

Discrepancies between longitudinal high slip and lateral low slip friction measurements on prepared ice surfaces

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ABSTRACT

The Swedish road administration requested that an independent organization facilitate friction tests with several types of friction measuring devices. These tests were done on the following three surfaces: macro rough and micro smooth ice, macro- and micro smooth ice and macro- and micro rough ice. The objective was to evaluate lateral low slip measuring devices against traditional longitudinal high slip devices. This was done by evaluating how they measure road grip, i.e. friction differences between road surfaces and the measuring tire. Tests were performed on Lake Kakel near Arjeplog, northern Sweden on March 18th, 2008. Weather conditions were stable with ice temperatures between -4°C (24.8°F) and -3°C (26.6°F). Tests showed that changes on the ice surfaces were readily detected with all four of the lateral low slip friction measurement devices and the two longitudinal high slip devices. Friction resolutions were higher with low lateral slip devices compared to high longitudinal slip devices. The tires on the devices were of different types and are the main reason for the difference in friction resolution. One major difference was detected; the lateral low slip method measured higher friction between its regular winter tire and the macro rough, micro smooth surface compared to the friction on the macro- and micro rough ice. Longitudinal high slip devices measured higher friction between its industrial friction tire and macro- and micro rough ice. Capacity to measure friction in curves was only displayed by the high longitudinal slip devices.

INTRODUCTION

Road surface conditions impact the safety of transportation on the Scandinavian road systems, especially during the winter months. One of the main challenges is to monitor and predict the dangerous conditions. High road grip, i.e. the total friction between road and tires is of great importance in avoiding hazards. The ability to decelerate and change direction quickly is affected mainly by speed and road grip, therefore knowledge of road grip and ways of measuring it are of great importance. There are many measuring devices, utilizing different methods to measure road grip. One challenge is to find out how relevant these measurements are to traffic.

Many tests have been made with different road grip measuring devices, for example see Tilley et al. (1), Evans (2) and Tokunaga (3). What is needed at this time is more information on how different devices measure road grip and how they correlate to each other. Even more important is establishing correlation between test devices and typical vehicles operating on the Scandinavian road systems.

The main objective of this paper is to show differences between road grip measurements made with lateral low slip devices (RT3) and longitudinal high slip devices (TWO). This was accomplished through a series of tests, including four RT3 units and two TWO units. In this paper we will present data and results from tests made on March 18th, 2008 on three different ice surfaces. We also present results on speed dependency.

METHODOLOGY

Devices used

For this article two types of devices were selected to be compared, RT3's utilizing low lateral slip to measure road grip, see FIGURE 1 and TWO's utilizing high longitudinal slip, see FIGURE 2.



FIGURE 1 RT3 tow hitch model mounted on Mitsubishi L200, in upper left corner tire pattern and in upper right corner display unit.



FIGURE 2 TWO device with type 523 Trelleborg friction tires.

The RT3's (4) used are towed friction measurement devices designed to be attached to the hitch of a vehicle. The RT3 utilizes a standard tire to interface with the test surface. In our tests Bridgestone Blizzak Nordic WN-01 winter tires were used. The measuring tire on the RT3 is mounted at a small offset angle to the longitudinal direction of the towing vehicle, generally around 1.5 degrees. This creates a lateral force between tire and road through hysteresis and/or adhesion which is measured by a load cell located in the hub. Lateral force acting on the tire is measured at 100 Hz. Data is averaged and down sampled to 10 Hz or less and can be exported to a peripheral logger. The PDA was also connected to a GPS via a Bluetooth link. Logged data contains:

- Geographical Positioning System (GPS) coordinates
- Road grip value (in Halliday Friction Number, HFN)
- Steering (unitless)
- Speed (in mph)
- Date and time (Year-Month-Day, Hour-Minute-Second)

Values were rounded to integers, complicating trend detection. Distance was calculated from speed and time. The HFN is calibrated to 0 with no lateral force, and adjusted to 100 when rolling over dry asphalt at 0°C with a speed of about 20 km/h. All HFN have a linear relation to the load cell force. Adjustments are made by changing the slip angle. Larger slip angle increases the hysteresis contributing to the force. An RT3 can be lifted with a hydraulic cylinder actuated with an on-board hydraulic unit, controlled from the main display located in the driver's cabin. An accumulator in the hydraulic system maintains the normal force between tire and test surface at a constant level during operation. One important benefit of this design is that a regular winter tire can be used during continuous measurements in winter conditions and a summer tire in summer conditions.

Traction Watcher One, TWO (5) is a towed friction measurement device attached to the back of a vehicle. It uses a two wheel configuration where the front reference wheel is pressed down with twice the force of the rear measurement wheel. Mechanical gears and a

chain connect the two wheels to ensure that the measurement wheel is rotating at 80 % of reference wheel speed. The largest part of the total slip occurs in the contact between the measurement wheel and the test surface, roughly 18 %. The balance of the slip occurs between the reference wheel and the test surface. Chain tension is measured between the two wheels. Normal forces acting on both tires are measured. This data is used for calculation of friction/road grip value. Data points are calculated averages and get logged with a laptop personal computer every 10 meters (32.8 feet). Log frequency is about 1 Hz - 3 Hz at normal driving speeds. Sensors log data at 100 Hz. Data points were stored with:

- Distance (in km)
- Speed (in km/h)
- GPS (in decimal latitude and longitude)
- Time (in GPS Coordinated Universal Time (UTC))
- GPS speed (in km/h)
- GPS distance (in km)

A TWO device can be enhanced with GPS, IR-temperature sensor and road surface camera. Everything but time was logged with a satisfactory resolution; time was logged in seconds.

The TWO is calibrated by pressing the reference wheel to the ground and thus locking it. A vertical strap mounted to a scale is wrapped around the rear measurement wheel and used to hold the wheel off the ground, at a height of between 0.5 – 2 cm, see FIGURE 3. The strap supplies a force transforming into tension in the chain between the wheels, and normal force acting through the pivot point. The TWO is calibrated at a tension of 294 N (66 pounds) and at 588 N (132 pounds), giving calibration constants for normal load and friction force. A TWO device has a shock absorber and is hydraulically lowered and elevated from the test surface.

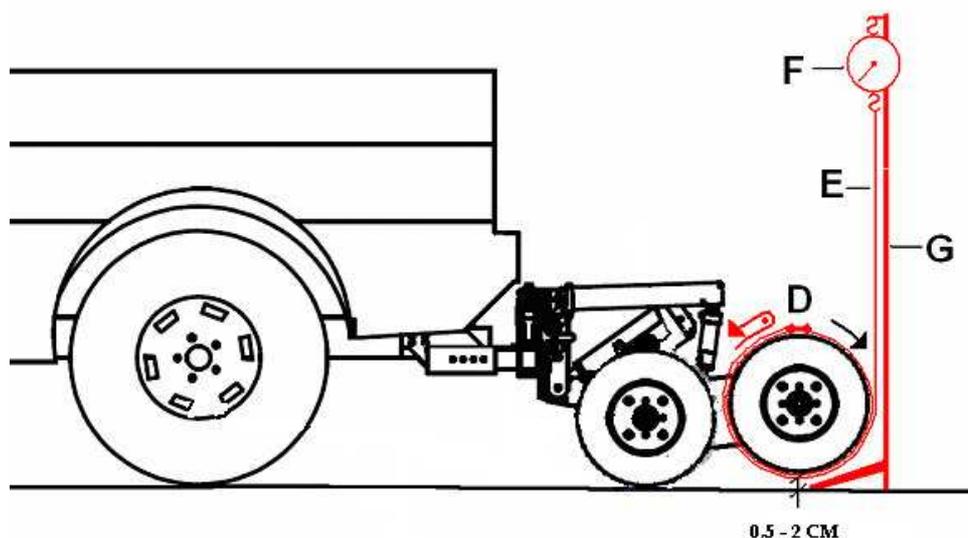


FIGURE 3 Calibration of TWO unit, D = Shackle, E = lifting strap, F = scale, and G = calibration stand.

TWO's use two Trelleborg friction tires of type 523. The two tires should be as similar as possible regarding type, age and wear. The tires are not standard winter tires, they

are made to test friction on airport runways, and have different characteristics than winter tires used for transport on winter roads. Tires with reduced thread pattern are needed in an application with high slip ratio, as wear rates would be high with tread patterns found on winter tires for cars.

Surface preparation and track layout

Tests were performed on Lake Kakel, Arjeplog, Sweden. Test tracks were prepared with three different ice surfaces in succession, see FIGURE 4. First was “Old System 2000 ice”, ice aged through weather and wear to micro smoothness while maintaining its macro roughness. “Brushed old polished ice”, is old polished ice which was snow covered and then brushed off, producing a macro smooth and micro rough surface. “New System 2000 ice”: freshly prepared ice surface with grated furrows created with System 2000, to create a macro- and micro rough surface. A light snowfall covered the first and last section of the track with about ten millimeters during the morning. Each surface section on the test track was about 130 meters long (426 feet). See FIGURE 5.

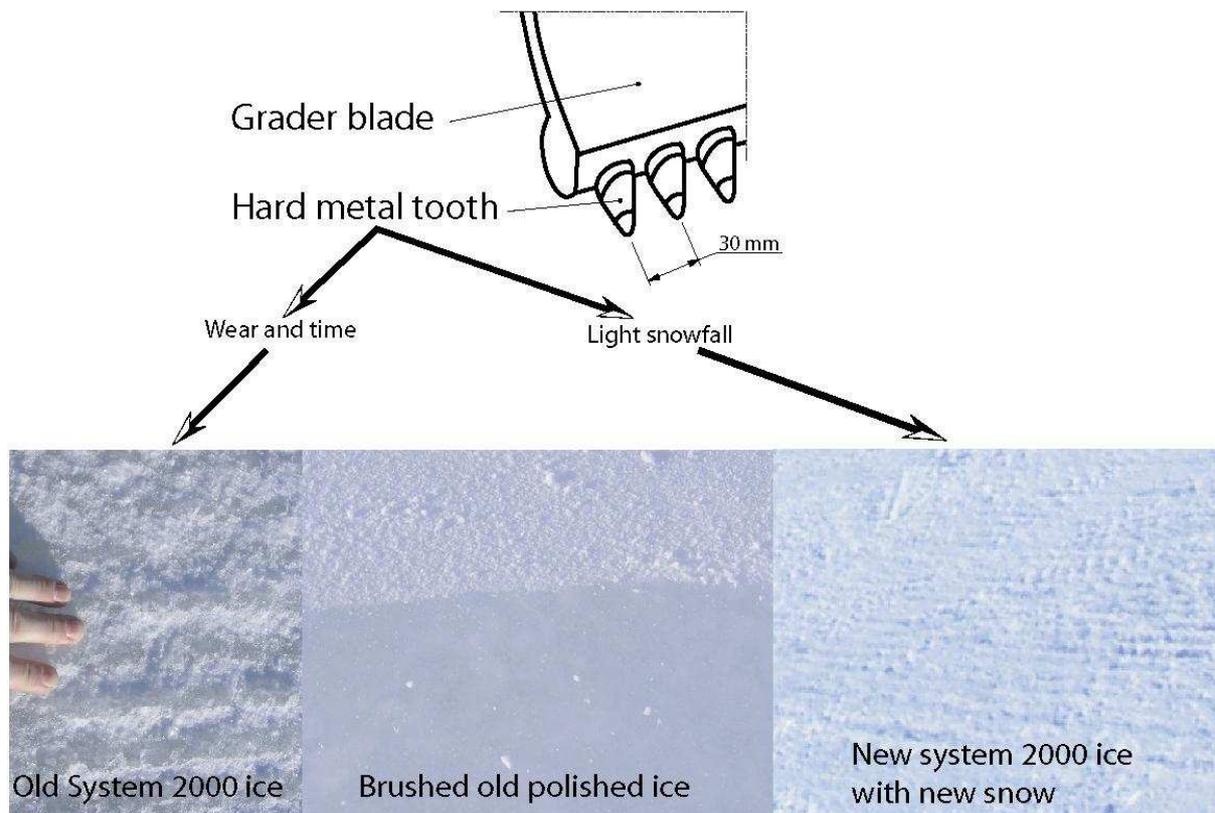


FIGURE 4 System 2000 tool, Old System 2000 ice, Brushed old polished ice and New System 2000 ice with new snow.

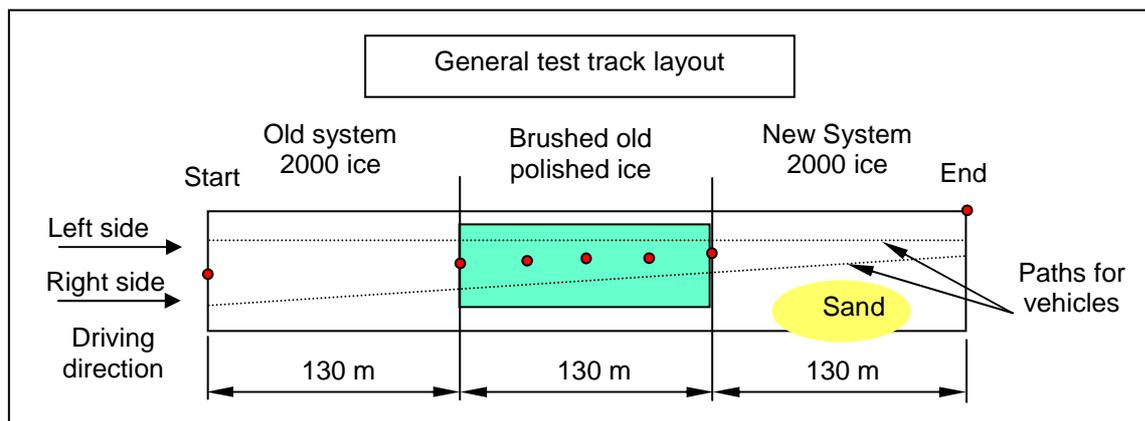


FIGURE 5 Test track layout on Lake Kakel.

Basic steps of a test were:

- Line up in the left or right lane, according to what type of tires the towing vehicle had.
- Distribute target speed to drivers. Drivers used the speedometer in the vehicle to maintain the speed required. Speeds used were 30 km/h, 50 km/h and 70 km/h.
- Accelerate each vehicle to target speed and maintain it throughout the run.
- RT3 drivers started logging data manually at the “Start” position, marked with a marker. The TWO units started the logging around 100 meters before the “Start” position, see FIGURE 5.
- Logging of data was stopped at the “End”, also marked with a marker.

TABLE 1 lists runs, time of test runs, speed in km/h and designation of each unit. The surfaces were separated into a left lane, for vehicles with studless tires, and a right lane, for vehicles with studded tires. At the end of the day, the two TWO’s changed to drive in the right lane.

TABLE 1 Test runs made on Tuesday, March 18, 2008. G0## is designations of different RT3 units, TWOV and TWOT are designations of TWO units.

Time	Runs	Speed [km/h] ¹	Units on right side	Units on left side
10:26 – 10:44	1 – 3	30	G065, G055	G053, G056, TWOV, TWOT
10:45 – 10:57	4 – 6	50	G065, G055	G053, G056, TWOV, TWOT
10:57 – 11:10	7 - 9	70	G065, G055	G053, G056, TWOV, TWOT
14:12 – 14:24	10 – 12	50	G065, G055	G053, G056, TWOV, TWOT
14:25 – 14:34	13 – 15	70	G065, G055	G053, G056, TWOV, TWOT
14:34 – 14:42	16 – 18	30	G065, G055	G053, G056, TWOV, TWOT
15:08 – 15:18	19 – 21	70	G065, G055, TWOV, TWOT	G053, G056
15:19 – 15:26	22 – 24	30	G065, G055, TWOV, TWOT	G053, G056
15:27 – 15:37	25 – 27	50	G065, G055, TWOV, TWOT	G053, G056

¹) 1 km/h is 0.621 mph

Weather conditions were recorded and stable during the day. Ice temperatures were between -4°C (24.8°F) and -3°C (26.6°F).

Data analysis

Measurement data was logged as machine readable ASCII files. Files were read into MATLAB, where important data such as distance traveled, road grip value and time were retrieved or calculated. One log file consisted of measurements from three ice surfaces; one section roughly 100 meters long from each ice surface was extracted. Average and standard deviations were calculated for each section, see FIGURE 6. Average road grip value, weighted over variance, was calculated for each vehicle on each section for a selection of runs. Measurements on runs with low precision do not contribute as much to the weighted average. Measurements are presented with average values and two un-weighted standard deviations, to ensure 95 % confidence intervals.

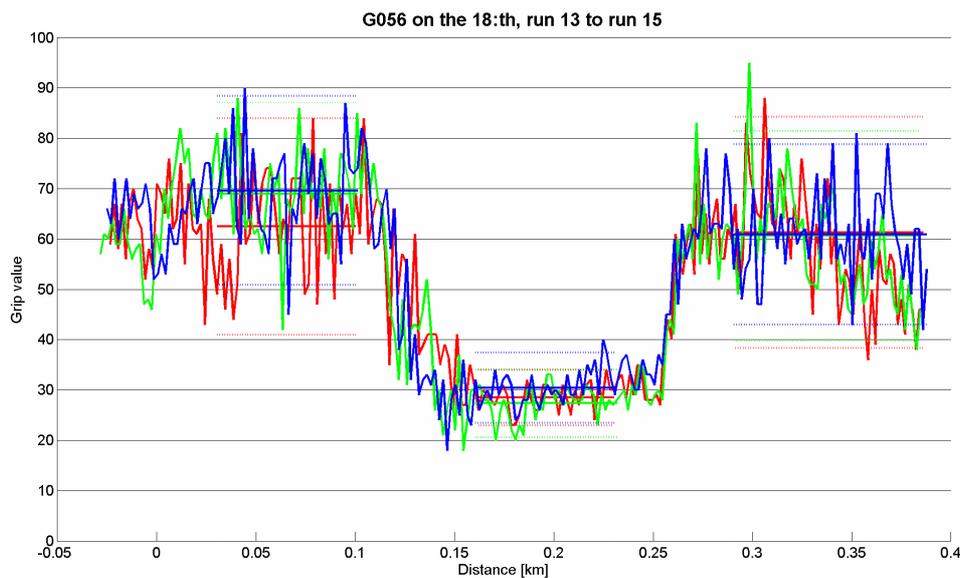


FIGURE 6 Raw data from three runs made by RT3 G056. Thick colored horizontal lines represent average road grip values for the selected section on that ice surface. Thin colored dotted lines are two standard deviations from averages.

RESULTS AND DISCUSSION

Discrepancies of friction measurement

FIGURE 7 illustrates normalized weighted road grip averages measured with all units at 30 km/h, as well as two standard deviations on each side of calculated average road grip. Note that average road grip is found in the center of the vertical lines representing four standard deviations. Road grip averages are normalized and have unit value on “Brushed old polished ice”. FIGURE 8 and FIGURE 9 illustrate normalized weighted road grip averages at 50 km/h and 70 km/h respectively. FIGURE 10 illustrates the result from all runs listed in TABLE 1. We see that the difference between highest and lowest friction is significantly higher for the RT3’s. We also see that the RT3 with low slip measures low values on new System 2000 ice. It is our opinion that the maximum friction value with optimal slip would be found on new System 2000 ice. Pilli-Sihvola (6) found that slip angles of between 3.5 and 6 degrees generate highest friction on smooth ice where slip angles up to 15 degrees were needed on packed snow. This is the reason why the RT3 with its low slip angle measures lower friction values on new System 2000 ice, a surface more similar to hard packed snow.

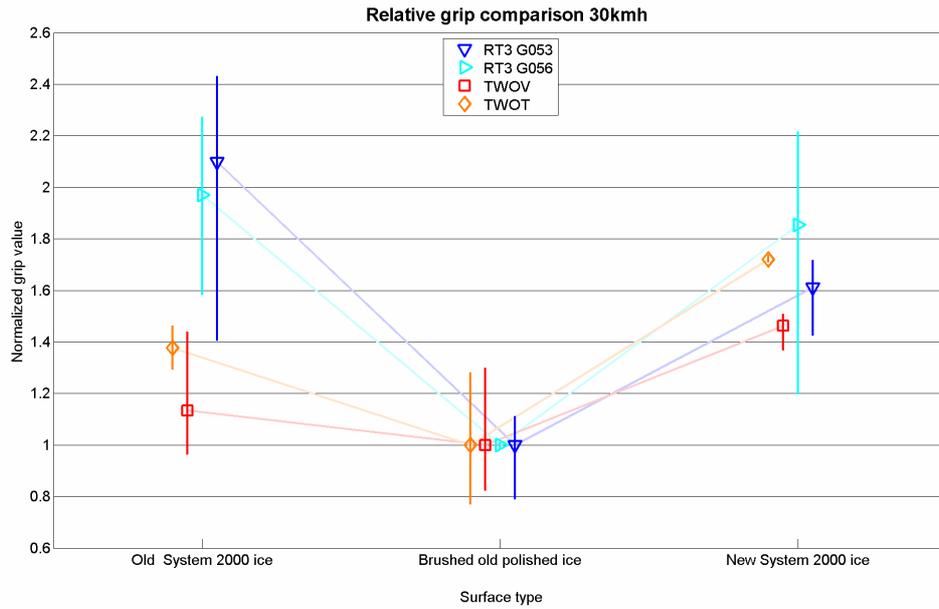


FIGURE 7 Normalized weighted road grip comparison at 30 km/h with RT3's G053 G056, TWO's TWOV and TWOT. Arjeplog March 18th, 2008.

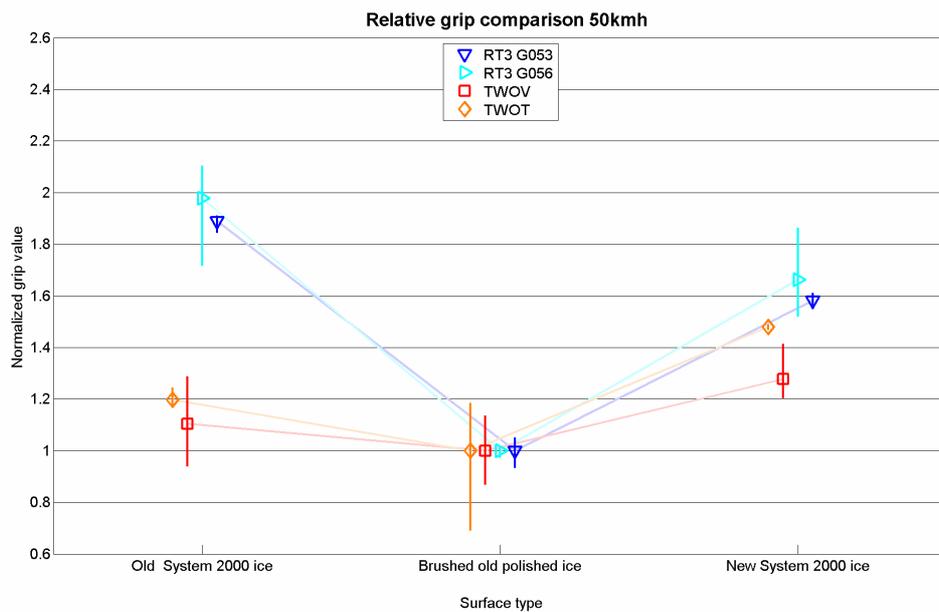


FIGURE 8 Normalized weighted road grip comparison at 50 km/h with RT3's G053, G056, TWO's TWOV and TWOT. Arjeplog March 18th, 2008.

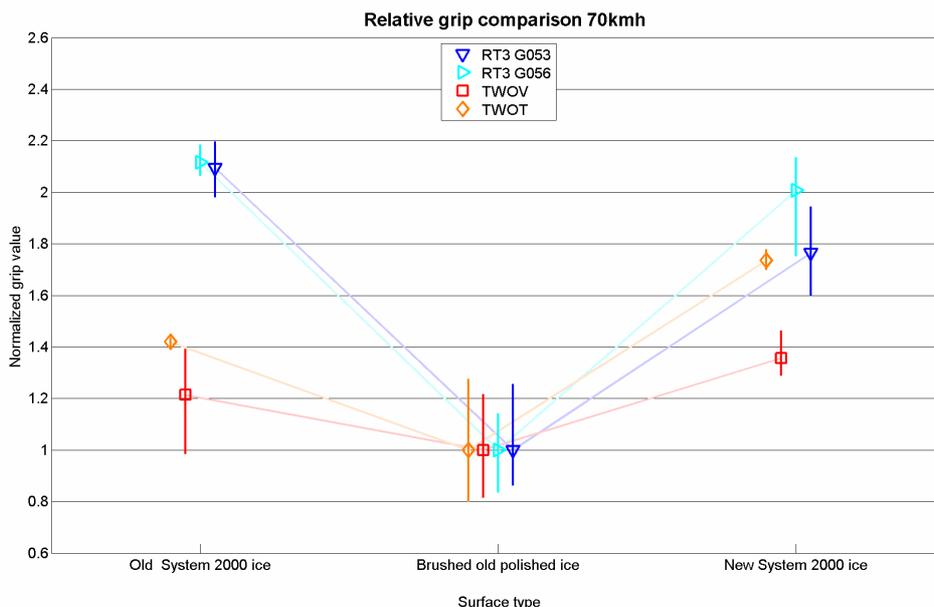


FIGURE 9 Normalized weighted road grip comparison at 70 km/h with RT3’s G053, G056, TWO’s TWOV and TWOT. March 18th, 2008.

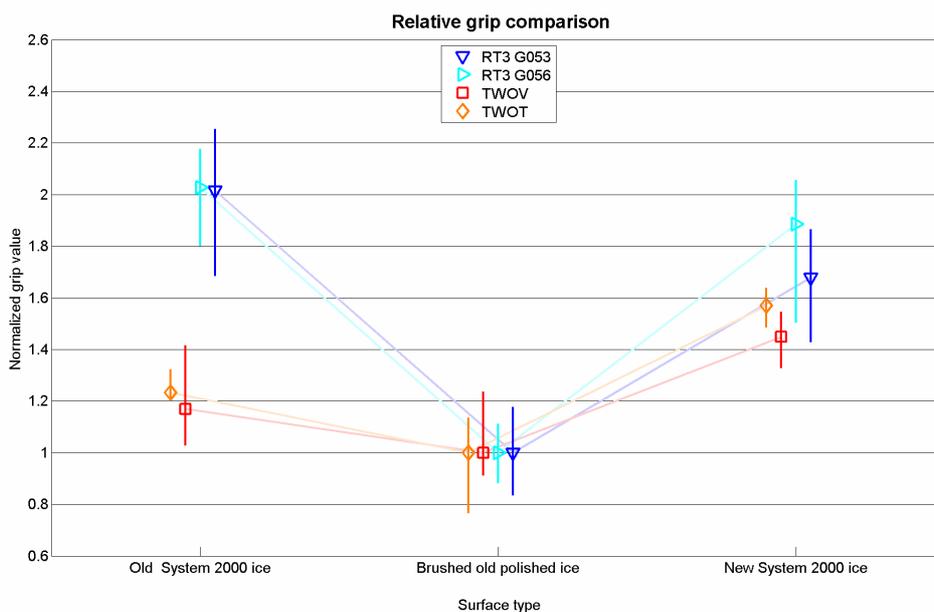


FIGURE 10 Normalized weighted road grip comparison, all speeds included. With RT3’s G053, G056 and TWO’s TWOV and TWOT. March 18th, 2008.

Speed dependency

In FIGURE 11-14 it can be seen that speed does not effect friction measurements made by the RT3 or the TWO in a statistically significant way. Measurements show friction changes as the day progress.

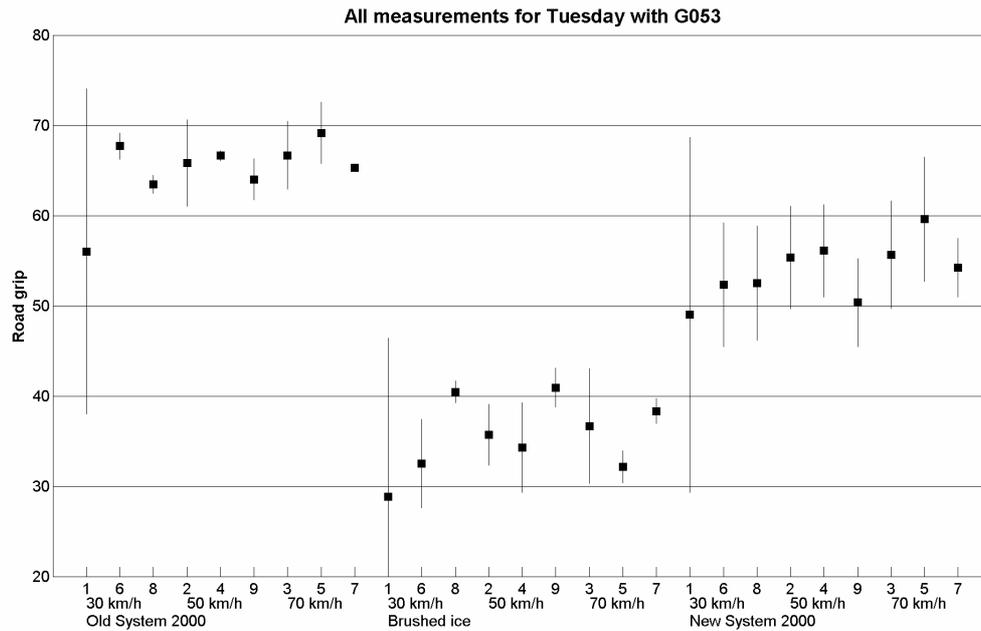


FIGURE 11 Measurements for RT3 G053, each marker representing an average of a triplicate of road grip measurements, with two standard deviations. Sorted first by surface type and then by speed.

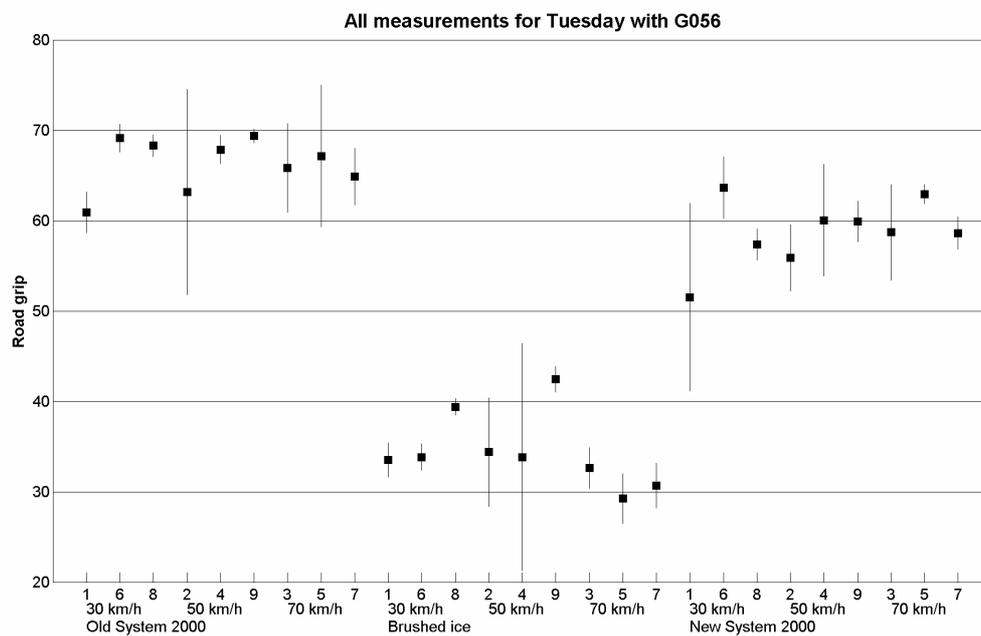


FIGURE 12 Measurements for RT3 G056, each marker representing an average of a triplicate of road grip measurements, with two standard deviations. Sorted first by surface type and then by speed.

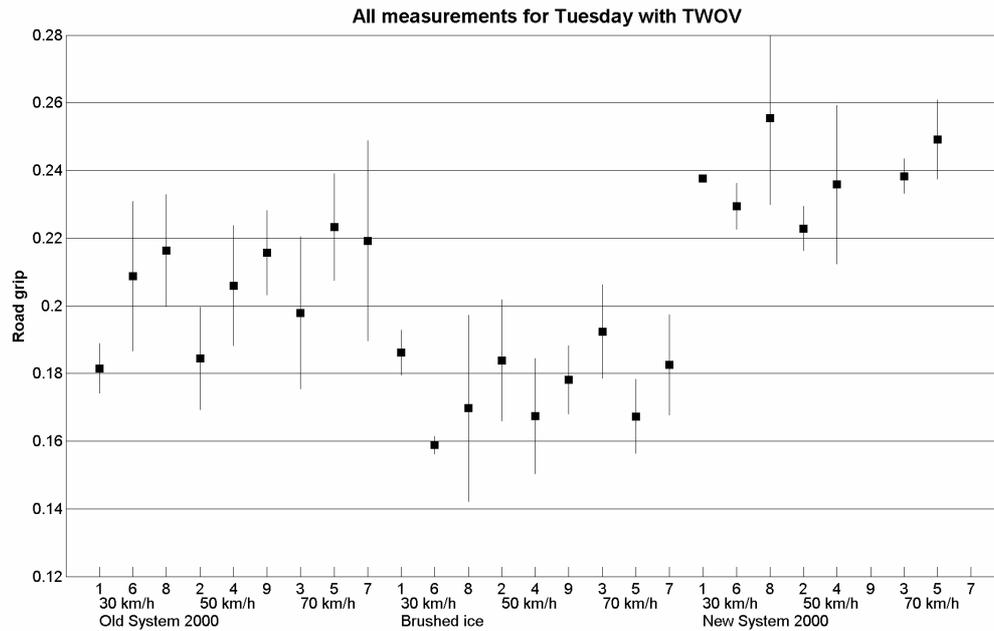


FIGURE 13 Measurements for T2O #1, each marker representing an average of a triplicate of road grip measurements, with two standard deviations. Sorted first by surface type and then by speed.

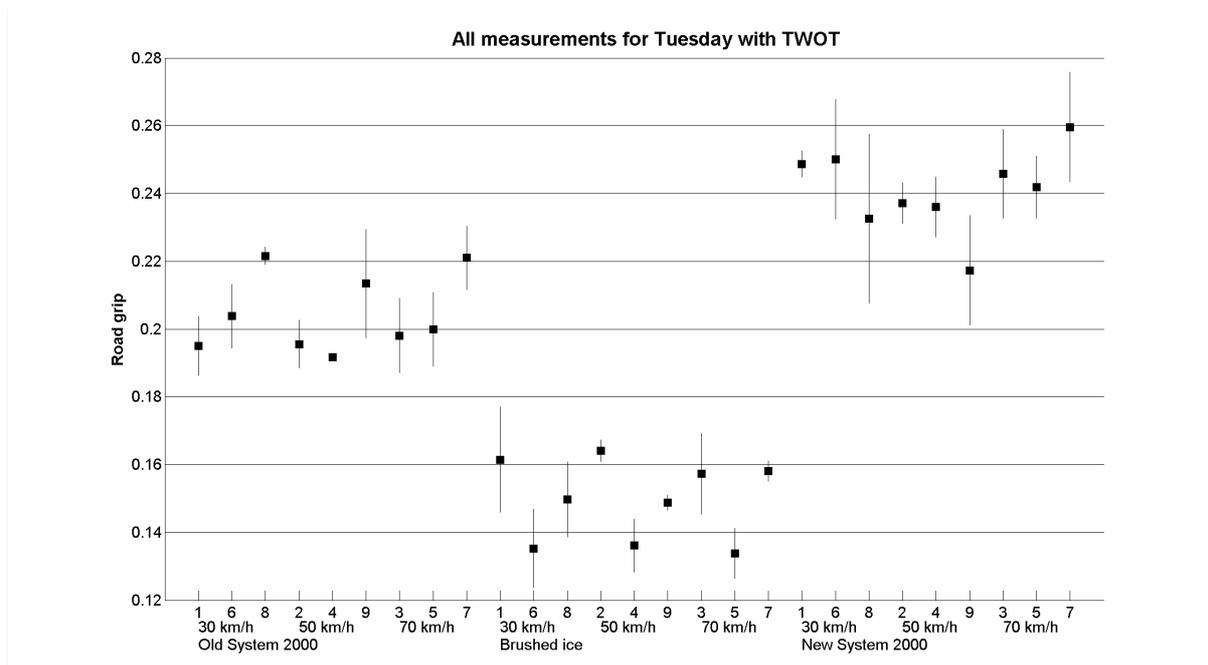


FIGURE 14 Measurements for T2O #2, each marker representing an average of a triplicate of road grip measurements, with two standard deviations. Sorted first by surface type and then by speed.

There are some points to be mention:

- Road tests should be performed with tires of similar type to the tires the vehicles operating on the road are equipped with.
- Further tests are needed to investigate how the different methods behave on more surfaces.

- The PDA type logger connected to the serial port on the back of the RT3 display used in this experiment had trouble sampling consistently at 10 Hz frequency and should be upgraded.

CONCLUSIONS

The main conclusion from these tests is that there are discrepancies between longitudinal high slip and lateral low slip friction measurements on prepared ice surfaces with furrows.

- Longitudinal high slip devices measure the absolute grip to be higher on new System 2000 ice compared to old System 2000 ice.
- Lateral low slip devices measure the road grip to be lower on new System 2000 ice compared to old System 2000 ice.
- Lateral low slip devices report larger relative difference between surface contacts with high road grip and surface contacts with low road grip compared to Longitudinal high slip devices.
- Speed did not affect road grip in a significant way during these tests.

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