Difference in remote road surface sensor performance by pavement type

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Civil Engineering Research Institute for Cold Region

Naoto Takahashi, Kenji Sato and Roberto Tokunaga

INTRODUCTION

Method for monitoring winter road conditions

- Road Weather Information Systems (RWIS)
  - Collection of weather monitoring sensors
- Friction measurement
  - Require contact between a tire and the road surface
    - Influenced by the type of vehicle and tire
    - Unable to measure friction when the vehicle is stationary.

Non-invasive surface state sensors

- Remotely measure road surface conditions
- Eliminate the need to install anything in the road
- Does not require contact between a tire and the road surface

Literature review

- Sensors' ability to provide reliable data has been tested
  - Haavasoja et al. (2006), Feng and Fu (2008), Bridge (2008), Jonsson (2009), Ewan et al. (2013), Vaa (2013), Takahashi et al. (2014), etc.
- No studies have addressed the reliability of the sensors on different pavement types.

➡ **Investigate the performance of a non-invasive surface state sensor on different pavement types**

STUDY METHOD

Devices used in the study

Continuous Friction Tester (CFT)

- Measure the axial force on a measuring wheel
- Halliday Friction Number (HFN): 0 - 100
- Affected by the vehicle's steering angle

Vaisala DSC111

- Thickness of water/snow/ice
- Grip level on a scale of 0.0 - 1.0

Test vehicle equipped with CFT and DSC111

Measuring system

- Data obtained by DSC111, CFT and other devices are aggregated to the in-vehicle computer
- Recorded at intervals of 0.1 seconds

•Data item

- •Date & Time (GPS)
- •Latitude & Longitude (GPS)
- •Friction I (HFN -CFT)
- •Speed (km/h -CFT)
- •Air Temp. (ºC -Surface Patrol)
- •Surface Temp. (ºC -Surface Patrol)
- •Weather (Visual assessment)
- •Point Marking (Manual)
- •Surface Condition I (Visual assessment)
- •Surface Condition II (DSC111)
- •Friction II (grip level -DSC111)
- •Water Layer (mm -DSC111)
- •Ice Layer (mm -DSC111)
- •Snow Layer (mm-DSC111)

Experimental site and design

Tomakomai test track

- 2,700 m in circumference, 1,200-m straightaway
- Paved with gap-graded asphalt (DGA), stone mastic asphalt (SMA) and porous asphalt (PA)

Road surface conditions

- Dry, wet, icy

Tomakomai test track

Road surface conditions

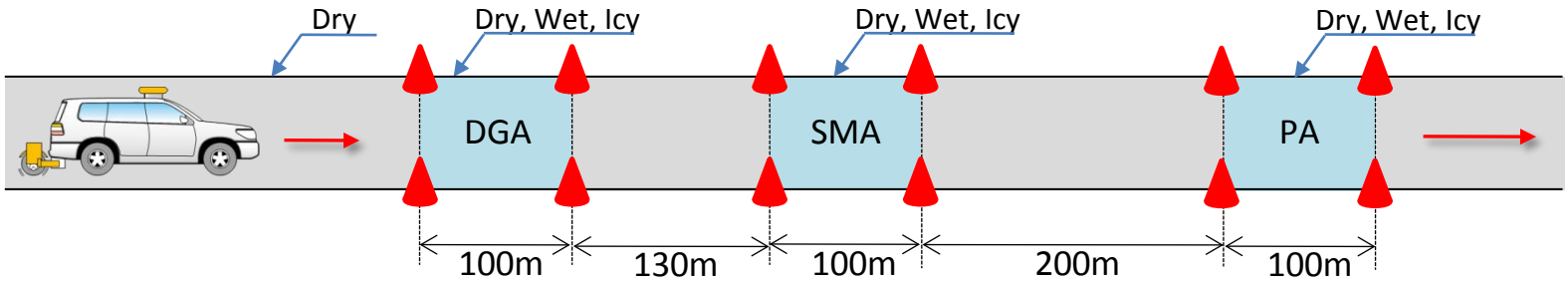
Creation of road surface conditions

- Wet: apply water to the dry surface with a road sprinkler
- Icy: sprinkle water when the air temp. was below zero
- Thickness: 0.5mm – 1.0mm (on DGA)
- Measured with a NASA water-film depth gauge

NASA water-film depth gauge

Test track layout and test conditions

- Surface conditions: Dry, Wet, Icy
- Test speed: 20km/h
- Calibration (dry signals): DGA,SMA, PA



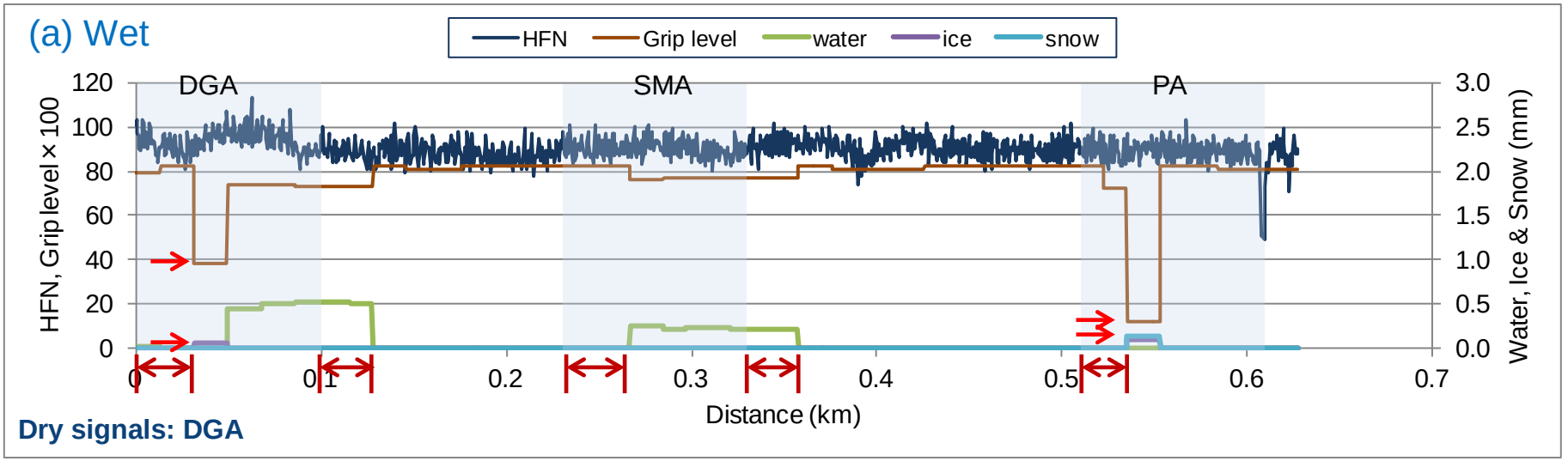
Test track layout

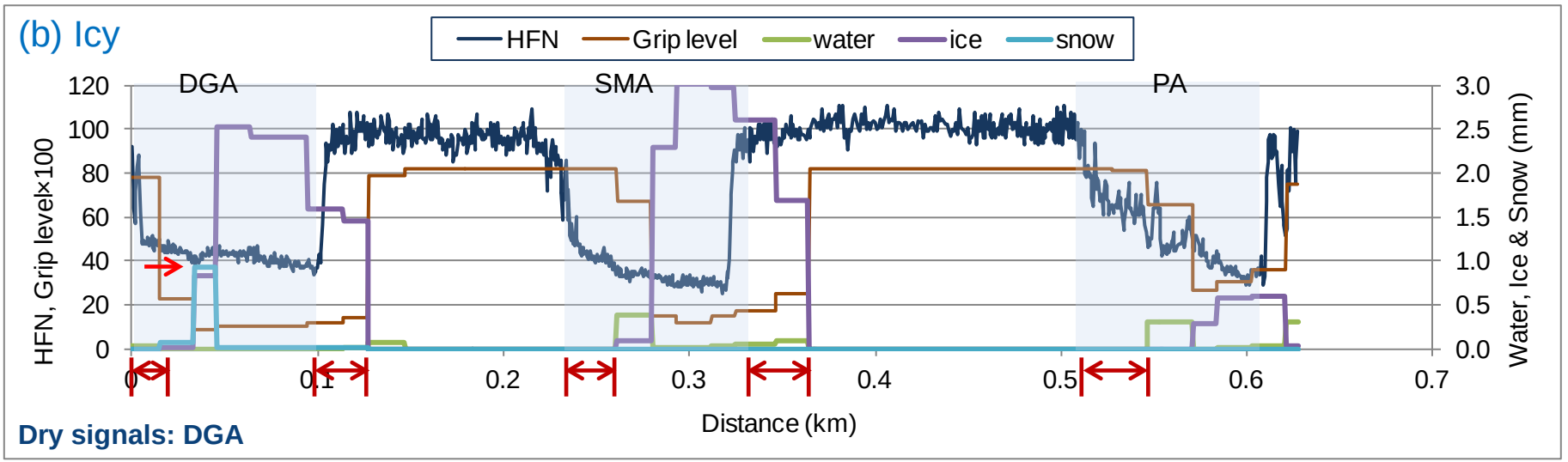
Weather conditions &Test conditions

Date	21-Jan-15	26-Jan-15	28-Jan-15
Weather	Clear	Clear	Clear
Time	14:50 ~ 18:51	14:01 ~ 20:02	14:01 ~ 18:03
Air Temp. (℃)	-4.4 ~ 4.1	1.3 ~ 9.3	-6.3 ~ 1.9
Surface Temp. (℃)	-4.2 ~ 5.9	-1.3 ~ 9.0	-6.4 ~ 7.0
Dry signals	DGA	SMA	PA
Surface conditions	Wet / Icy	Dry / Wet / Icy	Dry / Wet / Icy

TEST RESULTS

Example of measurement result

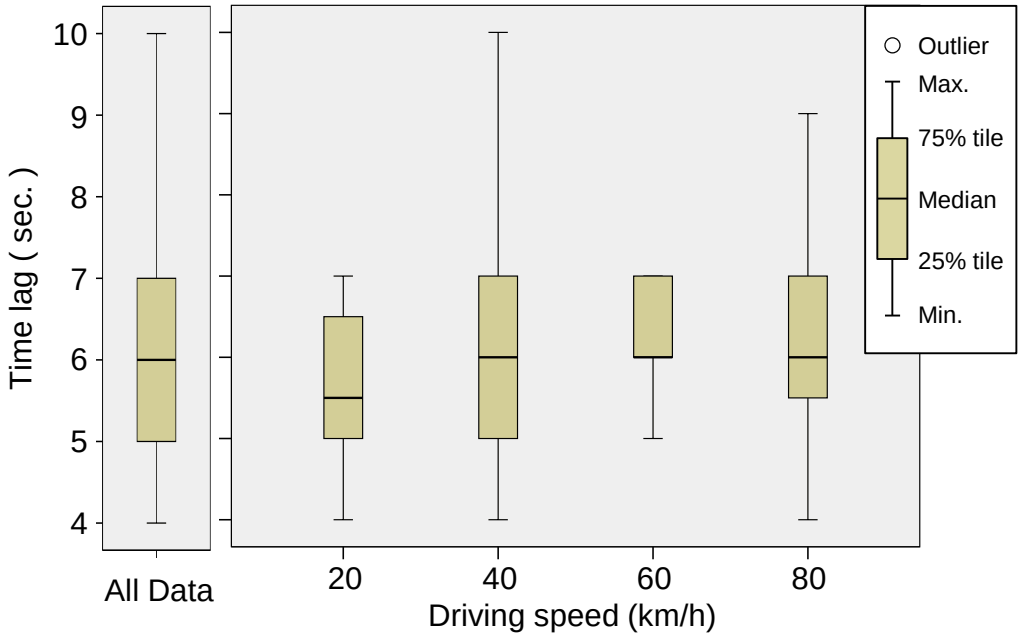




Time Lag between Measurement and Output

Takahashi et al. (2014)

- Time lag between measurements and outputs ranges from 4 to 10 sec., and averages 6 sec.
- The time lag is not affected by the driving speed of the test vehicle.



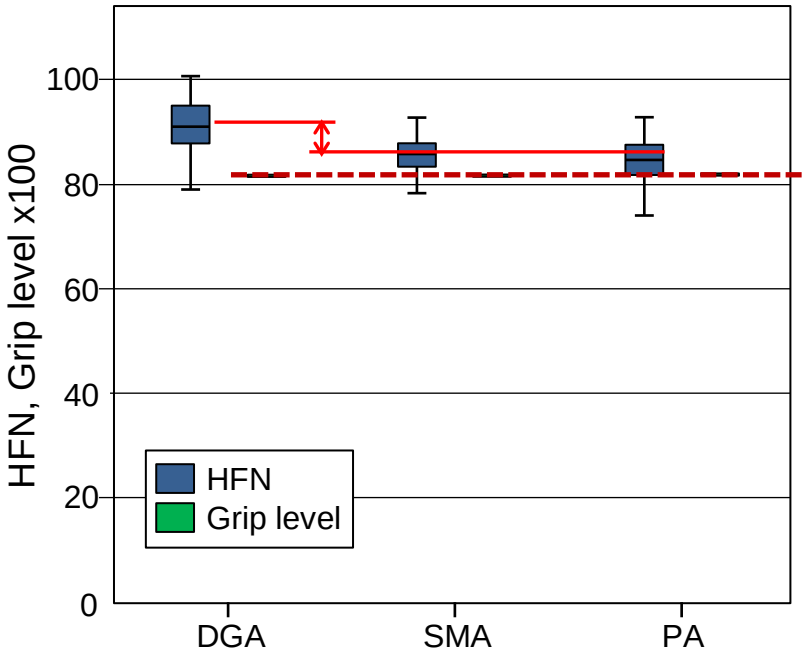
	Samples	Time lag (sec.)				
		Avg.	Med.	SD	Min.	Max.
All Data	69	6.2	6.0	1.5	4.0	10.0
20km/h	12	5.6	5.5	1.1	4.0	7.0
40km/h	33	6.3	6.0	1.8	4.0	10.0
60km/h	12	6.2	6.0	0.7	5.0	7.0
80km/h	12	6.3	6.0	1.6	4.0	9.0

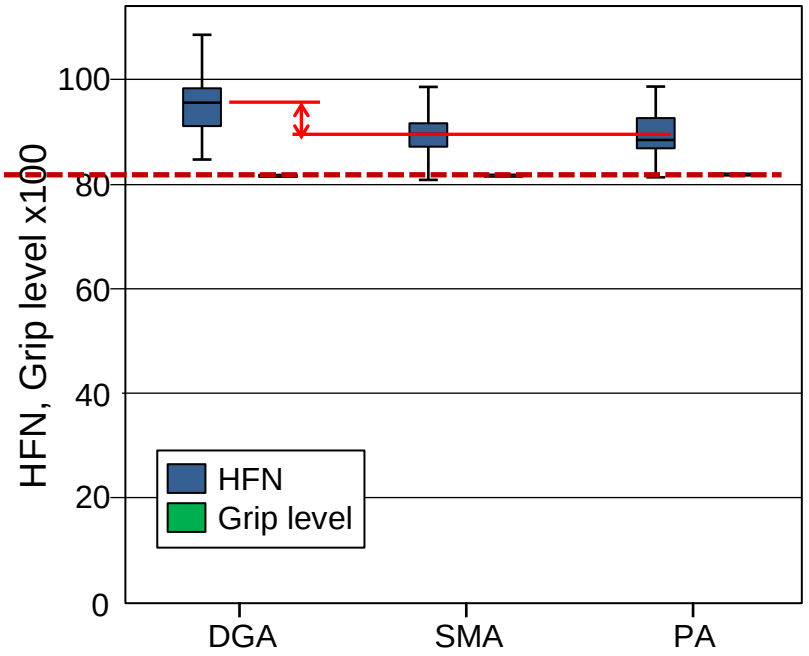
Time lag between measurement and output, from Takahashi et al. (2014)

➡ Exclude the data of the first 10 sec. to eliminate the influence of the time lag

Measurement results for the dry surface

- Surface condition: Dry
- Dry signals: SMA, PA
- Surface Temp.: -1.3 to 9.0 deg. C. (SMA), -6.4 to 7.0 deg. C. (PA)



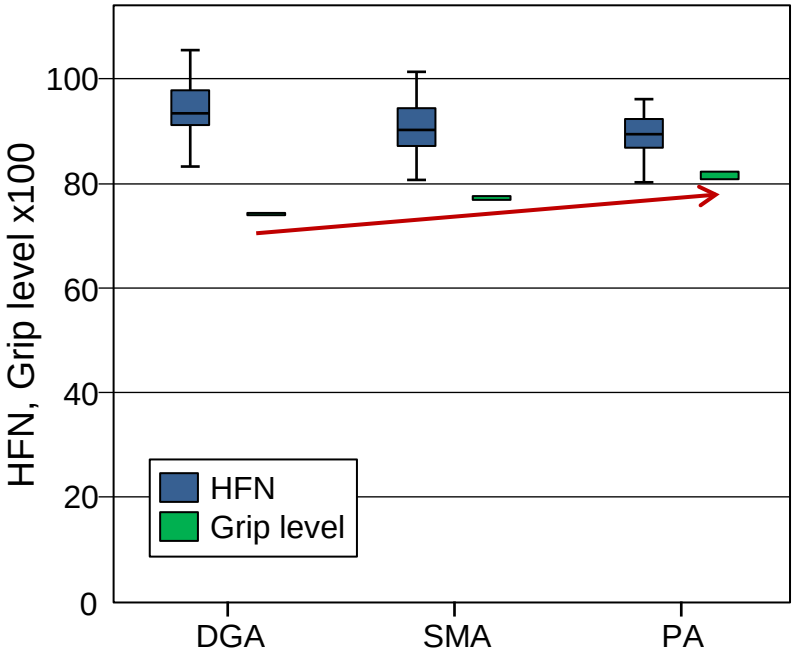


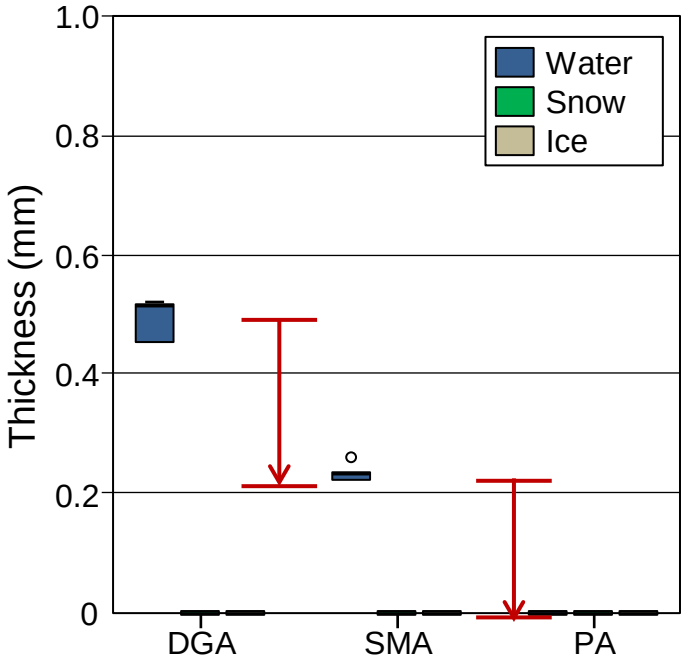
Device	Pavement	Samples	Ave.	Med.	SD	Min.	Max.
CFT	DGA	74	91.9	91.0	5.4	79.0	107.0
	SMA	69	85.4	86.0	3.7	78.0	93.0
	PA	75	85.1	85.0	4.3	74.0	93.0
DSC111	DGA	74	82.0	82.0	0.0	82.0	82.0
	SMA	69	81.9	82.0	0.2	81.0	82.0
	PA	75	82.0	82.0	0.0	82.0	82.0

Device	Pavement	Samples	Ave.	Med.	SD	Min.	Max.
CFT	DGA	59	95.0	96.0	5.2	85.0	109.0
	SMA	65	89.4	90.0	4.1	81.0	101.0
	PA	69	89.6	89.0	4.1	81.0	99.0
DSC111	DGA	59	82.0	82.0	0.0	82.0	82.0
	SMA	65	81.8	82.0	0.4	81.0	82.0
	PA	69	82.0	82.0	0.0	82.0	82.0

Measurement results for the wet surface

- Surface condition: Wet
- Dry signals: DGA
- Surface Temp.: -4.2 to 5.9 deg. C.



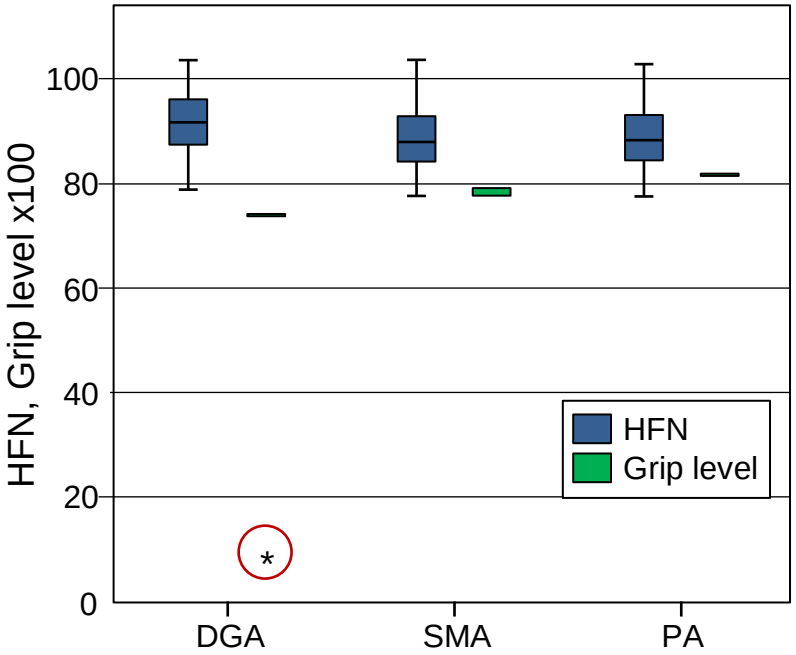


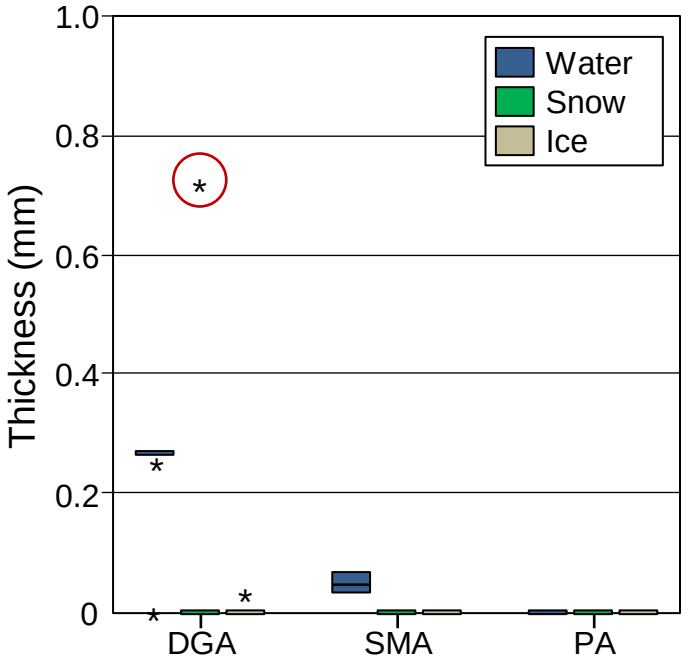
Device	Pavement	Samples	Ave.	Med.	SD	Min.	Max.
CFT	DGA	83	94.1	93.0	5.7	81.0	91.0
	SMA	81	90.3	90.0	4.4	80.0	94.0
	PA	79	89.1	89.0	4.3	80.0	88.0
DSC111	DGA	83	73.7	74.0	0.4	73.0	74.0
	SMA	81	76.8	77.0	0.4	76.0	77.0
	PA	79	81.5	81.0	0.5	81.0	81.0

Pavement	Layer	Samples	Ave.	Med.	SD	Min.	Max.
DGA	Water	83	0.49	0.51	0.03	0.45	0.52
	Snow	83	0.00	0.00	0.00	0.00	0.00
	Ice	83	0.00	0.00	0.00	0.00	0.00
SMA	Water	81	0.23	0.23	0.01	0.22	0.26
	Snow	81	0.00	0.00	0.00	0.00	0.00
	Ice	81	0.00	0.00	0.00	0.00	0.00
PA	Water	79	0.00	0.00	0.00	0.00	0.00
	Snow	79	0.00	0.00	0.00	0.00	0.00
	Ice	79	0.00	0.00	0.00	0.00	0.00

Measurement results for the wet surface

- Surface condition: Wet
- Dry signals: SMA
- Surface Temp.: -1.3 to 9.0 deg. C.



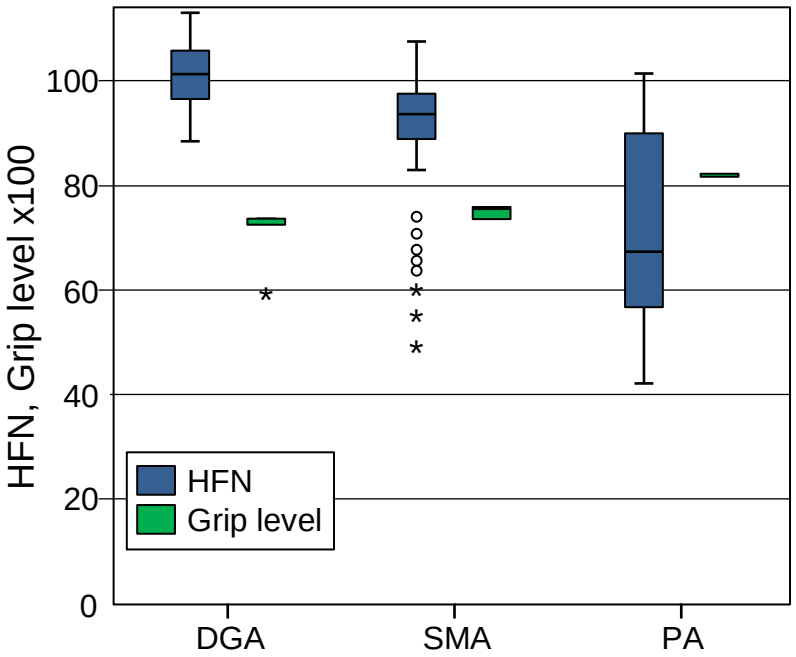


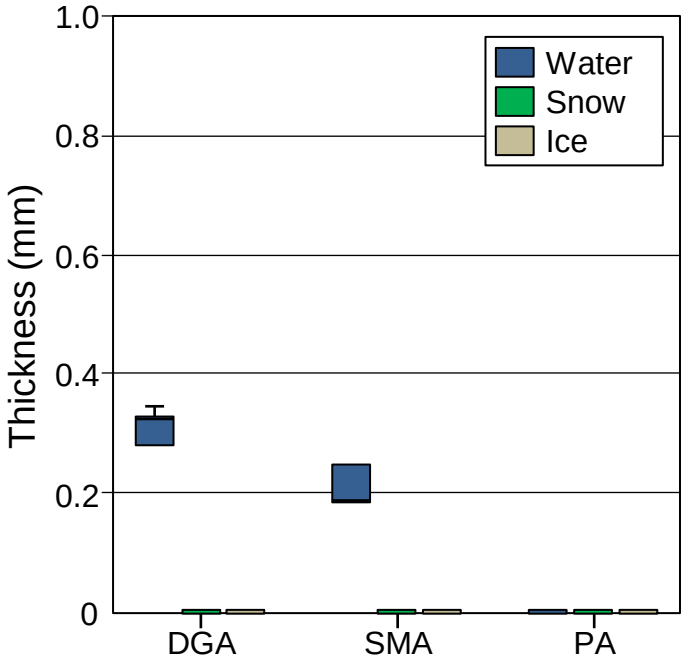
Device	Pavement	Samples	Ave.	Med.	SD	Min.	Max.
CFT	DGA	72	92.1	91.5	5.3	79.0	104.0
	SMA	76	88.6	88.0	5.4	78.0	104.0
	PA	77	89.2	89.0	5.2	78.0	103.0
DSC111	DGA	72	72.2	74.0	10.8	9.0	74.0
	SMA	76	78.7	79.0	0.5	78.0	79.0
	PA	77	82.0	82.0	0.0	82.0	82.0

Pavement	Layer	Samples	Ave.	Med.	SD	Min.	Max.
DGA	Water	72	0.26	0.27	0.04	0.00	0.27
	Snow	72	0.02	0.00	0.12	0.00	0.72
	Ice	72	0.00	0.00	0.01	0.00	0.05
SMA	Water	76	0.05	0.05	0.01	0.04	0.07
	Snow	76	0.00	0.00	0.00	0.00	0.00
	Ice	76	0.00	0.00	0.00	0.00	0.00
PA	Water	77	0.00	0.00	0.00	0.00	0.00
	Snow	77	0.00	0.00	0.00	0.00	0.00
	Ice	77	0.00	0.00	0.00	0.00	0.00

Measurement results for the wet surface

- Surface condition: Wet
- Dry signals: PA
- Surface Temp.: -6.4 to 7.0 deg. C.



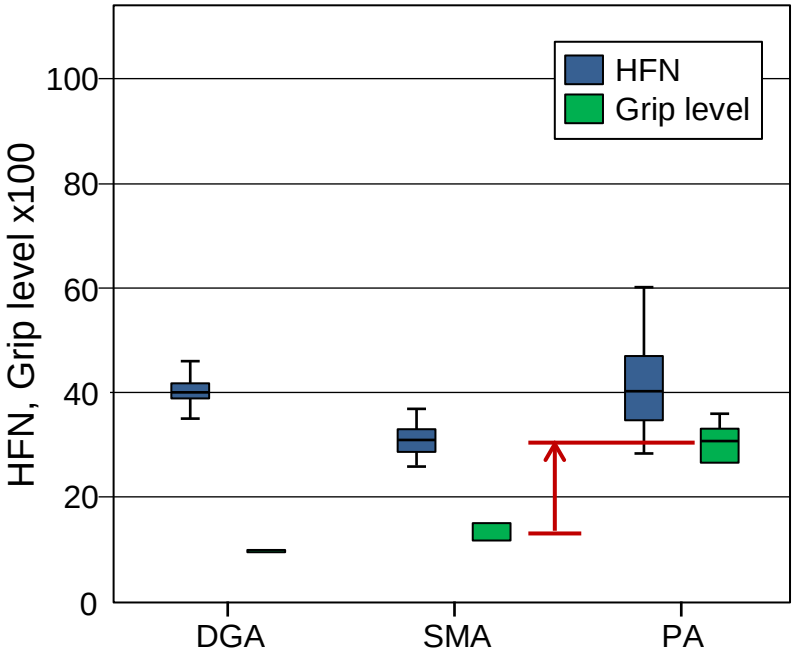


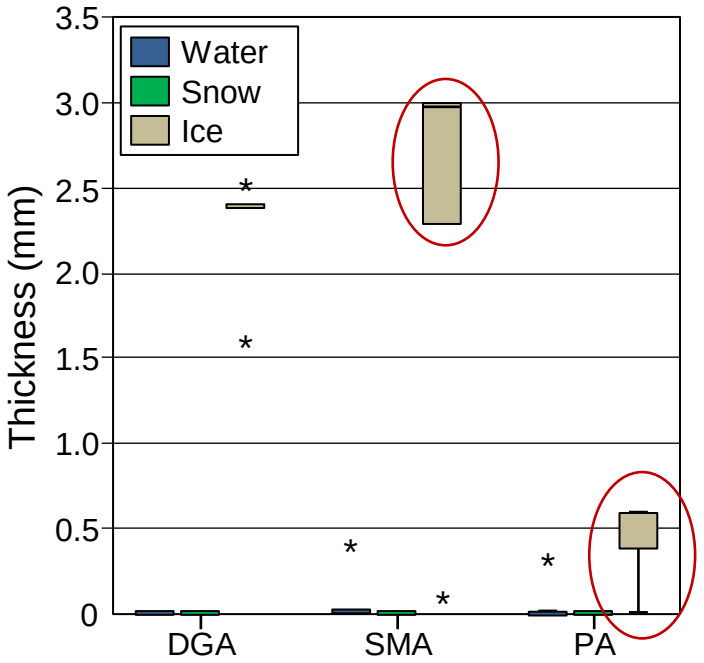
Device	Pavement	Samples	Ave.	Med.	SD	Min.	Max.
CFT	DGA	70	102.0	101.5	5.6	89.0	116.0
	SMA	73	91.7	94.0	11.4	50.0	108.0
	PA	72	72.6	67.0	18.7	42.0	102.0
DSC111	DGA	70	71.1	73.0	5.1	60.0	74.0
	SMA	73	75.0	76.0	1.0	74.0	76.0
	PA	72	82.0	82.0	0.0	82.0	82.0

Pavement	Layer	Samples	Ave.	Med.	SD	Min.	Max.
DGA	Water	70	0.32	0.33	0.02	0.29	0.35
	Snow	70	0.00	0.00	0.00	0.00	0.00
	Ice	70	0.00	0.00	0.00	0.00	0.00
SMA	Water	73	0.22	0.19	0.03	0.19	0.25
	Snow	73	0.00	0.00	0.00	0.00	0.00
	Ice	73	0.00	0.00	0.00	0.00	0.00
PA	Water	72	0.00	0.00	0.00	0.00	0.00
	Snow	72	0.00	0.00	0.00	0.00	0.00
	Ice	72	0.00	0.00	0.00	0.00	0.00

Measurement results for the icy surface

- Surface condition: Icy
- Dry signals: DGA
- Surface Temp.: -4.2 to 5.9 deg. C.



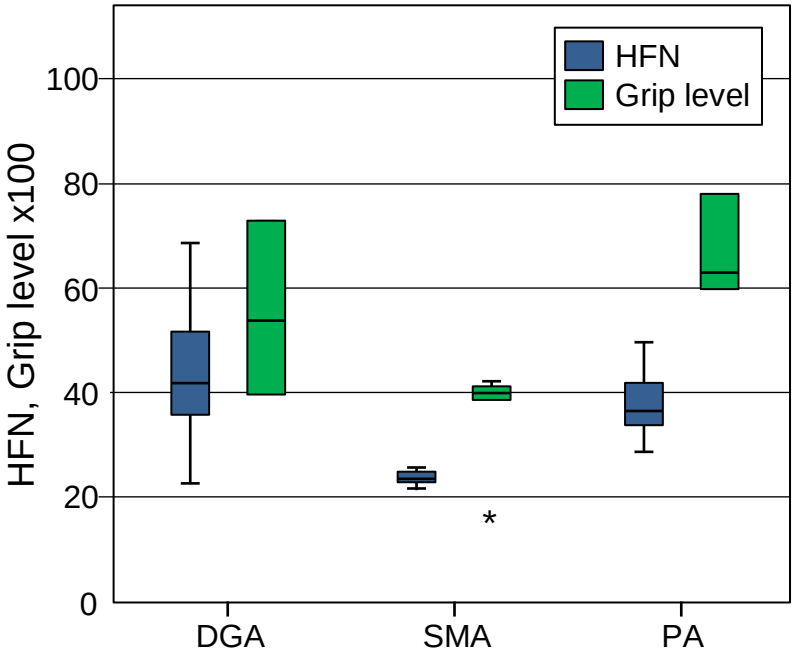


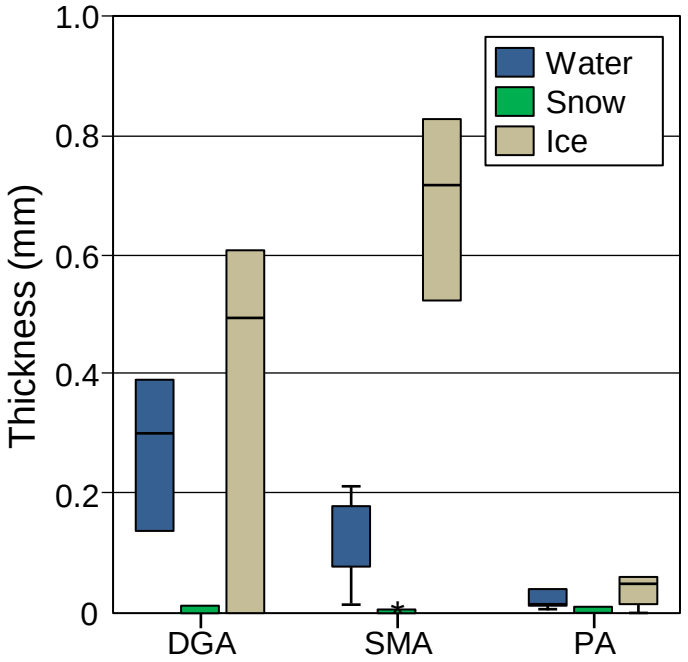
Device	Pavement	Samples	Ave.	Med.	SD	Min.	Max.
CFT	DGA	77	40.6	40.0	2.6	35.0	47.0
	SMA	73	31.4	31.0	2.3	26.0	37.0
	PA	76	41.3	40.0	7.4	29.0	60.0
DSC111	DGA	77	10.1	10.0	0.3	10.0	12.0
	SMA	73	21.4	15.0	19.4	12.0	67.0
	PA	76	38.1	31.0	15.7	27.0	66.0

Pavement	Layer	Samples	Ave.	Med.	SD	Min.	Max.
DGA	Water	77	0.00	0.00	0.00	0.00	0.00
	Snow	77	0.01	0.01	0.00	0.01	0.01
	Ice	77	2.42	2.41	0.14	1.60	2.53
SMA	Water	73	0.07	0.02	0.13	0.02	0.38
	Snow	73	0.00	0.00	0.00	0.00	0.00
	Ice	73	2.33	2.98	1.00	0.10	3.01
PA	Water	76	0.08	0.01	0.13	0.00	0.30
	Snow	76	0.00	0.00	0.00	0.00	0.00
	Ice	76	0.36	0.28	0.24	0.00	0.60

Measurement results for the icy surface

- Surface condition: Icy
- Dry signals: SMA
- Surface Temp.: -1.3 to 9.0 deg. C.



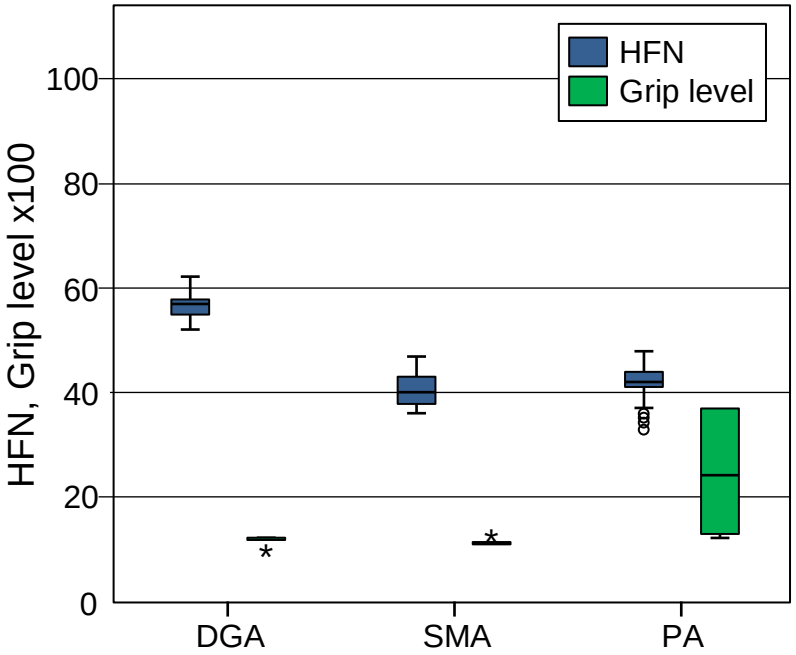


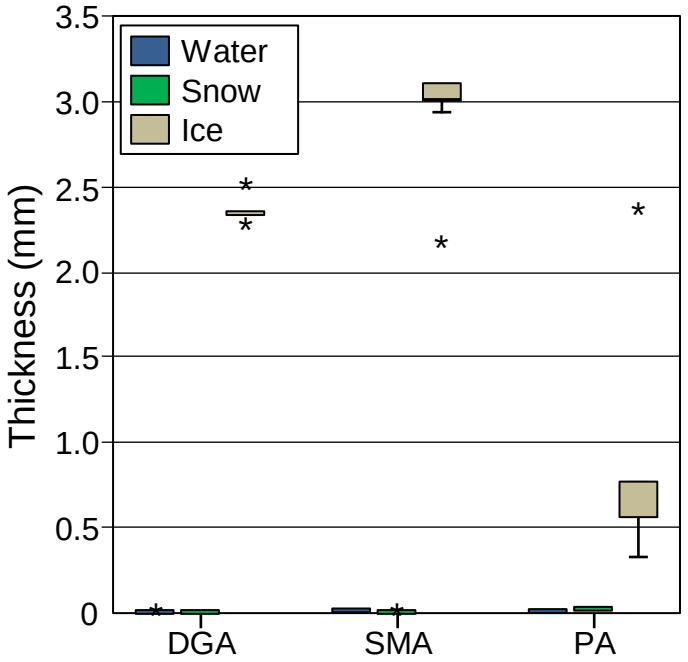
Device	Pavement	Samples	Ave.	Med.	SD	Min.	Max.
CFT	DGA	76	43.4	42.0	10.9	23.0	69.0
	SMA	69	23.9	24.0	1.2	22.0	26.0
	PA	81	38.1	37.0	5.3	29.0	50.0
DSC111	DGA	76	58.6	54.0	13.8	40.0	73.0
	SMA	69	35.6	39.0	9.5	17.0	42.0
	PA	81	68.1	63.0	8.2	60.0	78.0

Pavement	Layer	Samples	Ave.	Med.	SD	Min.	Max.
DGA	Water	76	0.30	0.30	0.10	0.15	0.39
	Snow	76	0.01	0.01	0.00	0.00	0.01
	Ice	76	0.31	0.49	0.28	0.00	0.61
SMA	Water	69	0.11	0.08	0.07	0.01	0.21
	Snow	69	0.00	0.00	0.00	0.00	0.01
	Ice	69	0.70	0.72	0.13	0.53	0.83
PA	Water	81	0.02	0.01	0.02	0.00	0.04
	Snow	81	0.00	0.00	0.00	0.00	0.01
	Ice	81	0.03	0.05	0.03	0.00	0.06

Measurement results for the icy surface

- Surface condition: Icy
- Dry signals: PA
- Surface Temp.: -6.4 to 7.0 deg. C.

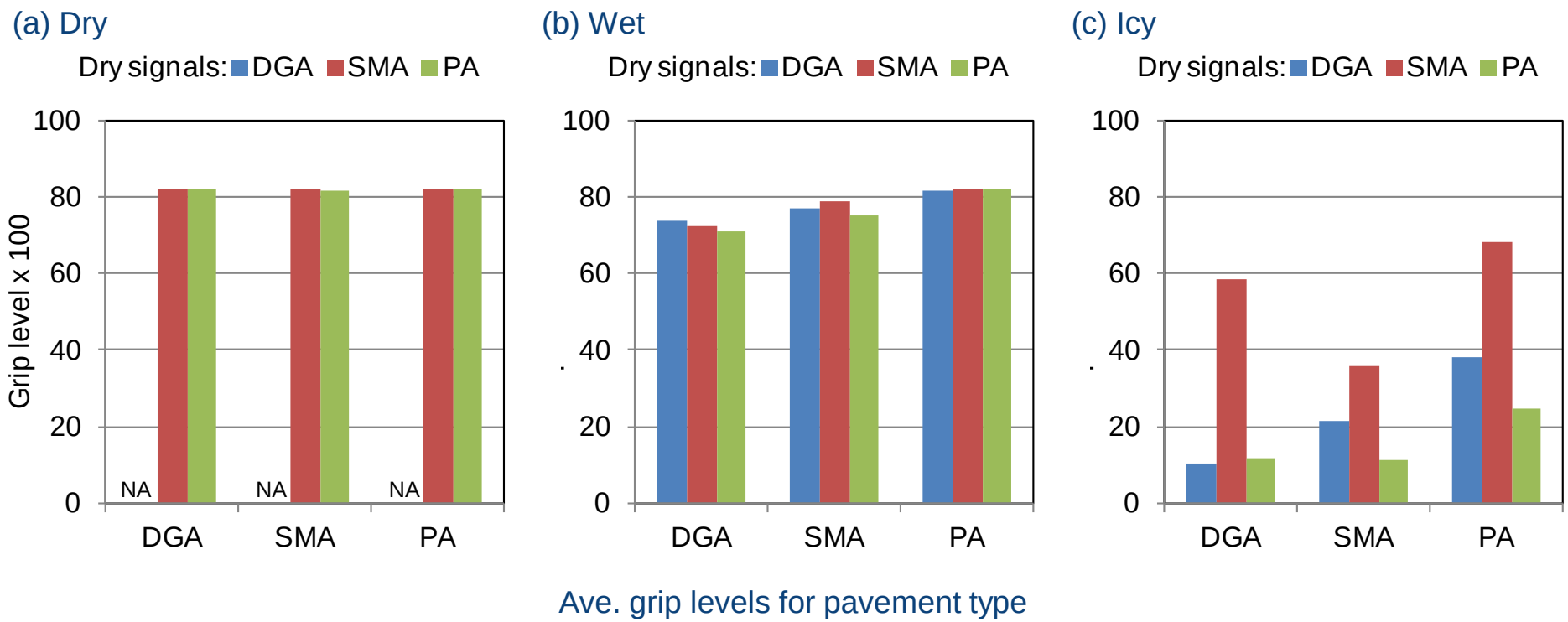




Device	Pavement	Samples	Ave.	Med.	SD	Min.	Max.
CFT	DGA	74	56.8	57.0	2.4	52.0	63.0
	SMA	72	40.7	40.0	2.9	36.0	47.0
	PA	77	41.9	42.0	3.2	33.0	49.0
DSC111	DGA	74	11.9	12.0	0.5	10.0	12.0
	SMA	72	11.4	11.0	0.8	11.0	13.0
	PA	77	24.8	24.0	9.3	12.0	37.0

Pavement	Layer	Samples	Ave.	Med.	SD	Min.	Max.
DGA	Water	74	0.02	0.02	0.00	0.01	0.02
	Snow	74	0.02	0.02	0.00	0.02	0.02
	Ice	74	2.35	2.35	0.05	2.30	2.52
SMA	Water	72	0.02	0.02	0.01	0.01	0.03
	Snow	72	0.01	0.01	0.00	0.00	0.01
	Ice	72	2.96	3.01	0.28	2.20	3.11
PA	Water	77	0.01	0.01	0.01	0.00	0.02
	Snow	77	0.01	0.01	0.00	0.00	0.01
	Ice	77	0.92	0.78	0.71	0.31	2.38

Influence of the pavement type on which “dry signals” was conducted



Ave. grip levels for pavement type

Dry & Wet surfaces: Dry signals were found to have little influence

Icy surfaces: Grip level showed high values in the case where the dry signals was conducted on SMA

CONCLUSIONS

(1) Grip levels are consistent for each surface and correspond to the friction values obtained by the CFT. The precision is good enough to discriminate between the different surfaces.

(2) The thickness of the ice layer on SMA obtained by the DSC111 was occasionally greater than the actual value. It is considered that the DSC111 might detect the ice within the voids in the SMA.

(3) The pavement type on which calibration of the DSC111 was conducted have little influence on the measurement results, except for those for the icy surface when dry signals was conducted on SMA.

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Thank you for listening!
車間注意
路面調査中
LAND CRUISER
79-85
takahashi-n24k@ceri.go.jp