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Use of a Portable Friction Tester on Snow and Ice Pavement

Amelia Menke, Sally Shoop, and Bruce Elder

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Amelia Menke, Sally Shoop, and Bruce Elder

Cold Regions Research and Engineering Laboratory
U.S. Army Engineer Research and Development Center
72 Lyme Road
Hanover, NH 03755

Final report

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Preface

This study was conducted for the Assistant Secretary of the Army for Acquisition, Logistics, and Technology under Program Element 622144, Project BL7, and Task 01, "Remote Assessment of Snow Mechanical Properties" (project 471941) for the Entry and Sustainment in Complex Contested Environments Program managed by Dr. John Rushing.

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COL Teresa A. Schlosser was the commander of ERDC and the director was Dr. David W. Pittman.

Use of a Portable Friction Tester on Snow and Ice Pavement

ABSTRACT

The objective of this project was to determine if portable friction testers could be used for friction measurements on compacted snow and ice surfaces. First, the effect of cold temperatures on the operation, consistency, and accuracy of commercially available portable pavement friction measuring tools was evaluated. Tests entailed a series of experiments in a controlled cold room environment. Two portable fixed slip continuous measurement devices and one deceleration spot measurement device were evaluated. The controlled temperature testing determined how ambient temperature and duration of exposure can affect results, but that with care, the devices could be operated in conditions as cold as -25°C. This was followed by using one of the devices on outdoor testing on snow, ice, and asphalt surfaces and compared the portable tester to the well-known SAAB vehicle runway friction tester. Results showed good agreement between the portable tester and the SAAB Friction tester, providing validation for the operational use of a portable tester on frozen surfaces.

INTRODUCTION

A variety of commercially available devices exist to characterize the friction, or skid resistance, of pavement surfaces. Friction testing is often performed in conjunction with construction activities as a means of quality control and assurance in meeting design specifications. In temperate regions, these tests usually occur during the summer construction season. Pavement friction testing is also performed throughout the year, most notably to monitor the condition of runways. Testing during the winter season can present unique challenges. A previous study of friction measuring equipment under winter conditions found that "correlations of ground vehicles on wet pavements do not apply to vehicles on surfaces covered by ice and snow" and recommended further investigation into the influence of temperature (ASTM 2009).

This study was conducted as part of a larger program assessing test equipment for characterizing the mechanical properties of snow and ice for vehicle mobility. The friction testing equipment was evaluated with an eye to potential use in characterizing pavements constructed solely of snow or ice. The three devices evaluated in this study were selected for their portability, in recognition of the need for easily-deployed equipment at remote field locations were such pavements are more likely to exist. The two Continuous Friction Measuring Equipment (CFME) systems evaluated in this study are the Findlay Irvine Micro Griptester (mGT) and the T2Go from SARSYS-ASFT. Continuous friction measuring equipment is often vehicle or trailer mounted, but these potable systems can be hand carried and operated. The deceleration spot measurement device, the Dynamic Friction Tester (DFT) from Nippo Sangyo, is relatively compact and can be powered by a vehicle battery.

Test values of pavement friction are known to vary with the type of testing device used, as well as with the speed at which the testing is performed. For example, the Federal Aviation Administration (FAA) requires a minimum reading of 0.43 when using the Findlay Irvine Griptester, and 0.50 when using the Airport Surface Friction Tester at 40 mph; and the minimum readings required for safe airfield operation using these devices are 0.24 and 0.34, respectively, when testing at 60 mph (FAA 1997). The Griptester and Airport Surface Friction Tester are each larger versions of the two CFME systems evaluated in this study - the Findlay Irvine Micro Griptester (mGT) and the T2Go from SARSYS-ASFT.

Though correlations may exist, previous studies have shown that friction numbers are notably "instrument specific" (Norheim et al. 2001). Thus, we made no attempt to compare test results (friction numbers) between devices until field validation. Friction is traditionally defined as the ratio of normal load to horizontal force developed at the interface between the moving and the static materials. Therefore, friction numbers are essentially dimensionless.

FRICTION TESTING EQUIPMENT

Dynamic Friction Tester (DFT): The DFT (Figure 1) is a portable instrument used to measure the frictional characteristics of paved surfaces. The system includes several components: the apparatus that engages with the pavement, a controller unit, a water supply tank, and a laptop computer. The test apparatus is approximately 0.4 m by 0.5 m with a spinning disk in the base. When the disk reaches the desired rotational speed, which can be programmed from 20 to 100 km/h, a weight is released onto the disk. Three rubber sliders 6 mm by 16 mm by 20 mm on the base of the disk come into contact with the test surface, and the torque generated by the sliding forces measured during the spin down is then used to calculate the friction as a function of speed (Nippo 2005).

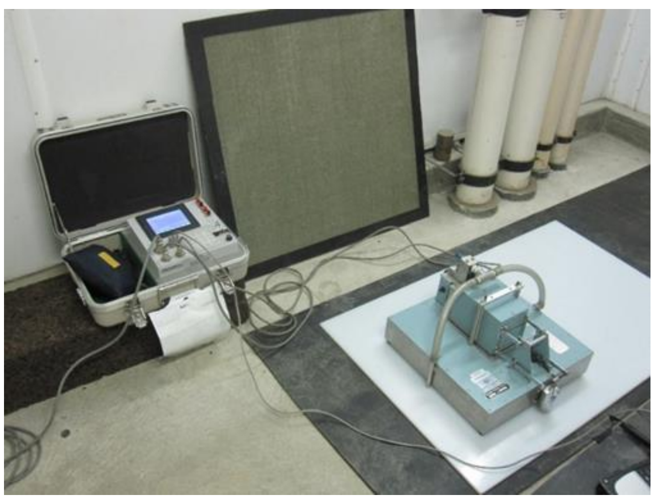

Figure 1. The DFT test apparatus (right) with controller unit (left) in the cold room.

The normal test procedure requires application of water to the surface being tested. Since the test objective temperatures are all below freezing, we conducted most of the tests dry. The wet method was used only during baseline (warm) testing at 25 °C. For the remaining tests, the water reservoir provided with the system was simply not used, which did not impede the system from operating normally. To operate the DFT with liquid water in an extremely cold environment presents several challenges. Most obviously, water can freeze in the hoses and valves potentially damaging the device. Also, the addition of warm water to the frozen pavement surface may alter the surface properties in a manner not representative of a moving vehicle. This is particularly true for a pavement surface of snow or ice. The effect of the water on the pavement surface, and thus the friction measured by the device, may also be sensitive to the temperature of the water being used, which would create more variables between tests.

At each temperature and exposure period, we recorded five repetitions of the DFT test. All tests used an initial rotational speed of 40 km/h. Higher speeds were not attempted to minimize the possibility of damaging the equipment under the stress of extreme cold. New rubber sliders were installed prior to testing at each temperature point in order to prevent changes in performance due to wear.

Micro Grip Tester (mGT): The mGT (Figure 2) is a continuous friction measuring device designed for use on a dry or wet surface. It is manually pushed with a three wheel design: two drive wheels in the rear and a smooth-tread measuring wheel mounted on an instrumented axle in front. The mGT is a battery powered and self-contained device which measures friction by the braked wheel, fixed slip principle (Findlay 2018). Tests can be completed by one trained operator.

Figure 2. The Micro GripTester (mGT).

During testing, speed is controlled by the operator, who simply pushes the device forward at a steady pace as they walk behind. The mGT includes a function allowing the operator to monitor their speed in real time on the device's handle-mounted control screen. The target test speed can be selected, and the device will beep to alert the operator when they are out of range. Our testing was performed with a target speed of 0.9 m/s.

Knowing that tire pressure changes with temperature, we verified that all tires were inflated to the manufacturer's recommended pressure prior to the start of testing at each temperature point. The tires were also cleaned to remove any grit or debris prior to testing. Once introduced to the cold room environment, tire pressure was not adjusted. The potential change in tire pressure is one aspect of the effect of cold on equipment accuracy.

At least four runs were conducted at each time and temperature interval, with the average taken from results of the most consistent three runs. The accuracy of ancillary features such as the onboard temperature sensor and GPS were not evaluated for this study.

T2Go Portable Continuous Friction Measuring Equipment: The T2Go, like the mGT, is a portable continuous friction measuring device. It features two in-line wheels, the reference wheel behind with the slip wheel in front. It is designed to operate in wet or dry conditions, and an optional water system is available. Most aspects of the test are controlled through a separate computer tablet loaded with the appropriate software. The T2Go provides several additional features such as temperature and humidity sensors and GPS tracking which were not evaluated in this study. The system can be used by one operator, but two are preferable due to the difficulty of using the tablet and test device simultaneously. Speed is controlled by the operator, and may be monitored in real time on the tablet.

As with the mGT, each tire was cleaned and checked to verify inflation to the manufacturer's recommended pressure prior to the start of testing at each temperature point. The target speed used during testing was the same as for the mGT: 0.9 m/s. Four test runs were conducted at each time and temperature interval, with the average taken from results of the most consistent three runs.

Figure 3. The T2Go and UHMW polyethylene test surface in the cold room.

LABORATORY TESTING TO GUIDE COLD TEMPERATURE OPERATIONS

The laboratory cold room testing was designed to evaluate the variability in friction test results and equipment performance due to duration of cold exposure. Each friction tester was subjected to temperatures of 0 °C to -25 °C for periods of up to 24 hours prior to being engaged in a standardized friction test. All tests were performed in a cold room on a sheet of ultra-high molecular weight (UHMW) polyethylene 9.525 mm thick and 0.76 m wide by 1.22 m long (Figure 3). This surface material was seated on a rubber mat approximately 0.9 m by 2.4 m. The role of the test material was not to replicate a specific pavement surface, but to provide a robust and inert surface that would offer consistent and repeatable surface properties throughout the range of testing tempertures.

Testing at ambient temperature, about 25 °C, was performed first to establish a baseline "warm" reading for comparison. During cold testing, each device was brought into the cold room environment from warm storage and a series of tests was conducted immediately; the test procedure was performed again after 30 minutes, 1 hour, 90 minutes and 2 hours of exposure to the cold. The friction-measuring devices were then left in the cold room to fully acclimate and a final test was performed after 24 hours of exposure to the test temperature. All detachable electronic components such as laptops and tablets were removed from the cold room between the short-term testing and the 24-hour cold soak tests.

The full series of exposure testing was performed at each of four temperature points (not all of the devices were capable of operating at some of the test temperatures). The cold room environment was adjusted to nominal temperatures of 0 °C, -10 °C, -20 °C, and -25 °C and allowed to stabilize at least 12 hours before testing. Actual air temperatures varied by ±1 °C during the course of testing.

COLD ROOM TEST RESULTS

Dynamic Friction Tester (DFT): The DFT records friction data at every 0.1 km/h interval from the initial rotational speed selected until it slows to a stop. The friction numbers recorded at 20 km/h, 40 km/h, 60 km/h, and 80 km/h are typically reported, when available (Nippo 2005). For our analysis, the readings taken at 20 km/h are used. The average coefficient of friction measured at 20 km/h in warm conditions was 1.016 using the dry method and 0.007 using the wet method. This difference between the wet and dry method results is extreme, and serves to illustrate the impact of test method and surface water on measuring and interpreting pavement friction.

Table 1 shows the average of five runs performed at each temperature point and time interval. These results reveal a consistent trend towards lower friction readings after longer periods of exposure. There is a significant drop in the friction numbers between 0 °C and -10 °C. However, at colder temperatures the results rose slightly from -10 °C levels with the exception of the 24 hour exposure period.

Table 1. DFT Friction Results at 20 km/h.

Temperature	0 min	30 min	1 h	90 min	2 h	24 h
0 °C	1.001	1.046	0.927	0.791	0.882	0.614
-10 °C	0.541	0.515	0.463	0.468	0.455	0.400
-20 °C	0.635	0.601	0.561	0.553	0.534	0.175
-25 °C	0.747	0.633	0.572	0.557	0.544	0.259

The effect of temperature on DFT results is significant. Tests performed within 30 minutes of exposure to 0 °C were very similar to baseline results, as shown in Figure 4, while all other tests showed significantly lower friction values. At temperatures below 0 °C, the drop in friction values was more dramatic.

A potentially significant influence on friction measurement with the DFT device is the change in stiffness of the rubber sliders on the base of the DFT. Being the points of contact with the target surface, changes in the properties of the sliders with temperature are likely to impact the measurement results.

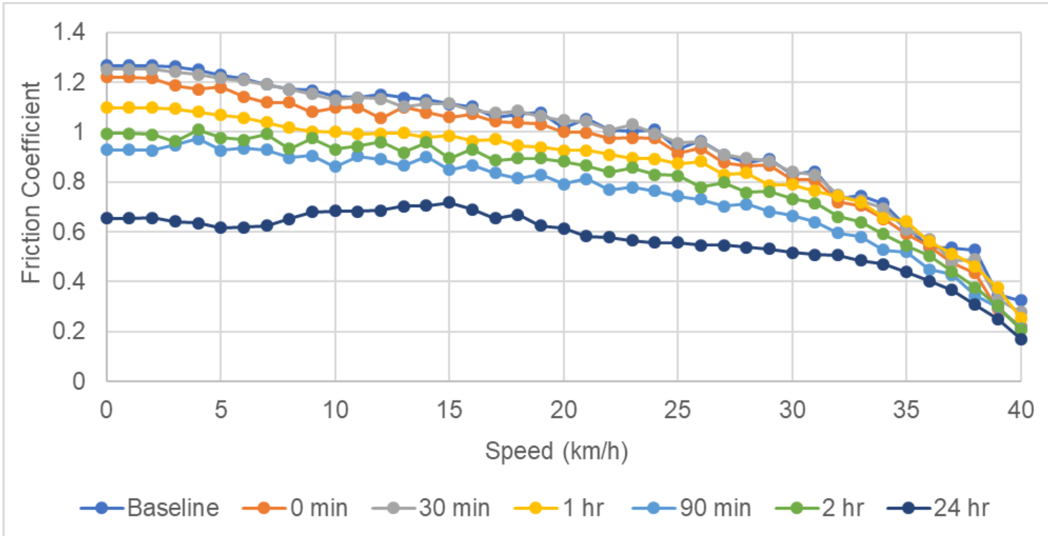

Figure 4. DFT test results after exposure to 0 °C compared to 25 °C baseline.

Other components of the DFT appeared to operate as expected with limited cold exposure. However, the controller screen became unreadable after 24 hours exposure to temperatures at or below -20 °C. Nonetheless, a meaningful test could still be performed using the laptop. Additionally, we noted that the DFT's cables are more difficult to connect and disconnect at cold temperatures, but this is very common in all manner of equipment.

Although the components of the DFT functioned adequately after exposure to a cold environment, its usefulness may be limited by the prescribed use of water in the standard test procedure. Significant differences were apparent in measured friction between wet and dry testing. While the system functioned well without use of the water reservoir, it is unclear if results from the dry test method have practical use. However, the values obtained during dry-method testing may be useful in assessing pavements, in spite of their failure to correlate to wet-method results. The ASTM Standard E1911 states that "the values measured in accordance with this method do not necessarily agree or directly correlate with those obtained utilizing other methods of determining friction properties or skid resistance" (ASTM 2009). The dry test method could be useful if a standard for interpretation of the results were established.

Table 2. mGT average GripNumber results.

Temperature	0 min	30 min	1 h	90 min	2 h	24 h
0 °C	0.28	0.29	0.32	0.29	0.26	0.28
-10 °C	0.30	0.27	0.27	0.28	0.28	0.27
-20 °C	0.27	0.24	0.25	0.25	0.25	0.24
-25 °C	-	0.25	0.23	0.22	0.23	0.22

Micro GripTester (mGT): Baseline testing of the mGT produced an average friction coefficient, referred to by the manufacturer as "GripNumber" or GN, of 0.29. As shown in Table 2, somewhat lower friction values were recorded at colder temperatures and after prolonged exposure. Data at 0 minutes exposure to -25 °C was not available solely due to a file transfer error. The most significant changes, greater than 20%, were seen after 1 hour or more exposure to -25

°C. At 0 °C and -10 °C, recorded friction numbers deviated from the baseline value of 0.29 by no more than 10%.

Throughout the course of testing the mGT provided excellent operability at each temperature and period of cold exposure. Only minor issues were encountered; a slight delay in screen function was noted after 24 hours of exposure to -25 °C. We noted that the yellow outer weather covering or shell is easily broken, especially if the device is lifted by the shell. This vulnerability, however, was also evident at warm temperatures.

Table 3. T2Go average friction number results.

Temperature	0 min	30 min	1 h	90 min	2 h	24 h
0 °C	0.27	0.24	0.25	0.24	-	-
-10 °C	-	-	-	-	-	-
-20 °C	0.29	0.23	0.22	0.22	-	-
-25 °C	0.26	0.22	0.22	0.22	0.23	0.23

T2Go Portable Continuous Friction Measuring Equipment: The results of warm baseline testing with the T2Go produced an average friction coefficient of 0.30. At colder temperatures, shown in Table 3, consistently lower values were recorded. Exposure to 0 °C, for 30 minutes or more resulted in 17% to 20% lower friction numbers. At -20 °C and -25 °C, recorded friction decreased by 23% to 27% after 30 minutes or more of cold exposure compared to the warm baseline reading. Prolonged exposure to the cold environment also resulted in consistently lower friction numbers compared to the "0 minute" test performed on initial entry into the cold room.

Figure 5. Irregular characters on the T2Go control screen.

The full test plan could not be completed with the T2Go. During testing, the device lost power or failed to start after storage in the cold room. Power loss occurred after as little as 90 minutes of cold exposure, despite extended battery charging periods. Due to the limited length of time the

T2Go was available for testing, the equipment was on loan from another agency, it could not be determined whether the battery failures were systemic or due to a problem with the battery pack.

During testing at -20 °C and -25 °C, the control screen mounted on the handle of the T2Go became unreadable, displaying irregular characters as shown in Figure 5. The screen typically appeared normal at start-up and malfunctioned after one to three test runs were completed. The screen could be restored to normal function temporarily by restarting the system. While inconvenient, the screen malfunction did not prevent further testing as the system can be operated by pressing a single button on the handle mounted unit to start and stop test runs, while all other functions can be completed through the associated tablet.

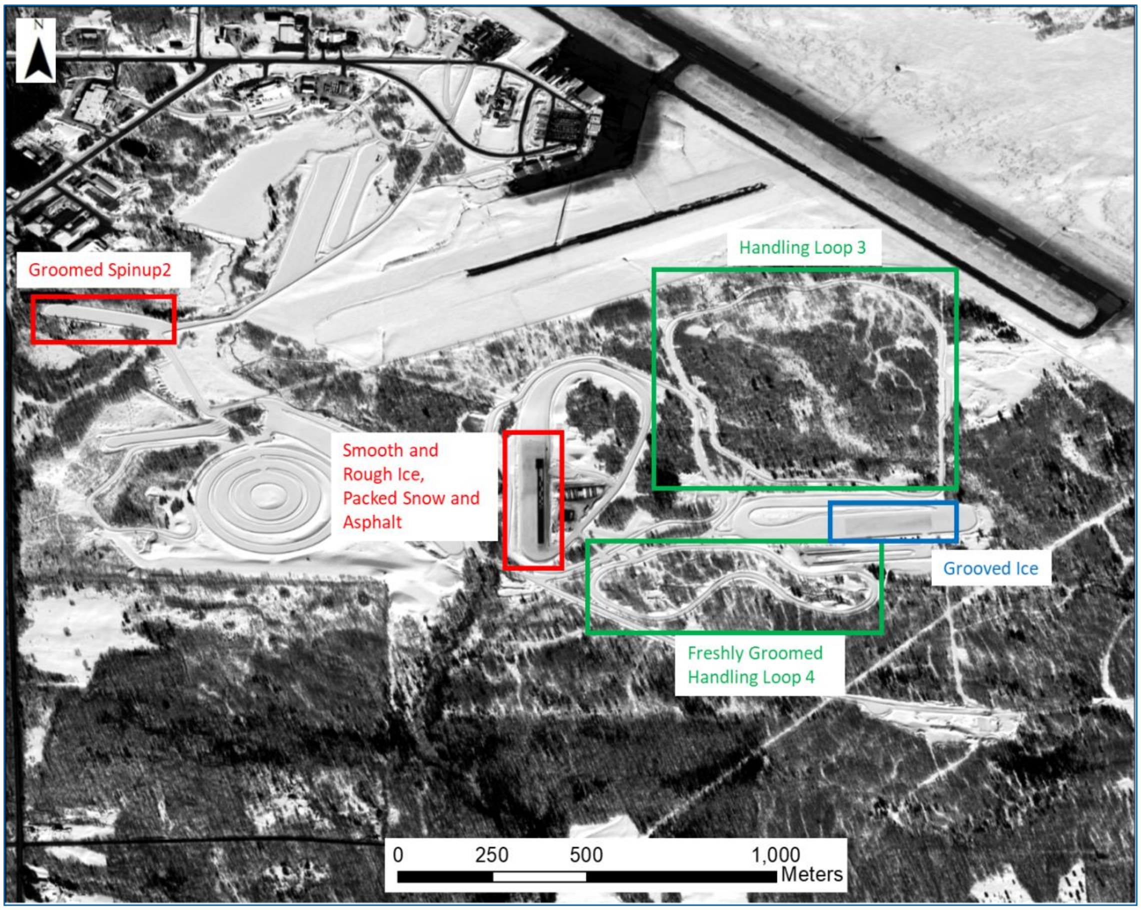

Figure 6. Image of KRC winter test course in Hancock, MI.

VALIDATION IN FIELD ENVIRONMENT

After the encouraging cold room use of the mGT, the opportunity to test this unit on outdoor winter surfaces came as part of a mobility testing program at the Keewenaw Research Center (KRC) during Feb 2020. KRC is located in Hancock, MI and operates a variety of winter surfaces specifically for vehicle testing and evaluation under winter conditions (Figure 6). KRC uses a SAAB friction tester to characterize the friction of their winter surfaces and to quantify improvements and treatments to those surfaces. Additional details regarding the SAAB friction tester and it's comparison to other winter traction testing devices in Shoop et al. (1994). Photos of the SAAB and the mGT winter surface testing are shown in Figure 7.

Figure 7. Winter testing with the mGT (left) and SAAB (right) on a packed snow.

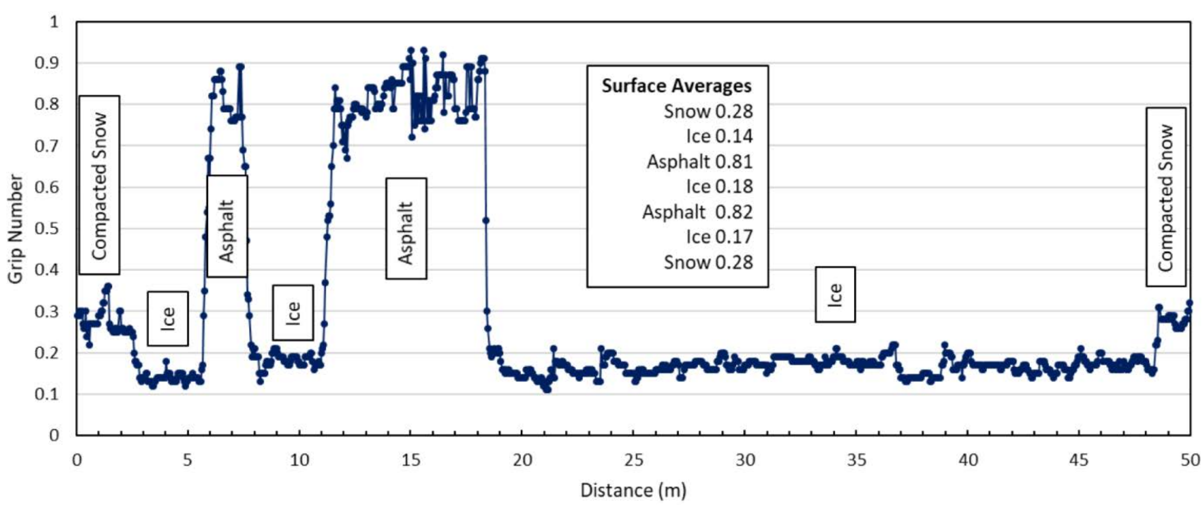

Figure 8. Friction measurements on various cold surfaces with the mGT.

The comparison tests were performed on a variety of packed snow and ice surfaces as well as split or alternating asphalt and ice surfaces used to tune vehicle stability control systems. Data from the mGT operated across an area that includes several types of winter surfaces is given Figure 8, showing a wide range of friction values on packed and groomed snow, ice, and asphalt.

A comparison of the SAAB and the mGT friction coefficient measurements on several of the winter test course surfaces is given in Figure 9, showing excellent agreement between the SAAB and mGT on the winter surfaces with exact agreement of friction coefficients to the nearest 0.01 for the well-groomed ice surfaces, and to within 0.03 for the snow surfaces; and even the largest variation, on the asphalt surface, showing a difference of only 0.05.

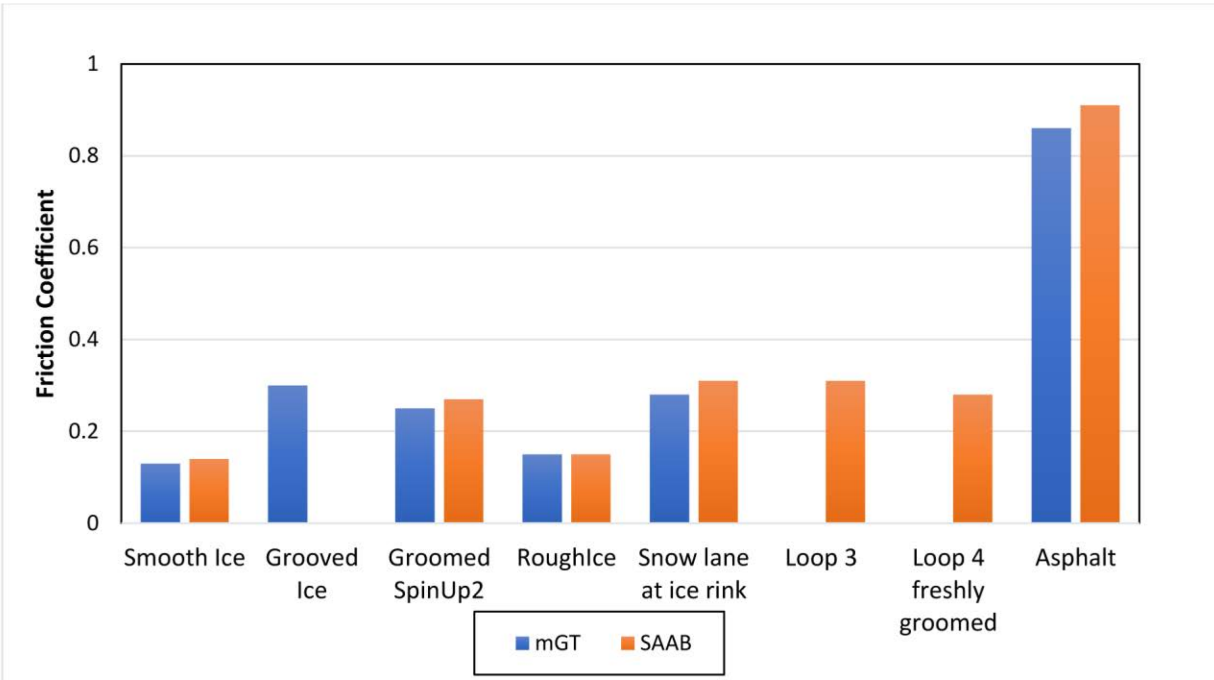

Figure 9. Comparison between the mGT and the SAAB Friction Tester on various surfaces.

CONCLUSIONS

Our results document the effect of cold exposure on the accuracy of pavement testing equipment. Tests performed immediately after bringing the devices into the cold room from warm storage were comparable to the baseline tests performed in warm conditions. Performance degraded with colder temperatures as well as longer periods of cold exposure. All three devices evaluated in this study exhibited the similar trends, to different degrees. Pronounced changes in the T2Go test results occurred after 30 minutes of exposure to -20 °C and below. The mGT was most robust to operating in cold temperatures, with significant decreases in measured friction occurring only after one hour of exposure to -25 °C. The DFT was most sensitive to temperature change with significant changes in friction readings after 90 minutes of exposure to 0 °C or any exposure to temperatures below 0 °C.

Not surprisingly, the display screens of all of the devices encountered problems during cold room testing. The mGT experienced only very minor delays in screen function, while the T2Go had persistent screen problems during testing at -20 °C and below. Like the mGT, the DFT controller screen only presented issues after prolonged exposure to -25 °C.

Based on the laboratory cold room study, comparing data from friction testing performed at different cold temperatures is problematic, as the variation between tests may arise from the effect of temperature on the equipment rather than changes in the pavement surface. Based on our experience, we advise that the test equipment should not be stored in freezing temperatures prior to testing, and that temperature and time of exposure should be recorded for each test.

To evaluate the portable friction testers in the field and compare results with a friction tester commonly used in cold environments, we evaluated the Micro GripTester (mGT) during field tests on packed snow and ice surfaces at the Keweenaw Research Center in Feb 2020. Several of these tests were run side by side with the SAAB Friction tester, which has been used on cold runway surfaces for many years. The testing showed excellent agreement between the SAAB and the mGT and therefore validating the use of the mGT portable friction tester for snow and ice surface friction measurements.

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14. ABSTRACT

The objective of this project was to determine if portable friction testers could be used for friction measurements on compacted snow and ice surfaces. First, the effect of cold temperatures on the operation, consistency, and accuracy of commercially available portable pavement friction measuring tools was evaluated. Tests entailed a series of experiments in a controlled cold room environment. Two portable fixed slip continuous measurement devices and one deceleration spot measurement device were evaluated. The controlled temperature testing determined how ambient temperature and duration of exposure can affect results, but that with care, the devices could be operated in conditions as cold as -25°C. This was followed by using one of the devices on outdoor testing on snow, ice, and asphalt surfaces and compared the portable tester to the well-known SAAB vehicle runway friction tester. Results showed good agreement between the portable tester and the SAAB Friction tester, providing validation for the operational use of a portable tester on frozen surfaces.

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