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Comparative Study of Friction Measurement Devices

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ABSTRACT

Since winter weather creates hazardous road conditions for road users, road managers are required to correctly understand the road surface conditions. One approach to determining the state of the road surface involves measuring the road surface friction, and the Civil Engineering Research Institute for Cold Regions (CERI) has been conducting such friction measurement by using a continuous friction tester (CFT) that is able to obtain friction values continuously on roadways. Although the CFT enables continuous measurement, it cannot measure friction when the vehicle is stationary. Recently, an indirect method using an optical sensor has been developed. The sensor optically measures the thickness of water/snow/ice on the road surface and estimates the grip level. Since this method does not require contact between a tire and the road surface, measurement is possible even when the vehicle is stationary. This study aims to verify the feasibility of using an optical sensor for such measurements, by conducting comparative tests between the CFT and an optical sensor at a test track. To compare the friction values obtained from the CFT with the grip levels determined by the optical sensor, a vehicle equipped with both devices ran on dry, wet, compacted-snow and thin-ice surfaces. The layer thickness values obtained by the optical sensor were compared with those measured with a ruler or with a NASA water-film depth gage. Additional measurements were conducted on thin-ice surfaces treated with salt or grit.

Keywords: Friction measurement, Continuous friction tester, Optical sensor, Comparative study, Salt, Grit

1 INTRODUCTION

Northern Japan has cold winters with snowfall heavier than that typically seen at its latitudes. Since winter weather creates hazardous road conditions for road users, winter road maintenance is essential in these regions. To carry out winter road maintenance appropriately, a correct understanding of the road surface conditions is required. One approach to determining the state of the road surface involves measuring the road surface friction, and various types of friction measuring devices have been developed and used by road agencies and researchers around the world. Friction has mainly been measured directly, by determining the frictional force produced from contact between the tire and the road surface, and the Civil Engineering Research Institute for Cold Regions (CERI) has been conducting such friction measurement by applying this method. Since this method requires contact between a tire and the road surface, the measurement results are influenced by the type of vehicle and tire; what is more, the direct method cannot measure friction when the vehicle is stationary. Recently, an indirect method using an optical sensor has been developed. The sensor optically measures the thickness of water/snow/ice on the road surface and gives an estimation of grip level. Since this method does not require contact between the tire and the road surface, measurement is possible even when the vehicle is stationary. Although a number of studies have evaluated the feasibility and accuracy of optical sensors, e.g. [1-5], few studies have tested their feasibility on road surfaces treated with salt or grit. This study aims to verify the feasibility of an optical sensor by conducting comparative testing between the CFT and an optical sensor not only on dry, wet, compacted-snow and thin-ice surfaces but also on thin-ice surfaces treated with salt or grit.

2 THE DEVICES COMPARED IN THE STUDY

In this study, a continuous friction tester (CFT) and an optical sensor (Vaisala DSC111) [6] were tested. The CFT calculates friction by measuring the axial force created by a measuring wheel installed at a 1- to 2-degree skew from the direction of travel. A friction value computed in this way is referred to as a Halliday friction number (HFN). The HFN scale was set by the device's designer, and it usually ranges from 0 to 100. The HFN is 0 when there is no force between the tire and the road, and 100 when there is lateral force between the tire and the road on dry pavement. Although the CFT enables continuous measurement, its measurements are affected by the measurement vehicle's steering angle, and it cannot measure friction when the vehicle is stationary. As for the optical sensor, the DSC111 optical sensor developed by Vaisala was used in this study. The DSC111 optically measures the thickness of water/snow/ice on the road surface and gives an estimation of grip level on a scale of 0.0 - 1.0. Since this method does not require contact between tires and the road surface, measurement is possible even when the vehicle is stationary. A test vehicle equipped with the CFT and the DSC111 were used in this study to compare the measurement results (Figure 1).

Figure 1. Test vehicle equipped with the CFT and the DSC111.

3 STUDY METHOD

The comparative tests were performed in January 2013 at the Tomakomai Test Truck of CERI. The test track is 2,700 m in circumference and its 1,200-m straightaway, which is paved with gap-graded asphalt concrete, was used.

3.1 Comparative Test #1

To determine the measurement characteristics of the DSC111, measurements were conducted under several types of road surface conditions. Wet, compacted-snow and thin-ice surfaces were artificially created, in addition to the dry surface on a straightaway (Figure 2). The wet surface was created by applying water to the dry surface with a road sprinkler (thickness: 0.5 to 1.0 mm). The compacted-snow surface was created by running a snow grader and a tire roller over snow, and then running vehicles to flatten out the surface and make a texture that is commonly seen. The thickness was approximately 150 mm and the unevenness is within 20 mm. The thin-ice surface was created by sprinkling water when the air temperature was below zero (thickness: 0.5 to 1.0 mm). The length of each road surface condition was around 500 m. Then, a test vehicle equipped with both devices ran on these surfaces at 20 km/h, 40 km/h, 60 km/h and 80 km/h, to compare the friction values obtained from the CFT with the grip levels determined by DSC111. In addition, the layer thickness values obtained by DSC111 were compared with those measured with a ruler or with a NASA water-film depth meter (Figure 3).

Figure 2. Road surface conditions used for the test

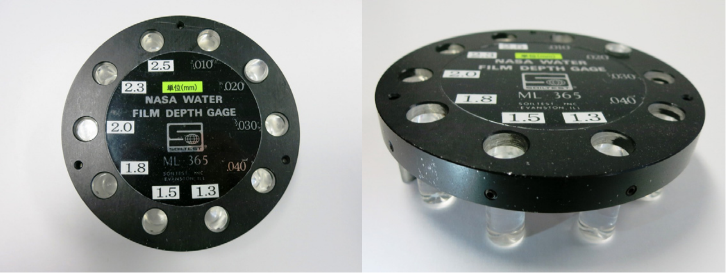


Figure 3. NASA water-film depth meter.

3.2 Comparative Test #2

In Comparative Test #2, measurements were conducted on thin-ice surfaces treated with salt or grit with the test vehicle travelling at a speed of 40 km/h. The course layout and the spreading rate of salt or grit are shown in Figure 4 and Figure 5. Dry surface sections were set in between road sections treated with salt or grit to prevent the test vehicle from dragging salt or grit to the next test section.

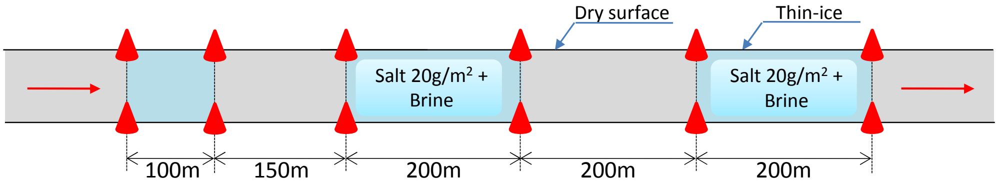


Figure 4. Test track layout for thin-ice surfaces treated with salt.

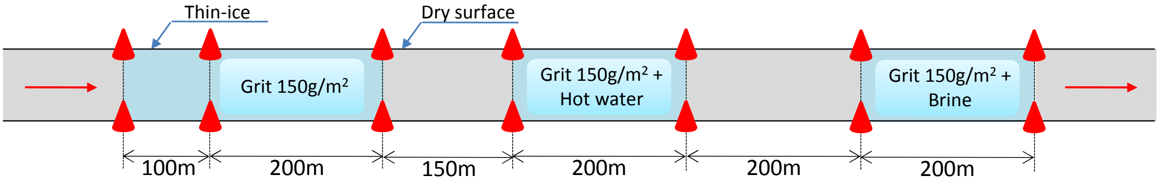


Figure 5. Test track layout for thin-ice surfaces treated with grit.

The basic steps of Comparative Test #2 are listed below (Figure 6):
- Create a thin-ice surface by sprinkling water when the air temperature is below zero.
- Spread salt or grit on the thin-ice surface
- Run the test vehicle on these surfaces immediately after the spreading.
- Run vehicles on these surfaces to duplicate traffic flow.
- Run the test vehicle after 50, 100, 150, 200, 250 and 300 vehicle passes.

Figure 6. Basic steps of Comparative Test #2

4 TEST RESULTS

4.1 Comparative Test #1

Figure 7 shows an example of measurement results on the wet, compacted-snow and thin-ice surfaces at the driving speed of 20 km/h. Although the DSC111 locally detected the ice layer and gave low grip levels on the wet surface, both the HFN and the grip level showed high values on the dry and the wet surfaces. However, a lag was found in the decrease in grip level and the detection of the snow layer on the compacted-snow surface relative to those determined by HFN. Since similar phenomena were observed on the thin-ice surface, the lag was attributed to the delay between measurement and output.

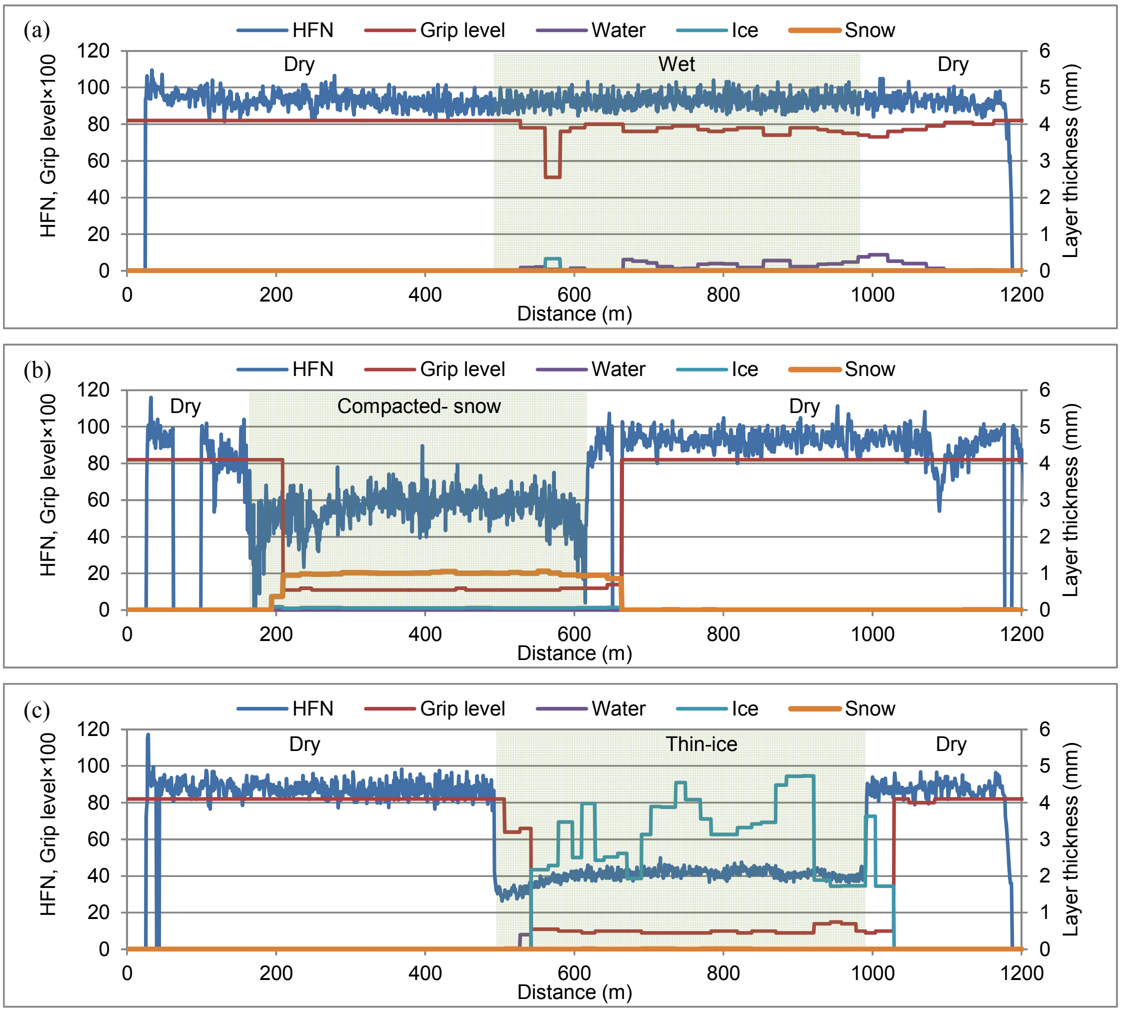
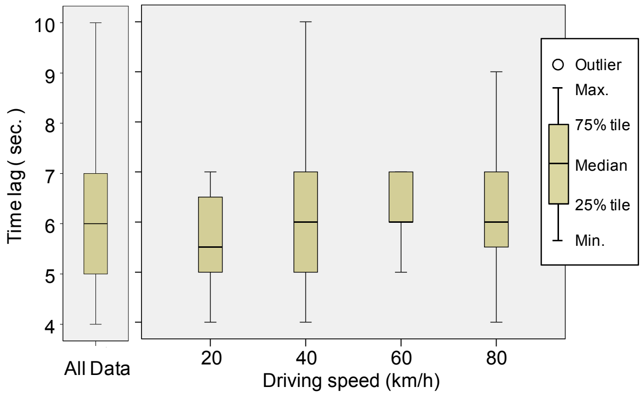


Figure 7. Example of measurement result. (a) wet, (b) snow, (c) thin-ice

4.1.1 Time Lag between Measurement and Output

As shown in Figure 7, the DSC111 takes time to output grip levels and layer thickness after measurement. Time lag analysis was conducted at the boundary point between the dry and the thin-ice surfaces, where the boundary is clear-cut. The time lags between measurements and outputs were identified by measuring the time when the grip level fell to a low level after the HFN dropped. These are plotted in a box-and-whisker chart (Figure 8). The bottom and top of each box are the first and third quartiles of time lags, and the line inside the box is the median. The ends of the whiskers represent 1.5 interquartile ranges. Outliers are defined as data outside the whiskers. The time lag ranges from 4 to 10 sec., and averages 6 sec. The time lag is not affected by the driving speed of the test vehicle.



	Samples	Time lag (sec.)				
		Avg.	Med.	SD	Min.	Max.
All Data	69	6.2	6.0	1.5	4.0	10.0
20km/h	12	5.6	5.5	1.1	4.0	7.0
40km/h	33	6.3	6.0	1.8	4.0	10.0
60km/h	12	6.2	6.0	0.7	5.0	7.0
80km/h	12	6.3	6.0	1.6	4.0	9.0

Figure 8. Time lag between measurement and output

4.1.2 DSC111 measurement results for each surface

Figures 9, 10 and 11 show the measurement results obtained by the DSC111 on the wet, compacted-snow and thin-ice surfaces, respectively. The left-hand box-and-whisker plot of each figure shows the grip level, and the right-hand box-and-whisker chart plot shows the layer thickness. Since the time lag between the measurements and outputs had a maximum value of 10 sec., the box-and-whisker charts were made by excluding the data of the first 10 sec. for each surface to eliminate the influence of the time lags. As shown in Figures 9, 10 and 11, grip levels are consistent for each surface and are unaffected by driving speed, but layer thickness values are influenced by driving speed, especially on the wet and the compacted-snow surfaces. The faster the test vehicle runs, the thinner is the value indicated by the DSC111 on the wet surface and the thicker is the value indicated by the DSC111 on the compacted-snow surface. The water and snow kicked up by the test vehicle's tires might have influenced the evaluation of water and snow layer thickness. Additionally, the average snow and ice layer thickness values obtained by the DSC111 range from 1.0 to 1.2 mm and from 2.2 to 3.1 mm, respectively. Snow and ice layer thickness values obtained by the DSC111diverge from those obtained by direct measurement.

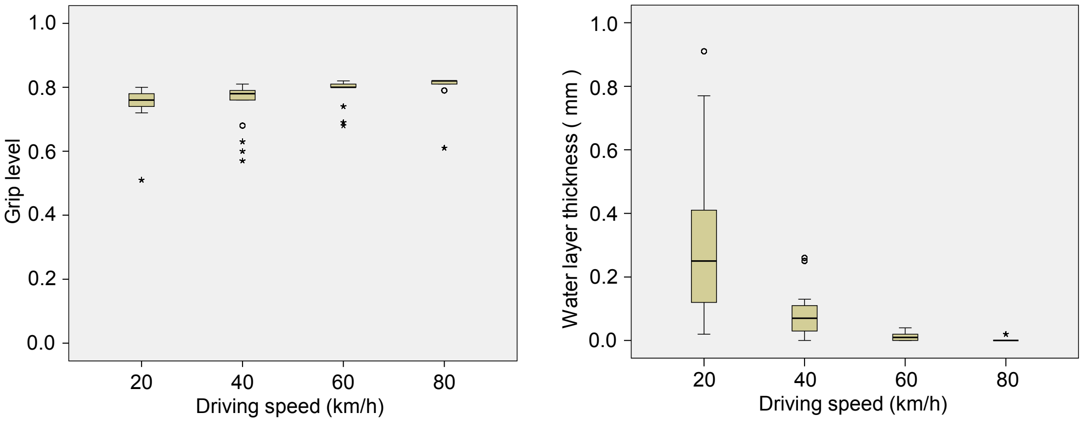


Figure 9. Grip level and water layer thickness on the wet surface

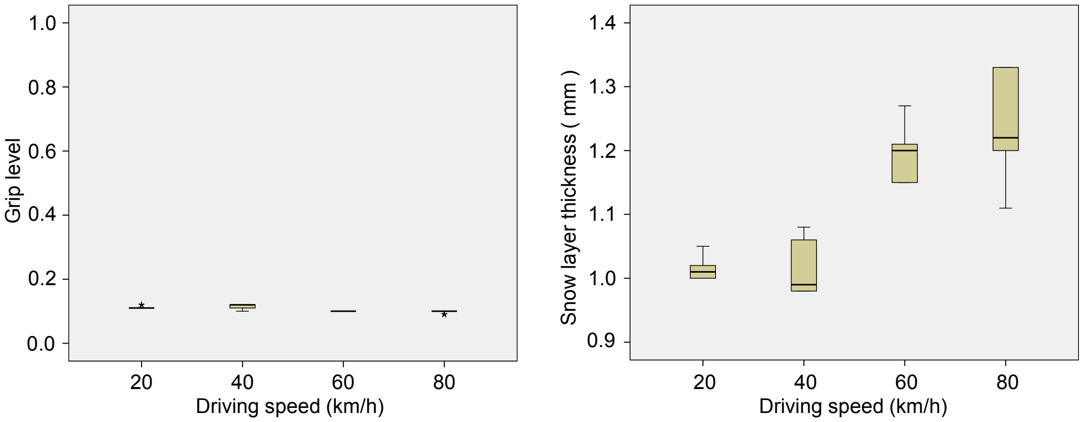


Figure 10. Grip level and snow layer thickness on the compacted-snow surface

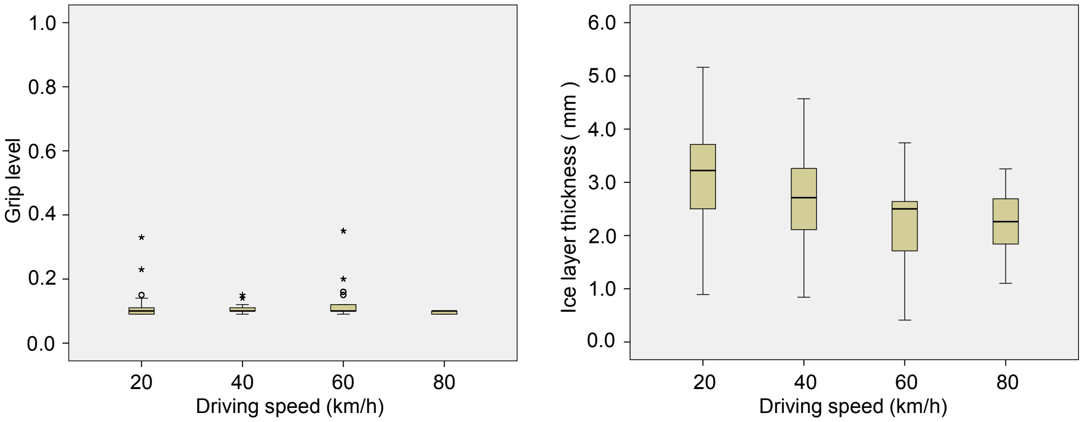
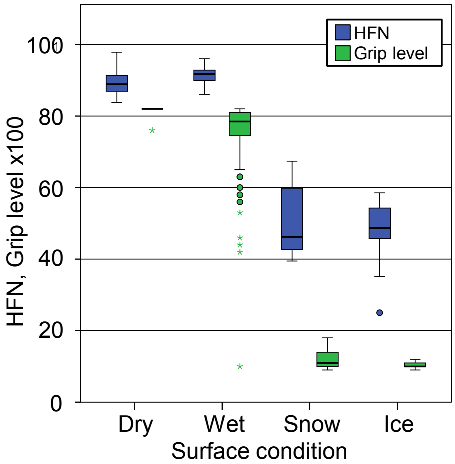


Figure 11. Grip level and ice layer thickness on the thin-ice surface

Figure 12 shows the HFN values and the grip levels. As discussed above, the graph was made by excluding the data of the first 10 sec. for each surface to eliminate the influence of the time lags. Although the DSC111 occasionally gave a low grip level on the wet surface, grip levels are generally consistent for each surface and correspond closely to the HFN values. The precision is good enough to discriminate between the different surfaces.



	Surface Condition	Samples	Avg.	Med.	SD	Min.	Max.
HFN (CFT)	Dry	80	89.8	88.9	3.5	83.8	97.8
	Wet	80	91.3	91.7	4.4	86.1	96.0
	Compacted-snow	41	48.6	48.7	6.8	25.0	58.6
	Thin-ice	58	50.2	46.2	8.7	39.5	67.4
Grip level x100 (DSC111)	Dry	80	81.9	82.0	0.7	76.0	82.0
	Wet	80	74.8	78.5	11.5	71.0	82.0
	Compacted-snow	41	10.6	10.0	0.8	9.0	12.0
	Thin-ice	58	11.9	11.0	2.5	9.0	18.0

Figure 12. HFN and grip level for each surface condition

4.2 Comparative Test #2

4.2.1 Measurement results for the thin-ice surface treated with salt

Figure 13 shows an example of measurement results for thin-ice surfaces treated with salt. Figure 14 shows the changes in HFN values and grip levels as a function of the number of vehicles passed. The HFN slightly increased with increased number of vehicles but tended to remain low under the condition of the lowest air temperature of -9.3 degrees Celsius. In contrast, grip level increased gradually until 150 vehicles passed, and then fell to a low level. Overall, the DSC111 seems to capture the changes in surface conditions after salt treatment, but the grip levels have a poor relationship with HFN values on the sections treated with salt.

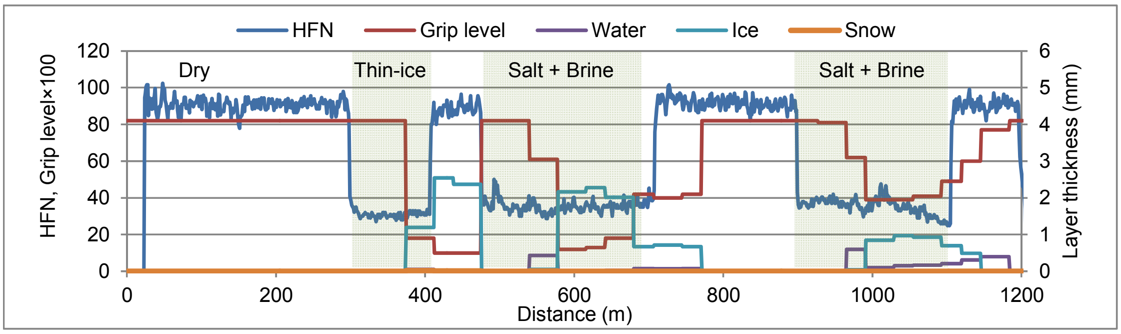
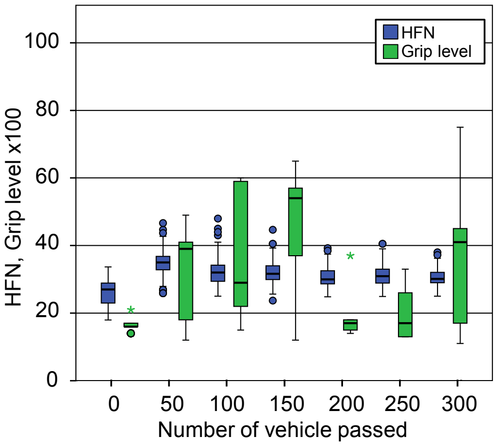


Figure 13. Example of measurement results for thin-ice surfaces treated with salt (after 50 vehicles passed)



	Number of vehicle passed	Samples	Avg.	Med	SD	Min.	Max.
HFN	0	153	26.2	27.0	3.6	18.0	34.0
	50	154	34.6	35.0	3.8	26.0	47.0
	100	163	32.4	32.0	3.8	25.0	48.0
	150	152	31.9	31.6	3.3	24.0	45.0
	200	154	30.6	30.0	2.9	25.0	39.0
	250	146	31.4	30.9	3.3	25.0	41.0
	300	164	30.6	30.1	2.5	25.0	38.0
Grip level x 100	0	153	16.2	16.0	2.0	14.0	21.0
	50	154	31.1	39.0	12.5	12.0	49.0
	100	163	36.2	29.0	16.8	15.0	60.0
	150	152	47.0	54.0	15.5	12.0	65.0
	200	154	18.7	17.0	6.4	14.0	37.0
	250	146	18.8	17.0	6.1	13.0	33.0
	300	164	35.3	41.0	22.8	11.0	75.0

Figure 14. HFN values and grip levels as a function of the number of vehicles passed

4.2.2 Measurement results for the thin-ice surface treated with grit

Figure 15 shows an example of measurement results for the thin-ice surface treated with grit. Figure 16 shows the changes in HFN values and grip levels as a function of the number of vehicles passed. As shown in Figure 16, the HFN remained low on the surface treated with grit, increased markedly on the surface treated with grit and hot water, and gradually increased on the surface treated with grit and brine. In contrast, the grip levels generally remained low regardless of spreading method, and no clear trend was found for the changes in grip levels. Since the DSC111 optically measures the thickness of water/snow/ice on the road surface, it might not be able to properly evaluate the surface conditions after grit is applied.

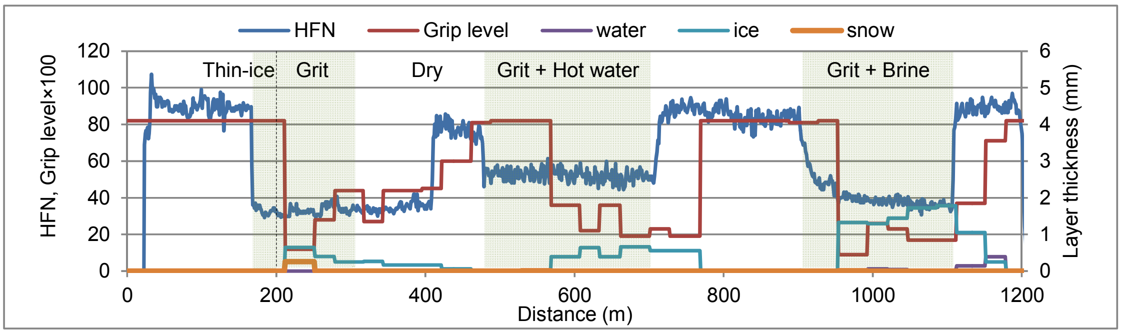


Figure 15. Example of measurement results for the thin-ice surface treated with grit (after 50 vehicles passed)

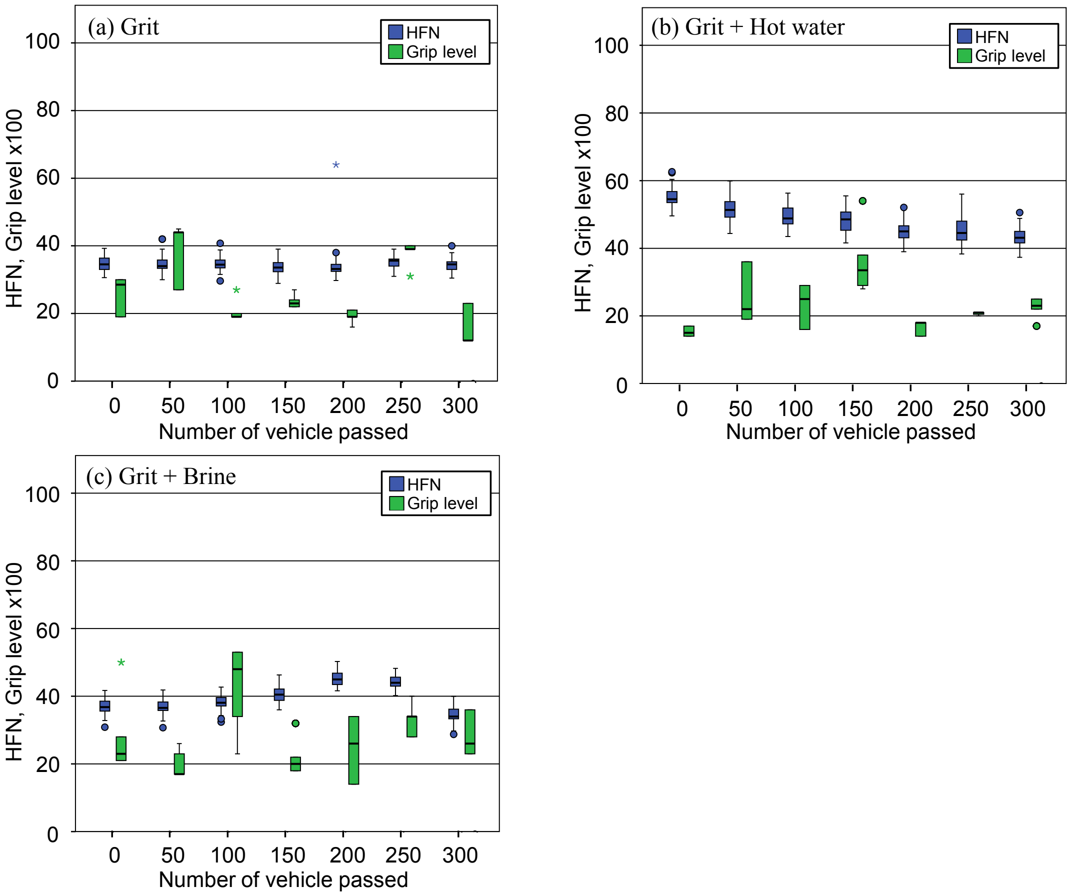


Figure 16. HFN values and grip levels as a function of the number of vehicles passed. (a) grit, (b) grit + hot water, (c) grit + brine.

5 CONCLUSIONS

The test results are summarised here.

- *Comparative test #1 (measurements on non-treated surfaces)*
  - Grip levels are generally consistent for each surface and correspond closely to the HFN values. The precision is good enough to discriminate between the different surfaces.
  - The DSC111 has a time lag between measurement and output. It ranges from 4 to 10 sec., and is unaffected by driving speed.
  - Grip levels are unaffected by driving speed, whereas layer thickness values are influenced by driving speed, especially on the wet and the compacted-snow surfaces.
- *Comparative test #2 (measurements on treated surfaces)*
  - The DSC111 seems to capture the changes in surface conditions after salt treatment; however, the grip levels have a poor relationship with the HFN values on the sections treated with salt.
  - No clear trend was found for the changes in grip levels on the surfaces treated with grit. Since the DSC111 optically measures the thickness of water/snow/ice on the road surface, it might not be able to properly evaluate the surface conditions treated with grit.

The next steps will be to obtain further test data on surfaces treated with salt or sand and to verify the feasibility and accuracy of optical sensors for evaluating friction on pavements of different textures.

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