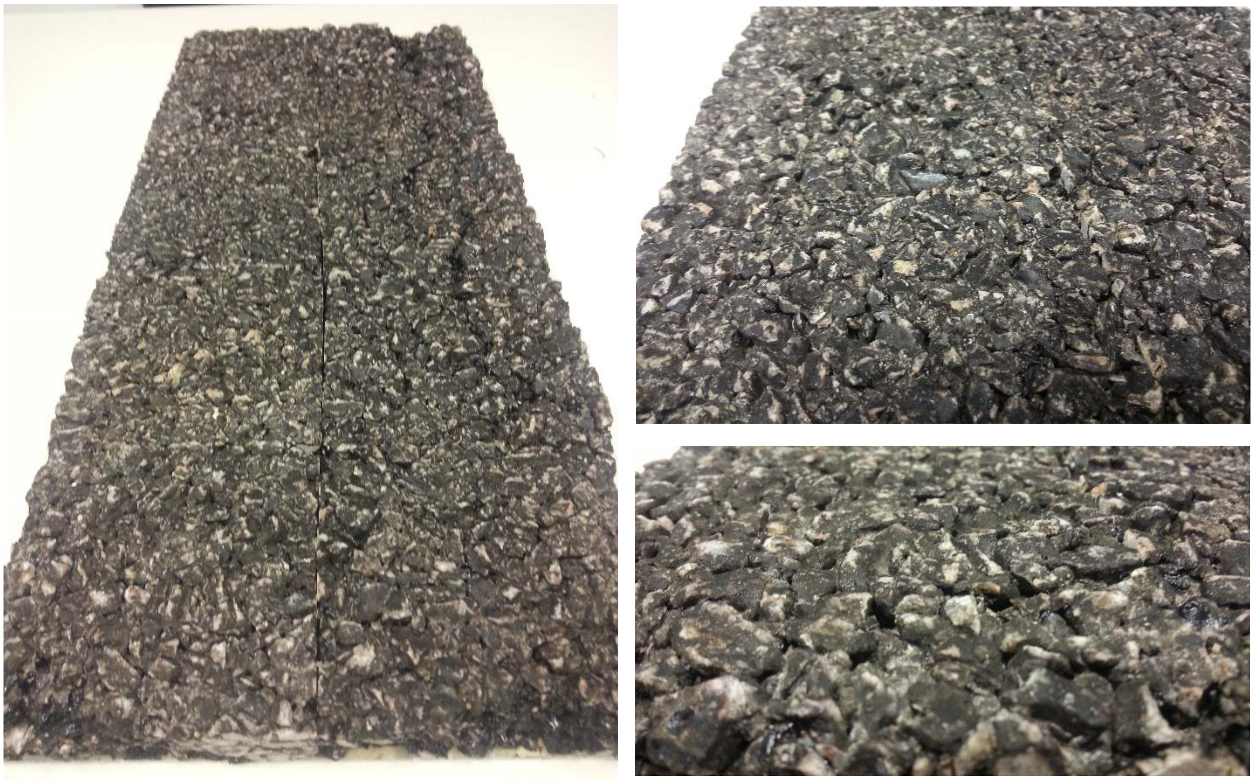


Figure 8: Open-graded friction course pavements from Massachusetts cores (OGFC-ma2y).

Figure 9: Open-graded friction course pavement from Massachusetts cores (OGFC-ma5y).

### 4.1.2 Sequence of Steps during a Lab Test

Four types of lab tests were conducted, distinguished by when and how salt (sodium chloride) was applied. The tests in which no salt was applied are referred to as the controls, and can be used to compare the effectiveness of deicing and anti-icing with salt. The sequence of steps during each of the four types of tests is shown in Table 8. Details of each activity (applying snow, applying salt, trafficking, and measuring snow–pavement bond and friction) are described next. All pavement samples were rinsed, scrubbed and dried before being placed back in the cold chamber.

**Table 8: Sequence of Steps for Lab Tests**

| Control (No Salt) | Anti-icing (Salt Brine) | Deicing (Dry Salt) | Deicing (Pre-wet Salt) |
|---|---|---|---|
| 1. Measure friction | 1. Measure friction | 1. Measure friction | 1. Measure friction |
| | 2. Apply salt brine | | |
| 2. Apply snow | 3. Apply snow | 2. Apply snow | 2. Apply snow |
| | | 3. Apply dry salt | 3. Apply pre-wet salt |
| 3. Traffic | 4. Traffic | 4. Traffic | 4. Traffic |
| 4. Measure snow–pavement bond | 5. Measure snow–pavement bond | 5. Measure snow–pavement bond | 5. Measure snow–pavement bond |
| 5. Measure friction | 6. Measure friction | 6. Measure friction | 6. Measure friction |

### 4.1.3 Snow Application

Snow was made by SSERF staff in the *Cold Hydrodynamics Chamber* at MSU using a constructed system with a high humidity cold- temperature chute. Snow crystals form on strings and drop into a tray. Snow was collected from the tray and stored in insulated coolers in the *Experiment Preparation and Instructional Chamber* (Figure 10). The air temperature during snow-making was -13°F and in storage was 5°F, which produces "drier" snow. The decision to make snow rather than collecting natural deposits from the field was to ensure consistency, which is critical for comparing lab tests which were conducted over a long period of time. The snow used in laboratory tests was stored for at least 4 days and not more than 4 months to ensure consistency in morphology of grain structure.

**Figure 10: Snow making process and snow storage.**

At the beginning of each day of testing, manufactured snow was carried to the *Cold Structures Testing Chamber* in an insulated cooler for that day's use (any extra snow was discarded and not returned to storage) and equilibrated to 28°F. The snow was sieved through a 1 mm mesh which breaks the bonds between the individual snow particles, and encourages sintering and bonding of the snow to the pavement surface. The loose, sieved snow had an average density of 19 lb/ft$^3$. The pavement sample was placed in a specially designed and constructed compaction box and 1.8 lb of sieved snow was evenly distributed across the surface. The loose depth of snow was about 0.75 in thick. The lid of the box was fitted with a flexible and soft rubber bladder to apply a uniform compactive stress directly to the surface of the snow. The bladder assembly was filled with compressed air at 60 psi for 5 minutes to compact the snow onto the surface of the pavement. The compacted depth of snow was about 0.5 in. The process of snow application and compaction is illustrated in Figure 11.

**Figure 11: Snow application and compaction sequence (top left: pavement sample in compaction box; top right: snow being re-sieved; bottom left: lid closed during compaction; bottom right: compacted snow).**

### 4.1.4 Salt Application

Deicing and anti-icing tests were conducted where deicing tests used solid rock salt applied on top of compacted snow and anti-icing tests used salt brine applied to the pavement surface before snow application. Sodium chloride was used because it is the most widely used product, particularly at temperatures of 28°F. Anti-icing tests were conducted by applying salt brine (23.3% solution with specific gravity of 1.179, verified with a hydrometer) to clean, dry pavement samples at a rate of 50 gallons per lane mile. Salt brine was applied using a calibrated paint sprayer fitted with a nozzle that produced a very fine spray. A clear chamber was used to prevent the wind in the lab chamber from affecting the spray during application (Figure 12). Application rates were validated frequently by spraying onto parchment paper and weighing the mass of salt brine on the paper. The salt brine was allowed to dry onto the pavement surface before continuing with the next step of the experiment (Figure 13), which took approximately 15 minutes.

Figure 12: Enclosure and sprayer for anti-icing pavements.

Figure 13: Close-up of a pavement sample after applying salt brine (left) and after drying (right).

Two types of deicing tests were conducted, using either dry rock salt or pre-wet salt. The solid rock salt was sieved to ensure similar sized particles were applied across the samples. All salt particles passed the No. 8 sieve and were retained on the No. 10 sieve. Individual salt particles were applied in a grid pattern with 1 inch spacing between particles across the entire pavement sample corresponding to a rate of 250 lb/LM. The total mass and number of salt grains varied based on the size of the pavement samples. Experiments with pre-wet salt used the same number and mass of salt particles as the dry salt experiments; however, salt brine was mixed onto the salt at a rate of 10 gal/ton just prior to applying the salt to the pavement. Photographs after deicer application indicate the salt particles penetrated through the snow and spread out under the snow (Figure 14).

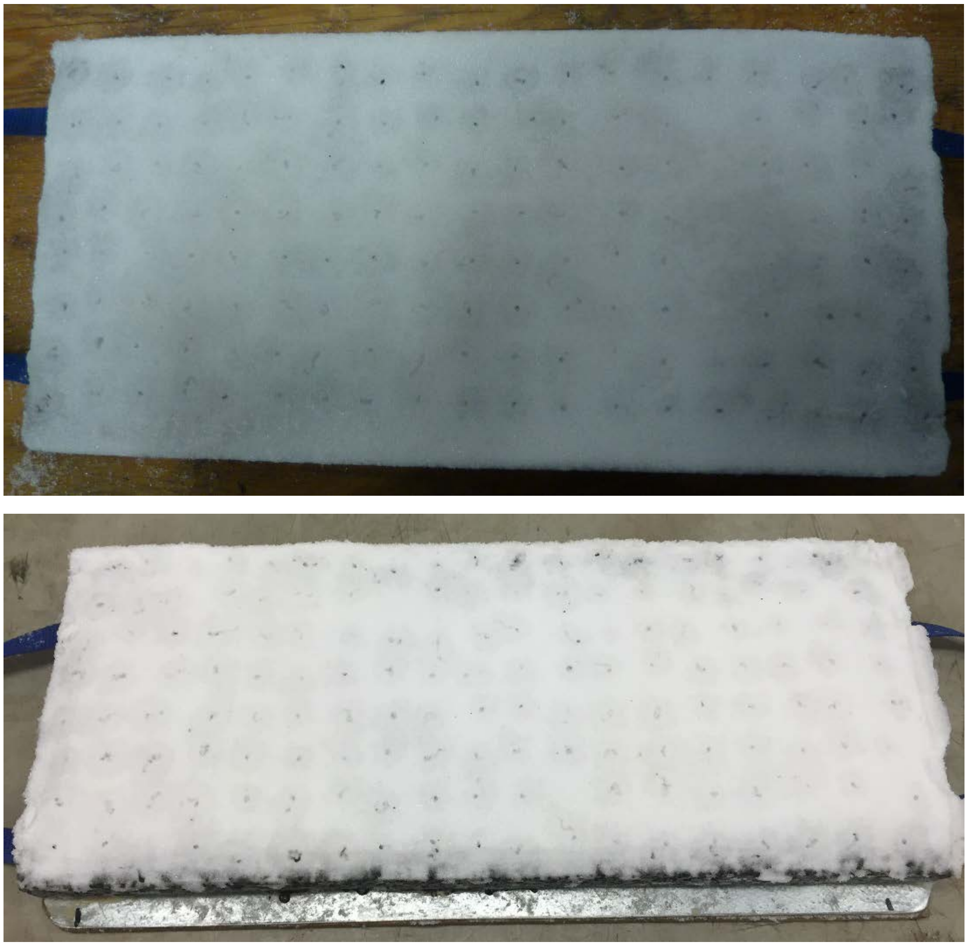


**Figure 14: Five minutes after deicing (upper: DGP with dry salt; lower: OGFC with pre-wet salt).**

### 4.1.5 Traffic Simulation

To simulate vehicle traffic in the laboratory, the pavement samples were trafficked using a custom built automated trafficking machine (Figure 15). Pneumatic cylinders apply load onto an axle fitted with a single tire, which presses down onto the pavement samples. The load applied to the pavement samples was 1,130 lb. The wheel assembly is stationary and a platform containing the sample translates back and forth under the tire, causing the tire to rotate. During testing the track moved at a speed of about 0.7 mph (1.0 foot per second). Traffic simulation occurred after snow compaction during control and anti-icing tests. During deicing tests, traffic simulation occurred 5 minutes after the last salt particle was applied to the snow. The samples were trafficked for 600 single tire passes (equivalent to 300 2-axle vehicles passes of a single tire on the pavement sample), which took 18 minutes. Photos of a pavement sample during a deicing test before and after trafficking are shown in Figure 16.

**Figure 15: Simulated trafficking device.**

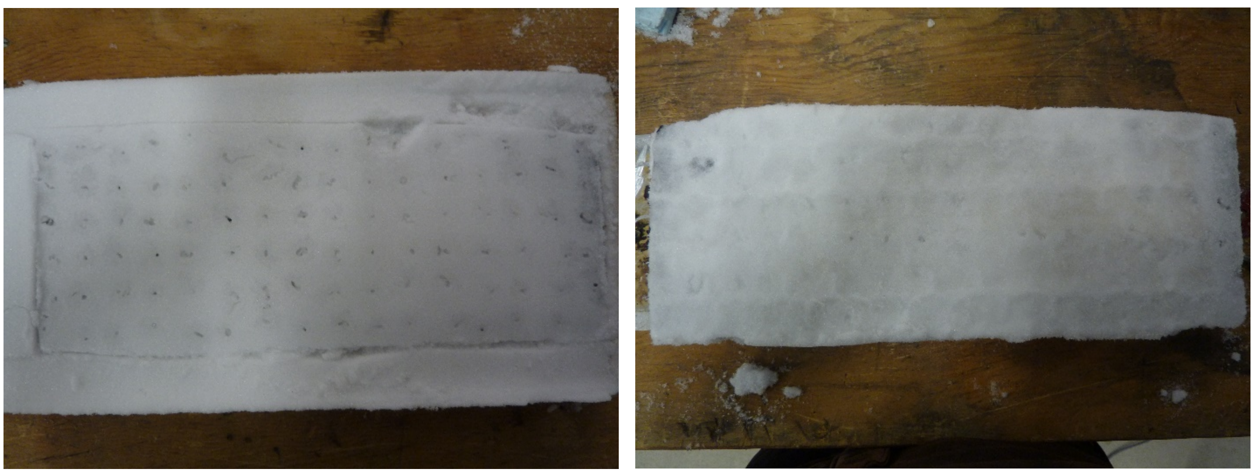


**Figure 16: UTFC-ny sample during a deicing test with dry salt before and after trafficking.**

### 4.1.6 Measurement of Snow–Pavement Bond

The shear force required to plow the snow from the pavement surface was measured to investigate the effect of deicing and anti-icing on the snow–pavement bond. After trafficking, individual sections of snow were isolated by cutting the snow with a serrated saw and carefully removing snow adjacent to intact 2-in square specimens. A hollow metal box was placed around the specimen and pulled horizontally using a spring scale to measure the maximum force required to shear the snow from the pavement. The process of isolating the snow specimens for shearing and shearing the sample from the pavement is shown in Figure 17. The number of shear tests varied for each type of pavement based on the size of the pavement sample. The larger area of the DGP and OGFC pavements accommodated 10 snow specimens, while only five samples fit on the smaller UTFC pavements.

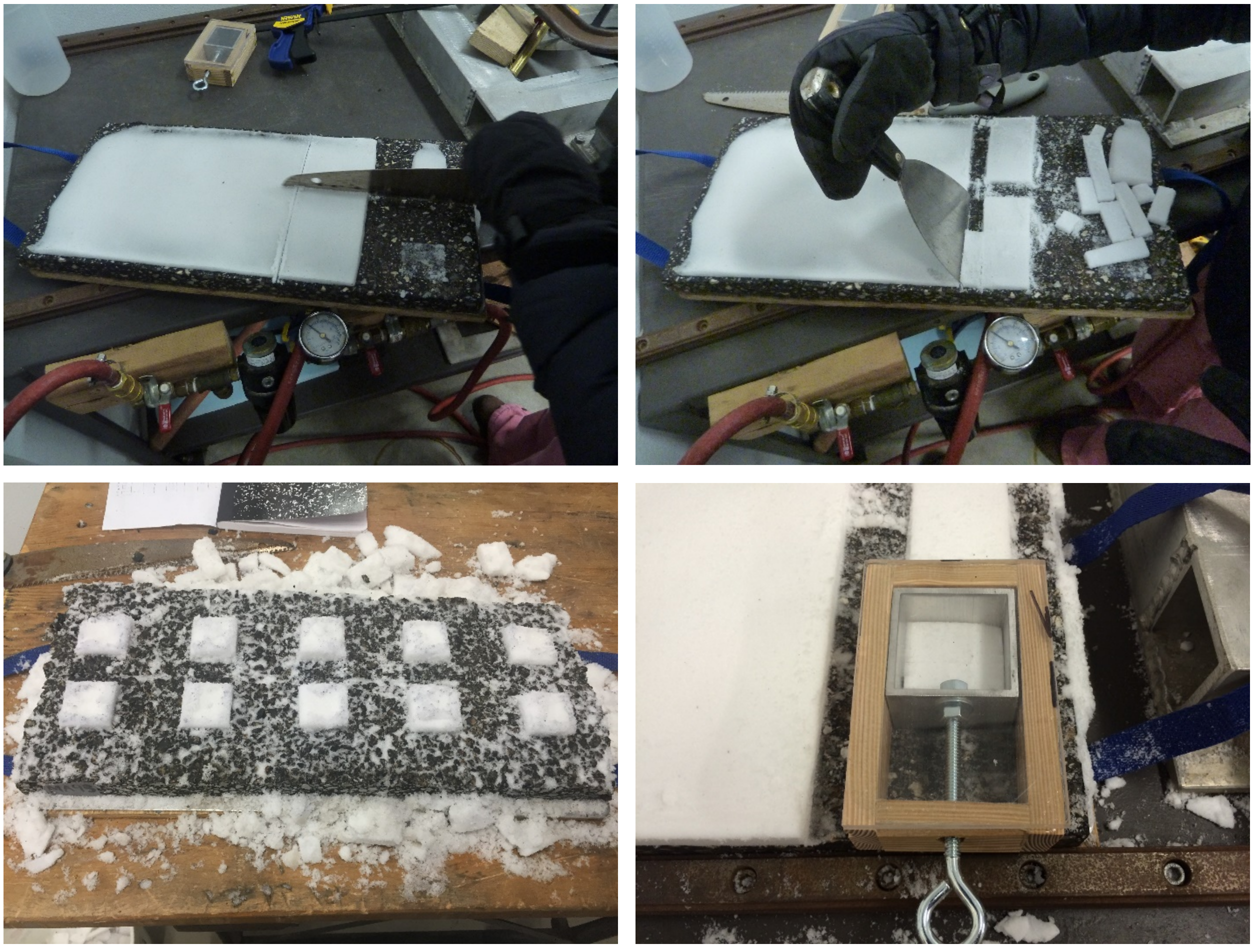


**Figure 17: Measuring snow-pavement bond by sawing and isolating snow samples for shearing and using a hollow metal box for plowing.**

Theoretically, weaker snow-pavement bonds should be more easily plowed, while stronger bonds should be more difficult to plow; however, specific limits of snow bond are not established, and direct correlations between the snow-bond measured in the laboratory and actual plowing stresses on roadways were not made. Thus, all snow bond measurement results should be viewed as relative comparisons to one another used to help understand how the various treatments affect the bonding of snow to the pavement. The results of snow-bond measurements for all tests are shown in Figure 18. Average snow bond ranged from about 0.5 to 10 psi. For a single pavement type, control tests with no salt generally had higher snow bond values than tests with salt. A statistical analysis was used to determine whether differences in snow-bond between pavement types and treatment types were statistically significant. The results of this analysis are presented and discussed in the next section.

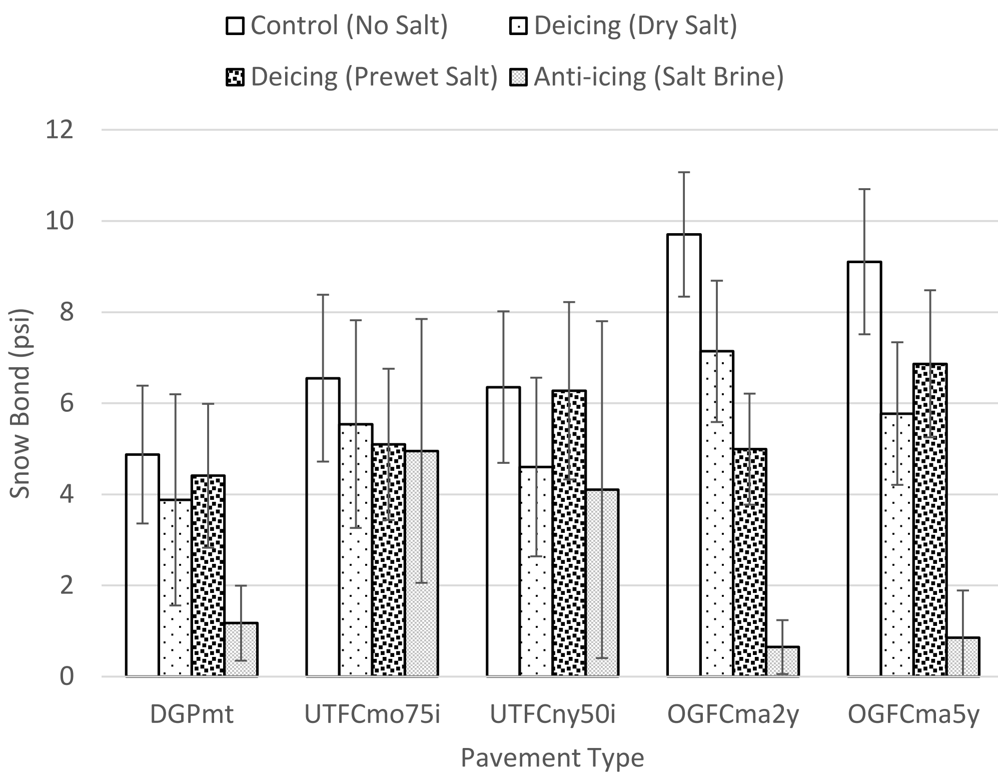



**Figure 18: Snow-pavement bond test results for each pavement type (average value ± 1 standad deviation).**

### 4.1.7 Measurement of Friction

Surface friction on the pavement surface was measured using a custom-made friction tester immediately after measuring the force required to shear the snow from the pavement (Figure 19). The static friction tester had a ¼-in thick, 2 in square neoprene rubber contact surface (durometer rating of 30A). The apparatus was pulled horizontally across the pavement surface at the same location as the sheared snow, and the force needed to overcome static friction was measured with a spring scale. The coefficient of static friction is defined as the ratio of the horizontal pulling force to the weight of the friction tester. Friction was measured on the pavement samples prior to each experiment on clean, dry pavement (baseline friction), on the compacted snow before trafficking (snow friction), and after shearing the snow (residual friction).

Figure 19: Friction tester.

Similar to snow-pavement bond strength, the residual friction measured in the laboratory with the static friction tester was not correlated to vehicle tire-to-pavement friction. The residual friction allows relative assessments of which pavement types or salting strategies have greater friction; however, specific values are not used to establish limits for “good” or “safe” road conditions. Friction measurement values ranged from 0.4 on compacted snow to 1.2 on clean, dry pavement (Figure 20). Obviously, greater values approaching 1.2 are better, while values nearer 0.4 are poorer. Baseline friction on the OGFC pavements was greater than DGP and UTFC pavements. Friction on compacted snow was similar amongst all pavements because the snow was thick enough such that the snow surface was unaffected by the pavement characteristics. Residual friction results shown in Figure 20 are the average of the control tests where no salt was applied, and was typically greater than compacted snow friction, particularly for the PPPs.

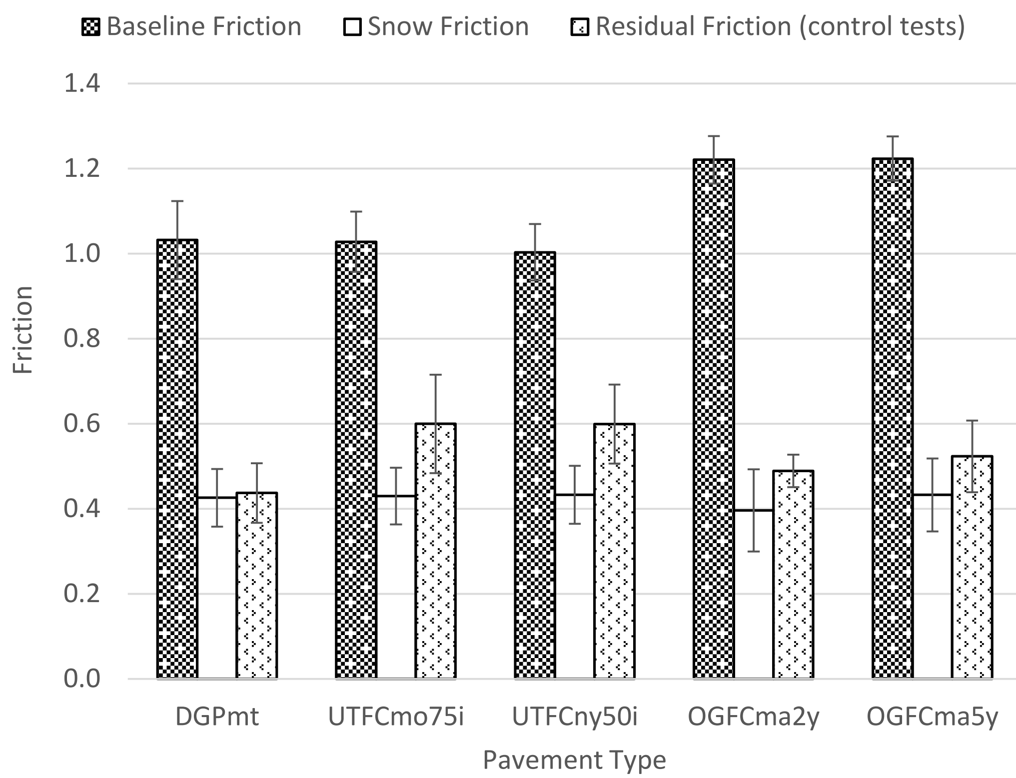



**Figure 20: Results of baseline, compacted snow, and residual friction measurements for each pavement type (average ± 1 standard deviation).**

The results of residual friction measurements for all pavement types organized by treatment type (control, deicing with dry salt, deicing with pre-wet salt, and anti-icing with salt brine) are shown in Figure 21. Residual friction of control tests generally ranged from 0.45 to 0.6, and treated tests from 0.5 to 0.65. These friction values are significantly less than baseline friction values (1.0 – 1.2), but greater than compacted snow friction (average = 0.43).

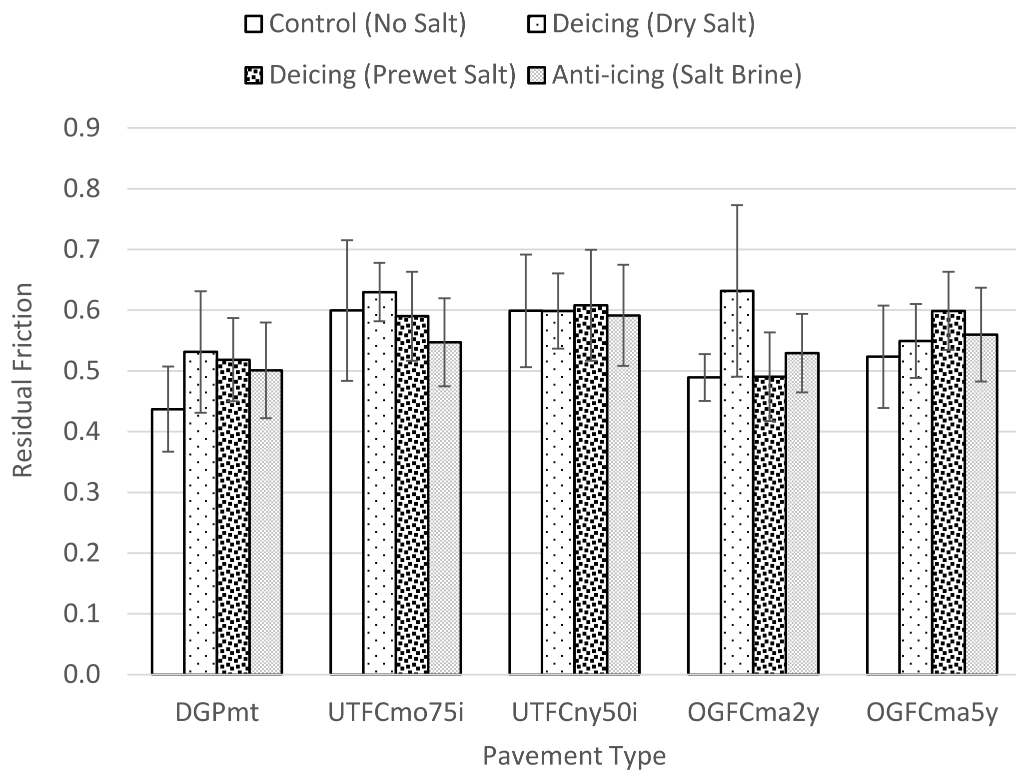



**Figure 21: Residual friction results with respect to pavement type and treatment type (average ± 1 standard deviation)**

#### Optical Friction and Salt Residue Measurements

Five lab tests were conducted in which friction and surface state were measured using an optical, non-contact mobile surface condition sensor (Mobile Ice Sight, manufactured by Innovative Dynamics, Inc). Three control (no salt) and two dry salt deicing tests were conducted. The snow sheared from the pavement during the deicing tests was collected and chloride concentration in the plowed, melted snow was measured. This measurement provided data needed to determine how much snow remained on the pavement surface after plowing. The results of these tests are shown in Table 9. Residual static friction ranged from 0.52 to 0.86 depending on pavement type and use of salt. Friction was higher on PPP samples than DGP, and higher with salt deicing than control (no salt) tests. Residual optical friction was 0.2 for all tests, regardless of pavement type or use of salt. The surface state after plowing was "snow" for all PPPs (because snow remained trapped in the pores, which the Mobile Ice Sight accurately detected) and "ice" for the DGPs. The chloride measurements in the plowed snow indicated a similar amount of salt remained on the pavement for both the DGP and PPP, however only two deicing tests were conducted.

**Table 9: Static and Optical Friction and Chloride Results from Five Additional Lab Tests with Photos of Pavement Sample after Simulated Plowing**

**DGPmt Control (no salt)**

| Parameter | Initial | Residual |
|---|---|---|
| Static friction | 0.89 | 0.52 |
| Optical friction | 0.5 | 0.2 |
| Surface state | Damp | Ice |
| % salt removed by plowing | — | — |
| % salt remaining on pavement | — | — |

**UTFCny50i Control (no salt)**

| Parameter | Initial | Residual |
|---|---|---|
| Static friction | 1.10 | 0.66 |
| Optical friction | 0.8 | 0.2 |
| Surface state | Dry | Snow |
| % salt removed by plowing | — | — |
| % salt remaining on pavement | — | — |

**UTFCmo75i Control (no salt)**

| Parameter | Initial | Residual |
|---|---|---|
| Static friction | 1.08 | 0.80 |
| Optical friction | 0.8 | 0.2 |
| Surface state | Dry | Snow |
| % salt removed by plowing | — | — |
| % salt remaining on pavement | — | — |

**DGPmt Deicing Dry Salt**

| Parameter | Initial | Residual |
|---|---|---|
| Static friction | 0.96 | 0.72 |
| Optical friction | * | 0.2 |
| Surface state | * | Ice |
| % salt removed by plowing | — | 69% |
| % salt remaining on pavement | — | 31% |

**UTFCny50i Deicing Dry Salt**

| Parameter | Initial | Residual |
|---|---|---|
| Static friction | 1.12 | 0.86 |
| Optical friction | 0.5 | 0.2 |
| Surface state | Damp | Snow |
| % salt removed by plowing | — | 75% |
| % salt remaining on pavement | — | 25% |

— Not applicable, * measurement not recorded (operator error)

Salt residue measurements with a computed tomography (CT) scanner located in the Subzero facility was also attempted. However, despite using small samples (1 in diameter cores from the pavement samples) and including a “tracer” (ISOVIEW-300, iodine solution used in medical CT scans) the CT scan resolution was too coarse to identify chloride ions (they are just too small to see) amongst the pavement components (asphalt and aggregate) and we were unable to develop a technique to quantify the amount of chloride in the pavement using the CT scanner.

## 4.2 DATA ANALYSIS

A matrix of laboratory tests was conducted to evaluate the performance characteristics of various treatment types on different types of pavements, namely snow-bond strength and surface friction. Meaningful comparisons were made to identify the effect of pavement type and treatment type on the performance. The comparison matrix included three pavement categories (DGP, UTFC, and OGFC) and four winter maintenance treatments (control, anti-icing with salt brine, deicing with dry salt, and deicing with pre-wet salt), as illustrated in Figure 22, where the control is when no treatment was applied to the pavement surface. The following comparisons were made to evaluate differences between the various pavement types: DGP vs. UTFC, DGP vs. OGFC, and UTFC vs. OGFC. Two types of UTFCs (½ in and ¾ in) and two types of OGFCs (new and old) were also incorporated in the analysis to refine these comparisons. The winter maintenance strategy comparisons that were made included: control vs. salt, anti-icing vs. deicing, and dry salt vs. pre-wet salt. These comparisons are shown by the orange arrows in Figure 22. In some comparisons, test results are combined. For instance when using “deicing” in a comparison it includes tests results of both dry salt and pre-wet salt tests, because dry and pre-wet are simply modifications of the treatment strategy referred to as “deicing.” Another example of combining test results is the group of “salt” tests, which includes the salt brine, dry salt, and pre-wet salt tests. Figure 22 shows which specific tests feed into the combinations by the thin blue lines that delineate the sub-categories.

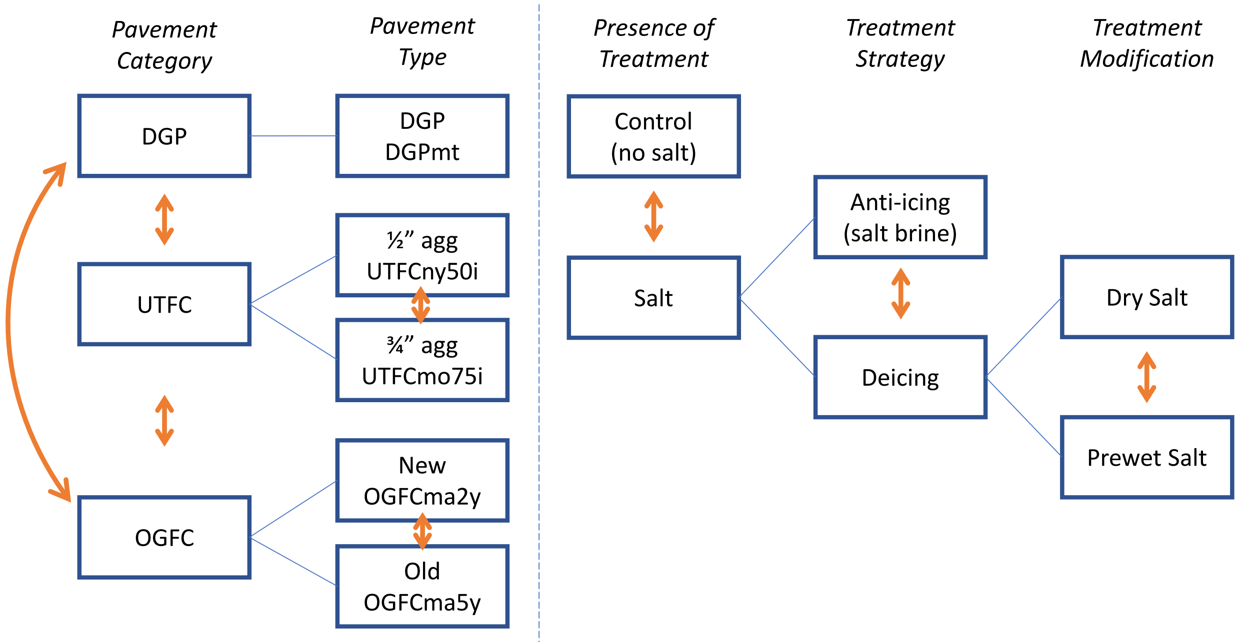



**Figure 22: Matrix of comparisons made with respect to pavements and treatments**

A two-sided t-test (for samples having unequal variance) was used as the statistical method to determine whether apparent trends in measured laboratory test results represent true differences between pavement category, treatment type, etc. The two-sample t-test is a statistical test used to determine if the averages of the two data sets are statistically different from one another based on a mathematical evaluation of the data scatter. In cases where the averages are statistically different, a direct comparison of the mean values indicates which value is greater. Otherwise, the means are considered statistically equal.

The output from this analysis is a parameter called a p-value. In this report, the p-value ranges from 0.50 to 1.00 (based on the one-tailed distribution). Although not typically shown this way, the p-values can be used to determine how two averages compare to one another. P-values closer to 0.5 indicate that the means are statistically more similar to one another and p-values closer to 1.0 indicate the means are statistically more different from one another. For the purposes of comparison in this project, and taking into consideration the relative variability typically observed in winter maintenance lab test data, a p-value greater than 0.90 was selected to indicate that the two means were statistically different from one another, while p-values between 0.50 and 0.90 indicated that the means were statistically the same. Certainly, the range of comparisons depends on the tolerance level of the analyst. Raw values are published below to allow the reader to analyze the data in a manner that best suits him or her.

### 4.2.1 Comparisons of Results Made with Respect to Pavement Type

Quantitative data collected during the lab tests included snow bond and residual friction, as described above. The combined mean values for the pavement categories (DGP, UTFC and OGFC) and pavement types (UTFC ½", UTFC ¾", OGFC new, and OGFC old) for control tests and salt tests are shown in Table

10.  The p-values of the comparisons of the mean snow bond and residual friction for the pavement categories and pavement types are shown in Table 11.  The p-values from comparisons between DGP and UTFC, DGP and OGFC, and UTFC and OGFC ranged from 0.98 – 1.0, indicating each pavement category is clearly different from the others in terms of snow bond and residual friction.  Therefore, mean values summarized in Table 10 can be used to make direct comparisons in the performance measures.  To determine which pavement category has greater or less residual friction one must refer to the mean values, shown in Table 10 and also in Figure 23.  Figure 23 shows the relative magnitude of snow bond and residual friction for the pavement categories for control tests and tests that used some form of salt.  A summary of the differences between the different pavement types, based on Figure 23 are as follows:

- Snow bond was lowest on DGP pavements and greater on OGFC pavements, which is consistent with the findings of the literature review which found snow and ice can become integrally "keyed" into PPPs.
- Residual friction was lowest on DGP sample and greater on both PPPs – also consistent with findings from the literature review.
- Snow bond was greatest on OGFC pavements in control tests and UTFC pavements in salt tests.
- OGFC pavements exhibited the greatest reduction in snow bond from salt application.
- UTFC pavements had the greatest residual friction, in both control and salt tests.
- Improvements in residual friction from salt application compared to control tests were similar for DGP and OGFC pavements.
- No differences between the UTFC ½" and UTFC ¾".

**Table 10: Combined Mean Values for Pavement Type Comparisons**

| | **Mean Value** | | | **Mean Value** | |
|---|---|---|---|---|---|
| | Snow Bond (psi) | Residual Friction | | Snow Bond (psi) | Residual Friction |
| **Control Tests** | | | **Salt Tests** | | |
| DGP | 4.9 | 0.44 | DGP | 3.5 | 0.52 |
| UTFC | 6.5 | 0.60 | UTFC | 5.0 | 0.59 |
| OGFC | 9.4 | 0.51 | OGFC | 4.4 | 0.56 |
| UTFC ½" | 6.4 | 0.60 | UTFC ½" | 4.9 | 0.60 |
| UTFC ¾" | 6.5 | 0.60 | UTFC ¾" | 5.2 | 0.59 |
| OGFC new | 9.7 | 0.49 | OGFC new | 4.3 | 0.55 |
| OGFC old | 9.1 | 0.52 | OGFC old | 4.5 | 0.57 |

Table 11: T-Statistic for Pavement Type Comparisons

| | P-Value | | | P-Value | |
|---|---|---|---|---|---|
| | Snow Bond (psi) | Residual Friction | | Snow Bond (psi) | Residual Friction |
| **Control Tests** | | | **Salt Tests** | | |
| DGP vs UTFC | **1.00** | **1.00** | DGP vs UTFC | **1.00** | **1.00** |
| DGP vs OGFC | **1.00** | **1.00** | DGP vs OGFC | **1.00** | **1.00** |
| UTFC vs OGFC | **1.00** | **1.00** | UTFC vs OGFC | **0.98** | **1.00** |
| UTFC ½” vs ¾” | 0.79 | 0.51 | UTFC ½” vs ¾” | 0.73 | 0.79 |
| OGFC new vs old | **0.99** | **0.98** | OGFC new vs old | 0.67 | **0.91** |

Numbers greater than 0.90 are **bolded**, the p-value chosen to indicate statistical significance for this analysis

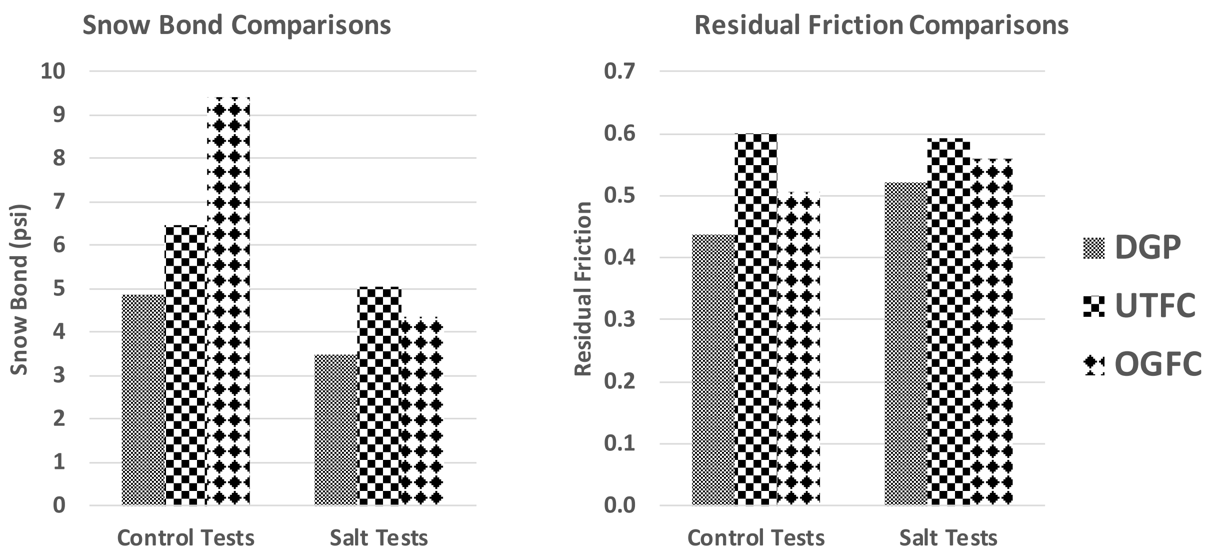



Figure 23: Snow bond and residual friction for pavement type comparisons.

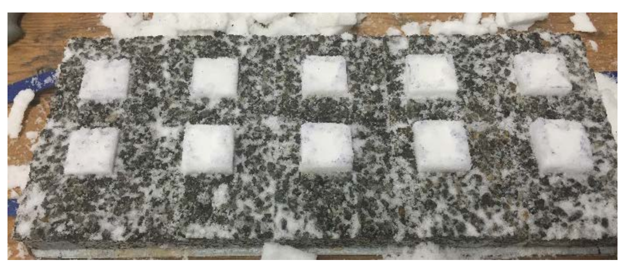
Various attributes of the pavements were compared between the two UTFCs (½-in vs. ¾-in maximum aggregate size) and two OGFCs (new vs. old) with results provided in Table 10 (means) and Table 11 (p-values). The differences between ½-in. and ¾-in UTFCs were not statistically different (p-values of 0.79 and 0.51 for control tests and 0.73 and 0.79 for salt tests – all less than 0.90). This means that the snow bond and residual friction from the ½-in and ¾-in UTFCs were similar, and could therefore be grouped together for the next analysis in which effective winter maintenance strategies were identified. When the two types of OGFCs (new and old) were compared to one another, the snow bond results were mixed – some p-values were greater than 0.90 and some less (0.99 and 0.67). However, with respect to residual friction, there were consistent statistically relevant differences between the two OGFCs (p-values of 0.98 and 0.91). The magnitude of the differences in terms of the actual values themselves is not relevant in this application (specifically residual friction of 0.49 vs. 0.52), where a difference of 0.03 does not represent appreciable difference in the two values. With respect to snow bond, a high p-value for the comparison between the control tests indicated that the bond strength in the new OGFC (9.7 psi) is stronger than the old OGFC (9.1 psi). However, comparisons between the newer and older treated OGFC samples indicated that the new and old OGFC had similar mean snow bond values.

Visual observations made throughout the lab testing also provided qualitative indications of performance between DGP and PPPs that may have significant implications for winter maintenance. Perhaps most notably, the PPPs appeared significantly more “snowy” than the DGPs after the snow was sheared from the pavement; however, the snow remaining on the PPPs was trapped in the pore space of the pavement surface and didn’t reduce friction significantly. Photos of control and dry salt tests run on a UTFC and OGFC (Figure 24) and a DGP (Figure 25) show that the PPPs have more visible snow on the pavement surface after removing snow than DGPs. Also noteworthy, is how similar the surface of the treated and untreated DGP sample appeared (Figure 25); however, the results of those treated with salt generally had significantly higher residual friction (about 0.5 instead of 0.4). The importance of this information is to illustrate that decisions on whether or not to treat a road surface should not be based solely on visual inspections. As an example, PPPs appear to need more treatment than DGPs, despite PPPs having higher friction after snow removal. These results should be verified prior to establishing a reliable protocol within each organization.


UTFCny50i Control test

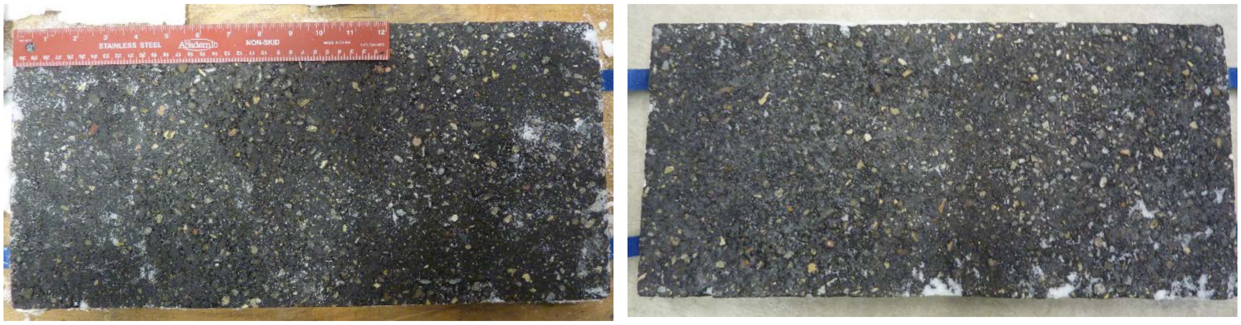

UTFCny50i Dry Salt test

OGFCma5y Control test



OGFCma5y Dry Salt test

**Figure 24: Photos showing the "snowiness" of PPPs after shearing snow (control tests on left, dry salt tests on right; UTFCs on top, OGFCs on bottom).**



DGPmt Control test DGPmt Dry Salt test

**Figure 25: Photos showing the "snowiness" of DGP sample after shearing snow (left: control test, right: dry salt test).**

### 4.2.2 Analysis of Results to Identify Effective Winter Maintenance Strategies

For a given pavement type, comparing various salting strategies to the control or other strategies can help determine the most effective winter maintenance strategies. The specific comparisons made within each pavement type are: control vs. salt, control vs. anti-icing, control vs. deicing, anti-icing vs. deicing, and dry salt vs. pre-wet salt.

The combined means and p-values for the tests on DGP samples are shown in Table 12. The control tests (i.e., no salt treatment) had the worst performance in terms of residual friction and second-worst for snow bond, indicating salt application provided significant benefits in terms of reduced snow bonding and improved friction. Anti-icing resulted in the lowest snow bond (1.2 psi) while deicing resulted in the greatest friction (0.53). The p-values comparing dry salt and prewet salt were 0.89 (for snow bond) and 0.77 (for residual friction), indicating insignificant differences between the treatment modification. The deicer application rate for these laboratory tests was 250 lb/LM, chosen in consultation with the project technical panel. This application rate was higher than typical for winter maintenance on DGPs at 28°F, thus three tests (providing 30 data points each for snow bond and residual friction) were run on this pavement at a reduced application rate. The salt grains were the same size (so deicer penetration was unchanged), but they were applied with greater spacing corresponding to 125 lb/LM. Interestingly, the reduced dry salt application had greater snow bond and lower residual friction than the greater salt application, which corresponds to intuition. However, compared to the control, snow bonding was greater on the reduced salt than no-salt scenario, which is counter-intuitive.

**Table 12: Combined Means and T-Statistic for Winter Maintenance Strategy Comparisons on DGP**

| | **Mean Value** | | | **P-Value** | |
|---|---|---|---|---|---|
| **Treatment** | Snow Bond (psi) | Residual Friction | **Comparison** | Snow Bond (psi) | Residual Friction |
| Control | 4.9 | 0.44 | Control vs Salt | **1.00** | **1.00** |
| Salt | 3.5 | 0.52 | Control vs Anti-icing | **1.00** | **1.00** |
| Anti-icing | 1.2 | 0.50 | Control vs Deicing | **1.00** | **1.00** |
| Deicing | 4.0 | 0.53 | Anti-icing vs Deicing | **1.00** | **0.93** |
| Dry salt | 3.9 | 0.53 | Dry salt vs Pre-wet salt | 0.89 | 0.77 |
| Pre-wet salt | 4.4 | 0.52 | Dry salt vs Dry salt (½) | **1.00** | **1.00** |
| Dry salt (½)* | 6.9 | 0.46 | | | |

*Dry salt test with reduced application rate (125 lb/LM instead of 250 lb/LM)

The combined means and p-values for the tests on UTFC samples are shown in Table 13. Because earlier comparisons between the two types of UTFCs (½" and ¾") indicated similar behavior, their results were grouped together for the analysis. Applying salt (whether salt brine, dry salt, or pre-wet salt) provided a statistically significant reduction in snow bond, but not a consistent improvement in residual friction. Because snow bond doesn't correlate to "ease of plowing" the practical implications of any reduction in snow bond are difficult to ascertain. The differences in residual friction are statistically significant with some strategies, but the overall range in friction is small (0.57 to 0.61), suggesting in practical terms, that friction across all the tests was similar, despite the statistical analyses indicating there were true differences.

**Table 13: Combined Means and T-Statistic for Winter Maintenance Strategy Comparisons on UTFC**

| | **Mean Value** | | | **P-Value** | |
|---|---|---|---|---|---|
| **Treatment** | Snow Bond (psi) | Residual Friction | **Comparison** | Snow Bond (psi) | Residual Friction |
| Control | 6.5 | 0.60 | Control vs Salt | **1.00** | 0.70 |
| Salt | 5.0 | 0.59 | Control vs Anti-icing | **1.00** | **0.97** |
| Anti-icing | 4.6 | 0.57 | Control vs Deicing | **1.00** | 0.73 |
| Deicing | 5.3 | 0.61 | Anti-icing vs Deicing | 0.89 | **1.00** |
| Dry salt | 5.1 | 0.61 | Dry salt vs Pre-wet salt | 0.87 | 0.79 |
| Pre-wet salt | 5.7 | 0.60 | | | |

The combined means and p-values for tests on the new and old OGFC samples ("new" in Table 14 and "old" in Table 15) are presented in separate tables because 1) some of the previous comparisons indicated differences between the two OGFC pavements, and 2) the literature review and interviews conducted in earlier tasks indicated newer/younger OGFC pavements needed greater salt application than older OGFC pavements. The comparisons of winter maintenance strategies for both OGFC pavements had several similar results: 1) the control tests had the greatest snow bond and lowest residual friction, and 2) anti-icing with salt brine resulted in the lowest snow bond while providing a modest increase in friction. Deicing with dry salt for the "new" OGFC and pre-wet salt for the "old" OGFC yielded the greatest residual friction.

**Table 14: Combined Means and T-Statistic for Winter Maintenance Strategy Comparisons on OGFC-new**

| | **Mean Value** | | | **P-Value** | |
|---|---|---|---|---|---|
| **Treatment** | Snow Bond (psi) | Residual Friction | **Comparison** | Snow Bond (psi) | Residual Friction |
| Control | 9.7 | 0.49 | Control vs Salt | **1.00** | **1.00** |
| Salt | 4.3 | 0.55 | Control vs Anti-icing | **1.00** | **1.00** |
| Anti-icing | 0.6 | 0.53 | Control vs Deicing | **1.00** | **1.00** |
| Deicing | 6.1 | 0.56 | Anti-icing vs Deicing | **1.00** | **0.94** |
| Dry salt | 7.1 | 0.63 | Dry salt vs Pre-wet salt | **1.00** | **1.00** |
| Pre-wet salt | 5.0 | 0.49 | | | |

**Table 15: Combined Means and T-Statistic for Winter Maintenance Strategy Comparisons on OGFC-old**

| | **Mean Value** | | | **P-Value** | |
|---|---|---|---|---|---|
| **Treatment** | Snow Bond (psi) | Residual Friction | **Comparison** | Snow Bond (psi) | Residual Friction |
| Control | 9.1 | 0.52 | Control vs Salt | **1.00** | **0.99** |
| Salt | 4.5 | 0.57 | Control vs Anti-icing | **1.00** | **0.96** |
| Anti-icing | 0.9 | 0.56 | Control vs Deicing | **1.00** | **1.00** |
| Deicing | 6.3 | 0.57 | Anti-icing vs Deicing | **1.00** | 0.79 |
| Dry salt | 5.8 | 0.55 | Dry salt vs Pre-wet salt | **0.99** | **1.00** |
| Pre-wet salt | 6.9 | 0.60 | | | |

## 4.3 SUMMARY OF LABORATORY TESTING AND ANALYSIS

The lab test performed for this project provided a consistent methodology for comparing the use of salt applied in various ways and measuring its effect on snow bond and friction. The suite of pavement specimens included the most common porous and permeable pavement surfaces: open-graded friction course and ultrathin friction course. The OGFC samples were made from cores of in-service pavements and are fairly representative of OGFCs in general, but state specifications vary throughout the US and the samples used in this project were only from one state. The two UTFC samples were made from pavement mix from two different states, but were made into slabs using the same machine, which should be taken into consideration.

The results of the laboratory tests indicate PPPs have higher friction, require greater force to shear snow from the surface, and had much visible snow trapped in the pores after scraping snow.  A summary of significant results from the laboratory testing are as follows:

- Snow bond is generally stronger on PPPs than DGPs.
- PPPs appear more snow-covered after scraping snow from the surface.
- Anti-icing generally provides the greater reduction in snow bond.
- Friction on PPPs is significantly greater than on DGP.
- Friction on PPPs was only slightly greater on salt tests compared to control tests.

# CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

According to the prevailing knowledge of winter maintenance on porous and permeable pavements ascertained from the literature review and agency interviews, PPP surfaces freeze more quickly, accumulate snow faster, require greater deicer application rates, require deicer applications for longer duration, and stay wet longer (dry slower) than traditional dense graded pavements. Most of reported difficulties with PPPs were at near-freezing temperatures (28–35°F). For temperatures lower than 27°F the consensus was that winter maintenance on PPPs was similar to DGPs. PPPs offer better drainage during rainfall than DGPs. However, when snow is melted with deicers, the pumping action of traffic on PPPs makes the roads appear wetter for longer than DGPs. Such that when DGP wheel paths are dry (often resulting from traffic), PPP wheel paths are wet (due to traffic). It is important to keep in mind that PPPs tend to have better frictional properties when wet than DGPs, and that wet PPPs do not need additional deicer application unless significant moisture is present (e.g., improper drainage across pavement, clogged PPP pores, etc.) and forecast temperatures are very low.

Laboratory testing demonstrated that compacted snow bonds more strongly to PPPs, yet friction of PPPs was significantly greater than traditional dense graded pavements (DGPs) after snow removal, even without the use of salt. The PPPs appeared more white and snowy, and this appearance may be contributing to unnecessarily high application rates of salt. Even when snow is trapped in PPPs, friction tends to be higher than DGPs treated for snow and ice control, owing to the overall greater frictional properties of open graded, ultrathin and permeable friction courses. Field testing is recommended to better understand the frictional behavior of PPPs during a variety of winter storm conditions and deicer application strategies.

## 5.1 RECOMMENDED WINTER MAINTENANCE ON PPPS

### 5.1.1 Materials

A wide variety of products are used for winter maintenance including sand/abrasives, sodium chloride (NaCl), magnesium chloride ($MgCl_2$), calcium chloride ($CaCl_2$), and other materials. At temperatures above 28°F, sodium chloride tends to be the most commonly used material for winter maintenance. Specific recommendations for material application on PPPs are:

- Do not use sand or abrasives on PPPs
- Liquid applicators should use flood or fan nozzles, not stream nozzles
- Larger-grain solid salt is recommended to avoid "losing" the salt in the voids

### 5.1.2 Treatment Methods and Application Rates

**Plowing:** PPPs can be more easily damaged by snowplows than DGPs and compacted snow tends to bond stronger to PPPs. To reduce damage to pavement surfaces, shoes should be used to keep plow blades just above the pavement surface.

**Frost/Ice Prevention:** Icing and frost formation occurs more often on PPPs than DGPs during cold, clear nights on pavements located near bodies of surface water. Frost and icing can be prevented with liquid material application (e.g., salt brine), or treated with liquid or prewet solid deicers at these locations.

**Anti-icing**: Anti-icing PPPs prior to snowfall is recommended to reduce the snow–pavement bond. Anti-icing is recommended if temperatures are above 20°F and snow is not blowing/drifting across the road. Anti-icing with liquids should use flood or fan nozzles (not stream nozzles). Application rates of 50 gal/LM for salt brine (NaCl) or 40 gal/LM for $MgCl_2$ or $CaCl_2$ are recommended unless sufficient localized testing is performed to justify reduced application rates.

**Deicing:** Deicing PPPs during and after a storm is typically required even if anti-icing is conducted prior. PPPs will appear whiter and snowier than DGPs, but will tend to have greater friction than DGPs, making it difficult to use visual observations or optical road surface state equipment in deciding when to apply deicers. Until sufficient field testing is conducted to assess frictional properties of PPPs during winter snowstorms, deicer application rates on PPPs should be 50 percent greater than DGP application rates: (e.g., treat DGP at 100 lb/LM, PPP at 150 lb/LM, treat DGP at 200 lb/LM and PPP at 300 lb/LM).

## 5.2 FIELD TESTING RECOMMENDATIONS

### 5.2.1 Pavements and Road Classification

Traditional dense graded asphalt pavement, open graded friction course and ultrathin friction course pavement surfaces should be included. Multiple sites will likely be needed because OGFC and UTFC pavements may not be adjacent, as most states use either OGFC *or* UTFC. DGP pavements should be included in the field tests to compare PPPs to DGPs – however, if DGP surfaces are not adjacent to PPPs and a secondary road with different traffic and winter operations is used, the comparisons could be more confounding than useful.

At least four sites in the US should be chosen for field testing. Site 1 with new OGFC pavements and Site 2 with old OGFC pavements, located in the same state (suggested states: Massachusetts, New Jersey or Virginia). Site 3 with ¾ inch maximum aggregate UTFC pavements (suggested states: Missouri or New York) and Site 4 with ½ or ⅝ inch maximum aggregate UTFC (suggested states: Kansas or New York). These are the minimum site suggestions – if multiple states or locations are willing to participate in the field testing, that would be preferable. Lab tests on UTFC pavements from Missouri and New York performed similarly, however, multiple UTFC pavements are recommended for field testing because of the inherent limitations of lab testing, and because the UTFC samples were made from the same asphalt lab compactor that may not mimic field construction and compaction conditions.

Multi-lane roads (at least 2 lanes in a single direction) with at least 8,000 AADT volume and posted speed limit of at least 45 mph are recommended. Higher speed and higher traffic volumes can help pump deicers trapped in pores of PPPs, bringing them back up to the surface which can help with continued snowfall. However, the pumping action of high speed traffic can also bring water to the surface, making the road appear wetter for longer than DGPs.

### 5.2.2 Data to be Collected

The following types of information should be collected during each field test to document test conditions and the effects of plowing and deicer application.

**Weather Data:** Meteorological data, ideally from a nearby RWIS which includes at minimum:

- air temperature,
- relative humidity,
- road surface temperature,
- wind speed and direction,
- solar radiation or visual observations of sunny, cloudy, partly cloudy, shade, etc.
- precipitation information including type (rain, graupel, sleet, wet snow, dry snow), intensity (in/hour), depth, density and snow–water equivalent.

**Friction and Surface Conditions:** A mobile optical road surface state sensor (such as Lufft MARWIS, Teconor RCM411, Innovative Dynamics Mobile Ice Sight, Vaisala vehicle-mounted DSC111, etc.) that provides surface state condition (such as Dry, Wet, Slush, Snow, Ice, or similar variety) and friction or grip. Sensors that also indicate depth of water, ice or snow are preferable.

Physical friction measurements should be collected in addition to the optical non-contact sensor because snow trapped in the pores of PPPs may affect optical friction results and actual physical friction is critical to the success of the field tests. The following options for physical measurements should be considered, depending on budget and availability of equipment and personnel:

- Friction "wheels" These are trailers with sensor-enabled wheels attached to a patrol vehicle. Examples include: Halliday Technologies RT3, ASFT T-5, Neubert Aero Corp Dynamic Friction Tester, and the Transtec Group GripTester.
- Deceleration Devices These are simple devices that use a sensor mounted inside a vehicle to calculate friction while the driver brakes or decelerates. Commercial options include Vericom RFM4000 and Neubert Aero Corp Dynamic Friction Decelerometer. Smart phones and tablets have accelerometers and several commercial Android and iOS mobile apps are available, including Teconor µTEC and Neubert Aero Corp Dynamic Friction Decelerometer Mobile App.
- Static Friction Devices These are manually operated rubber-bottom weighted friction devices. Small, easily portable versions can be made with steel blocks and a rubber membrane glued to the bottom. A hook or eyelet is needed to attach a spring scale for horizontal force measurements (static friction is calculated by the maximum horizontal pulling force divided by the weight of the friction tester). Another option is to make one from a trailer tire cut in half and partially filled with concrete, adding a handle for portability and an eyelet for the spring scale (or purchase the Braker Box Drag Sled). Static friction devices are manually operated and more time is usually needed to collect a sufficient amount of data. Data should be collected within wheelpaths of the lanes, requiring traffic control for each test section during measurements.

**Winter Maintenance Actions:** All winter maintenance activities should be documented, which are expected to include liquid, dry solid and/or prewet solid material application and plowing. All spreaders should be re-calibrated within a few weeks of the field tests to ensure accurate application rates. The spreading pattern should also be documented. The type of plow truck, plow blade, and whether shoes are used on the plow should also be documented.

**Photographs:** Photographs of the test sections should be taken before and during the field tests, specifically during all winter maintenance activities and at regular intervals (10 or 20 minutes) after deicer application. Light trailers should be available at each test section to provide sufficient light for photographs during the night. Bridges can provide a nice vantage point for photographing test sections. All cameras should be set to the current time. Camera white balance setting should also be performed multiple times during a test when light conditions change (daylight to shade to dusk to light trailers turned on, etc.) using card stock with the same type of brightness and weight for all site locations (e.g., 110 lb, 92 bright or 65 lb 95 bright – just be consistent).

### 5.2.3 Winter Storms

Several types of winter weather events should be included in the suite of field tests, including light snow, heavy snow, freezing rain and frost. A light snow event has a maximum snowfall intensity of ½ to 1 in/hr, less than 4 in total snow in a duration less than 24 hours with temperatures above 25 °F. A heavy snow has snowfall intensity around 1.5 to 2 in/hr, at least 6 in total snow, and temperatures above 25 °F. Tests should be conducted during freezing rain to observe the drainage characteristics of PPPs and see if deicers are washed through the pavement or remain in the pores. PPP surfaces have a greater tendency than DGPs of frost growth because of their greater surface area and being a cooler surface. Frost conditions can be difficult to predict, but road sections located in low areas or valley and near ponds or lakes are more likely to experience frost or icing during cold clear nights with light winds. Field tests are needed during frost conditions to determine friction on a frosted surface and the best actions for prevention and treatment during frost conditions.

### 5.2.4 Test Sections, Controls and Treatments

Test sections should be at least 500 ft long and separated by a buffer of at least 500 ft. Multiple test sections should be identified and marked with cones or poles. All test sections should be located within a small enough region to ensure similar traffic and weather conditions. Friction should be measured at times after deicer application that is consistent across test sections, which may require plow/spreader trucks to pause and wait between test sections if a drag sled device is used because the manually operated friction devices require more time (and traffic control) for measurements. The buffer needs to be long enough for the material spreader truck to be able to change the material application rate and be applying product before and after the test section boundaries and travel at a consistent speed within each test section.

Multiple deicer application rates should be included in each field test: a low application rate appropriate for the prevailing conditions (e.g., 20 gal/LM salt brine or 50 lb/LM solid salt), a medium application rate that is 25% more than the low rate, and a high application rate that is 50% more than the low rate. The actual material, application rates, and timing of treatments depends on the actual temperature and precipitation during the field test. Test sections on public roads during winter storms will be the most realistic with respect to pavement wear/surface conditions and traffic action. The disadvantage of this is that all test sections should be treated with deicers and a no-salt scenario ca not be safely conducted, unless appropriate signage and reduced speed limits are posted. If the PPP surface treatment exists on the shoulder, and snow can be plowed from the shoulder in a manner consistent with the test sections, then friction and photographs can be collected from the shoulder and considered a control, no-salt scenario. At least 3 light snow, 2 heavy snow, and 2 freezing rain field tests should be conducted on each UTFC and OGFC pavement surfaces. The DGP test sections should be as close as possible to the PPP. The number of application rates needed during the storm depends on the storm duration and normal cycle time for the plow/material trucks at the site chosen for testing. Once test sites and test sections have been identified, all 3 light snow, 2 heavy snow, and 2 freezing rain tests should be conducted at those locations. At least 8 test sections are needed for each deicing test (Table 16).

**Table 16: Deicing Application Rate Test Sections**

| **Deicing, App Rate Field Tests (7 tests at each site)**<br>3 light snow, 2 heavy snow and 2 freezing rain tests | |
|---|---|
| Test Section 1 (PPP):<br>Deice with low app rate | Test Section 5 (DGP):<br>Deice with low app rate |
| Test Section 2 (PPP):<br>Deice with medium app rate | Test Section 6 (DGP):<br>Deice with medium app rate |
| Test Section 3 (PPP):<br>Deice with high app rate | Test Section 7 (DGP):<br>Deice with high app rate |
| Test Section 4 (PPP shoulder):<br>Do not deice (plow only) | Test Section 8 (DGP shoulder):<br>Do not deice (plow only) |

At least one field test at each site (2 UTFC locations and 2 OGFC locations) should include test sections that do and do not get anti-iced with salt brine (or other liquid product) at least 8 hours before snowfall. DGP test sections are not required for this testing. Two types of nozzles should be tested – fan and stream nozzles. Friction should be measured before anti-icing, within 15 minutes of anti-icing, 4–12 hours after anti-icing, and then at regular intervals after snowfall begins. If the anti-icing nozzle type testing is conducted during a light snow or heavy snow event, and deicing is required during the storm, then a total of nine test sections is required (Table 17). If deicing is performed with liquid products, the nozzle type used for deicing a test section should be the same as the one for anti-icing, which would require multiple liquid trucks to avoid switching nozzles during the winter storm.

Table 17: Anti-Icing Test Sections

| **Anti-icing, Nozzle Type Field Test**<br>Appropriate for light snow or heavy snow | | |
|---|---|---|
| Test Section 1 (PPP):<br>Anti-ice using stream nozzles<br>Deice with low app rate | Test Section 4 (PPP):<br>Anti-ice using fan nozzles<br>Deice with low app rate | Test Section 7 (PPP):<br>Do not anti-ice<br>Deice with low app rate |
| Test Section 2 (PPP):<br>Anti-ice using stream nozzles<br>Deice with medium app rate | Test Section 5 (PPP):<br>Anti-ice using fan nozzles<br>Deice with medium app rate | Test Section 8 (PPP):<br>Do not anti-ice<br>Deice with medium app rate |
| Test Section 3 (PPP):<br>Anti-ice using stream nozzles<br>Deice with high app rate | Test Section 6 (PPP):<br>Anti-ice using fan nozzles<br>Deice with high app rate | Test Section 9 (PPP):<br>Do not anti-ice<br>Deice with high app rate |

Field tests for frost conditions may be the most difficult to conduct. If the sites identified for the other winter tests (light snow, heavy now, freezing rain) are not frost-susceptible, then other locations will need to be identified. The frost testing should have multiple test sections to determine if pre-treating, post-treating, or both are required, and the best type of product (liquid only, prewet solid, or a combination), as suggested in Table 18. Frost tests should be conducted after the anti-icing nozzle type tests and use either stream or fan nozzles, depending on which type is preferred for PPPs. In the table below of possible test sections to include, pre-treat refers to material application before frost conditions and post-treat refers to material application after frost has occurred on the shoulder or other untreated PPP test sections.

Table 18: Frost Test Sections

| Frost Field Test | |
|---|---|
| Test Section 1 (PPP):<br>Pre-treat with liquid at low app rate<br>Do not post-treat | Test Section 8 (PPP)<br>Do not pre-treat<br>Post-treat with liquid at low app rate |
| Test Section 2 (PPP):<br>Pre-treat with liquid at low app rate<br>Post-treat with liquid at low rate | Test Section 9 (PPP)<br>Do not pre-treat<br>Post-treat with liquid at medium app rate |
| Test Section 3 (PPP):<br>Pre-treat with liquid at low app rate<br>Post-treat with prewet solid at low app rate | Test Section 10 (PPP)<br>Do not pre-treat<br>Post-treat with liquid at high app rate |
| Test Section 4 (PPP):<br>Pre-treat with liquid at medium app rate<br>Do not post-treat | Test Section 11 (PPP)<br>Do not pre-treat<br>Post-treat with prewet solid at low app rate |
| Test Section 5 (PPP):<br>Pre-treat with liquid at high app rate<br>Do not post-treat | Test Section 12 (PPP)<br>Do not pre-treat<br>Post-treat with prewet solid at medium app rate |
| Test Section 6 (PPP):<br>Pre-treat with prewet solid at low app rate<br>Do not post-treat | Test Section 13 (PPP)<br>Do not pre-treat<br>Post-treat with prewet solid at high app rate |
| Test Section 7 (PPP):<br>Pre-treat with prewet solid at medium app rate<br>Do not post treat | Test Section 14 (PPP shoulder)<br>No material application |

### 5.2.5 Concluding Remarks Regarding Field Testing

The field testing recommendations presented herein include a variety of pavements, winter storm conditions and material application type and equipment.  The suite of field tests should provide sufficient data to finalize recommendations for winter maintenance practices on porous and permeable pavements.  Site location and physical friction measurements are critical to the success of the field testing.  Sites with cooperative and enthusiastic maintenance and operations personnel are preferable.  Field testing requires personnel dedicated to remain on site throughout the storm, with only short breaks for eating and sleeping.  Training is essential for the friction measurements to ensure accurate data is collected.  An estimated budget for field testing is highly dependent on the number of sites at which testing will occur, whether DOT staff can assist with data collection, and whether friction devices need to be borrowed, rented or purchased for testing.

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# APPENDIX A
# SUMMARY OF GRADATION AND AIR VOIDS CONTENT FOR OPEN-GRADED AND ULTRATHIN FRICTION COURSE PAVEMENT TYPES FROM STATE SPECIFICATIONS

### Table A-19: Aggregate Gradations and Air Void Contents for Open-Graded Overlays

| US Sieve | Sieve Opening (mm) | California | | Georgia | | | Indiana | |
|---|---|---|---|---|---|---|---|---|
| | | -1- 2006 §39-2.02 | | 2012 §828.2.01A | | | 2012 §401.05 | |
| | | Open-Graded Asphalt Concrete ½ in. max | Open-Graded Asphalt Concrete ⅜ in. max | 9.5mm OGFC | 12.5mm OGFC | 12.5mm PEM | Open-Graded Mixture Designation OG19.0 | Open-Graded Mixture Designation OG25.0 |
| 1.5 | 37.5 | | | | | | | 100 |
| 1 | 25 | | | | | | 100 | 70-98 |
| ¾ | 19 | 100 | | | 100 | 100 | 70-98 | 50-85 |
| ⅝ | 15.9 | | | | | | | |
| ½ | 12.5 | 95-100 | 100 | 100 | 85-100 | 80-100 | 40-68 | 28-62 |
| ⅜ | 9.5 | 78-89 | 90-100 | 85-100 | 55-75 | 35-60 | 20-52 | 15-50 |
| No. 4 | 4.8 | 28-37 | 29-36 | 20-40 | 15-25 | 10-25 | 10-30 | 6-30 |
| No. 8 | 2.4 | 7-18 | 7-18 | 5-10 | 5-10 | 5-10 | 7-23 | 7-23 |
| No. 16 | 1.2 | 0-10 | 0-10 | | | | 2-18 | 2-18 |
| No. 30 | 0.6 | | | | | | 1-13 | 1-13 |
| No. 50 | 0.3 | | | | | | 0-10 | 0-10 |
| No. 200 | 0.075 | 0-3 | 0-3 | 2-4 | 2-4 | 1-4 | 0-8 | 0-8 |
| % Air Voids -2- | | | | 18-20 | 18-20 | 20-24 | 15-20 | 15-20 |

Notes

-1- Year and Section of Standard Specification (or Supplemental or Special Provision, as noted)

-2- Acceptable range or minimum

### Table A-19: Aggregate Gradations and Air Void Contents for Open-Graded Overlays (continued)

| US Sieve | Sieve Opening (mm) | Kentucky | Massachusetts | Michigan | Nevada | |
|---|---|---|---|---|---|---|
| | | 2004 §404 | 2012 (Supp) §M3.11.03 | 2003 §902-1 | 2001 §705.03.02 | |
| | | Open-Graded Friction Course | HMA OGFC | Open-Graded Drainage Course | Type 12.5mm | Type 9.5mm |
| 1.5 | 37.5 | | | 100 | | |
| 1 | 25 | | | | | |
| ¾ | 19 | | | 60-80 | | |
| ⅝ | 15.9 | | | | | |
| ½ | 12.5 | 100 | 100 | 35-65 | 100 | 100 |
| ⅜ | 9.5 | 90-100 | 90-100 | | 90-100 | 95-100 |
| No. 4 | 4.8 | 25-50 | 30-50 | | 35-55 | 40-65 |
| No. 8 | 2.4 | 5-15 | 5-15 | 10-25 | | |
| No. 16 | 1.2 | | | | 5-18 | 12-22 |
| No. 30 | 0.6 | | | 5-18 | | |
| No. 50 | 0.3 | | | | | |
| No. 200 | 0.075 | 2-5 | 1-3 | | 0-4 | 0-5 |
| | % Air Voids | 15 | | | | |

### Table A-19: Aggregate Gradations and Air Void Contents for Open-Graded Overlays (continued)

| US Sieve | Sieve Opening (mm) | New Jersey | | | Oregon | |
|---|---|---|---|---|---|---|
| | | 2007 §902.03.03 | | | 2008 §745.12 | |
| | | OGFC-9.5mm | MOGFC-12.5mm | MOGFC-9.5mm | ½" Open Mix Type | ¾" Open Mix Type |
| 1.5 | 37.5 | | | | | |
| 1 | 25 | | | | | 99-100 |
| ¾ | 19 | | 100 | | 99-100 | 85-96 |
| ⅝ | 15.9 | | | | | |
| ½ | 12.5 | 100 | 85-100 | 100 | 90-98 | 55-71 |
| ⅜ | 9.5 | 80-100 | 35-60 | 85-100 | | |
| No. 4 | 4.8 | 30-50 | 10-25 | 20-40 | 18-32 | 10-24 |
| No. 8 | 2.4 | 5-15 | 5-10 | 5-10 | 3-15 | 6-16 |
| No. 16 | 1.2 | | | | | |
| No. 30 | 0.6 | | | | | |
| No. 50 | 0.3 | | | | | |
| No. 200 | 0.075 | 2-5 | 2-5 | 2-4 | 1-5 | 1-6 |
| | % Air Voids | 15 | 20 | 18 | | |

**Table A-19: Aggregate Gradations and Air Void Contents for Open-Graded Overlays (continued)**

| US Sieve | Sieve Opening (mm) | Rhode Island | Utah | Virginia | | Wyoming |
|---|---|---|---|---|---|---|
| | | 2010 §M.03.01 | 2012 §02786 | 2011 (Spec Prov) | | 2010 §803.6.1 |
| | | Dense Friction Course | Open-Graded Surface Course | PFC 9.5 | PFC 12.5 | Plant Mix Wearing Course |
| 1.5 | 37.5 | | | | | |
| 1 | 25 | 100 | | | | |
| ¾ | 19 | 90-100 | | | | |
| ⅝ | 15.9 | | | | | |
| ½ | 12.5 | 70-90 | 100 | 100 | 90-100 | 100 |
| ⅜ | 9.5 | 45-75 | 90-100 | 85-100 | 55-75 | 97-100 |
| No. 4 | 4.8 | 20-40 | 35-45 | 20-40 | 15-25 | 25-45 |
| No. 8 | 2.4 | 8-18 | 14-20 | 5-10 | 5-10 | 10-25 |
| No. 16 | 1.2 | | | | | |
| No. 30 | 0.6 | | | | | |
| No. 50 | 0.3 | 4-12 | | | | |
| No. 200 | 0.075 | 2-6 | 2-4 | 2-4 | 2-4 | 2-7 |
| | % Air Voids | 8 | | 16 | 16 | |

### Table A-20: Aggregate Gradations for Ultrathin Friction Courses

| US Sieve | Sieve Opening (mm) | California | | Kansas | | | New Jersey |
|---|---|---|---|---|---|---|---|
| | | 2006 (Spec Prov) §39-640[-1-], Bonded Wearing Course – Gap Graded (used in freeze-thaw areas) | | 2007 (Spec Prov) §613 Ultrathin Bonded Asphalt Surface (UBAS) | | | 2007 §902.04.02 Ultra-Thin Friction Course |
| | | ⅜ in. | No. 4 | Type A | Type B | Type C | UTFC |
| ¾ | 19 | | | | 100 | 100 | |
| ½ | 12.5 | 100 | 100 | 100 | 93-100 | 75-100 | 100 |
| ⅜ | 9.5 | 80-100 | 95-100 | 93-100 | 75-100 | 50-80 | 75-100 |
| ¼ | 6.35 | [-1-] | | | | | |
| No. 4 | 4.75 | 25-40 | 42-55 | 40-55 | 25-38 | 25-38 | 23-38 |
| No. 8 | 2.38 | 19-32 | 19-32 | 22-32 | 17-27 | 17-27 | 19-31 |
| No. 16 | 1.20 | 16-22 | 16-22 | 15-25 | 15-23 | 15-23 | 15-23 |
| No. 30 | 0.60 | 10-18 | 10-18 | 10-18 | 10-18 | 10-18 | 10-18 |
| No. 50 | 0.30 | 8-13 | 8-13 | 8-13 | 8-13 | 8-13 | 8-14 |
| No. 100 | 0.15 | 7-11 | 7-11 | 6-10 | 6-10 | 6-10 | 5-10 |
| No. 200 | 0.075 | 6-10 | 6-10 | 4-6 | 4-6 | 4-6 | 4-7 |

<u>Notes</u>

-1- Year and Section of Standard Specification (or Supplemental or Special Provision, as noted)

**Table A-20: Aggregate Gradations for Ultrathin Friction Courses (continued)**

| US Sieve | Sieve Opening (mm) | Missouri | | | New York | | |
|---|---|---|---|---|---|---|---|
| | | 2011 §413.30.25 Ultrathin Bonded Asphalt Wearing Surface (UBAWS) | | | 2013 (Spec Prov) §927 Paver Placed Surface Treatment | | |
| | | Type A | Type B | Type C | Type A | Type B | Type C |
| ¾ | 19 | | | 100 | | | 100 |
| ½ | 12.5 | | 100 | | | 100 | 85-100 |
| ⅜ | 9.5 | 100 | 75-100 | 75-100 | 100 | 85-100 | 60-90 |
| ¼ | 6.35 | | | 50-80 | 85-100 | 30-55 | 30-55 |
| No. 4 | 4.75 | 40-55 | 25-38 | | 40-80 | 24-45 | 24-45 |
| No. 8 | 2.38 | 22-32 | 19-27 | 25-38 | 21-45 | 21-37 | 21-37 |
| No. 16 | 1.20 | 15-25 | 15-23 | 19-27 | 16-32 | 16-26 | 16-26 |
| No. 30 | 0.60 | 10-18 | 10-18 | 15-23 | 12-25 | 12-20 | 12-20 |
| No. 50 | 0.30 | 8-13 | 8-13 | 10-18 | 8-16 | 8-16 | 8-16 |
| No. 100 | 0.15 | 6-10 | 6-10 | 8-13 | 5-10 | 5-10 | 5-10 |
| No. 200 | 0.075 | 4-6 | 4-6 | 6-10 | 5-7 | 5-7 | 5-7 |