ASSESSMENT AND EFFECTIVE MANAGEMENT OF PAVEMENT SURFACE FRICTION

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ABSTRACT

Pavement friction and its contribution to driver safety is complex. Vehicle collisions on a roadway are typically the result of many contributing factors including roadway design details, pavement surface characteristics, traffic levels, vehicle operating parameters, tire properties, environmental conditions, e.g. rain/snow and driver experience and visual distractions. Contributions of the pavement surface to accidents may or may not be "real" due to the inaccuracy of post-accident assessments. The development of a rational and consistent friction management plan can assist in identifying friction related contributions to accidents and reduce owner liability through accurate tracking and assessment of pavement surface condition, collision reporting and annual statistics.

This paper presents the critical components of pavement friction, overall friction management plan, methods to monitor the surface friction for both flexible and rigid pavements for highway and municipal infrastructure and the correlation between different equipment's and methods

INTRODUCTION

Pavement friction is the force developed at the pavement-tire interface that resists sliding when braking forces are applied to the vehicle tires. Surface friction is significantly influenced by surface texture and surface drainage (cross-slope). The measurement of pavement surface friction survey enables us to assess available frictional resistance, and the potential for hydroplaning and wet weather accidents. Pavement friction plays a vital role in keeping vehicles on the road as it gives drivers the ability to control their vehicles in a safe manner in both the longitudinal and lateral directions.

Out of the total 189,000 highway crashes reported in Canada in 2012, up to 35 percent of the wet weather accidents were a result of skidding and 10 percent were splash and spray related accidents. Similarly, a 1980 report by the U.S. National Transportation Safety Board estimated that 16 to 18 percent of the fatal accidents in the United States occurred when the pavements were wet. The U.S. Nationwide Personal Transportation Survey conducted in 1990 similarly reported that of almost 25 million reported accidents, 18.8 percent occurred on wet pavements. Pavement surface friction measurement is an important part of the overall pavement evaluation process. This process usually includes the measurement of both micro-texture and macro-texture of the pavement surface and pavement longitudinal and transverse slopes. This paper discusses the critical components of surface friction, overall friction management plan, methods and equipment to monitor surface friction, and the correlation between the equipment with an example case study.

FRICTION MANAGEMENT PLAN

Pavement friction management plan should include practical, well-defined work activities and be based on reliable information. To develop a successful friction management policy, an agency should identify an approach for management and process for implementation. An example of a typical friction management plan is shown in Figure 1 and includes the following key components:

- Network Definition: Highway network is subdivided into distinct pavement sections and grouped according to the friction need.

- Network-Level Data Collection: This stage involves the gathering of all the necessary information for the FMP including the collection of collision data.

- Network-Level Data Analysis: An analysis of friction and collision data is performed during this stage to assess the overall network conditions and identify friction deficiencies. During this process, areas that need detailed site investigation are identified for intervention.

- Detailed Site Investigation: This step involves evaluation of pavement sections to determine potentially deficient locations, their causes and remedies, frictional characteristics (microtexture and macrotexture) and factors causing high collision rate. Non-friction related items such as alignment; the layout of lanes and traffic control devices; the presence, amount, and severity of pavement distresses; and longitudinal and transverse pavement profiles, etc. are also evaluated during this process.

- Selection and Prioritization: This step involves the selection and prioritization of short and long term maintenance and rehabilitation strategies to address any deficiencies, frictional or otherwise. This would typically involve: scheduling remediation activities as part of overall pavement management process; identification of candidate restoration techniques best suited to correct pavement deficiencies; and comparison of costs and benefits of the different restoration alternatives over a defined analysis period.

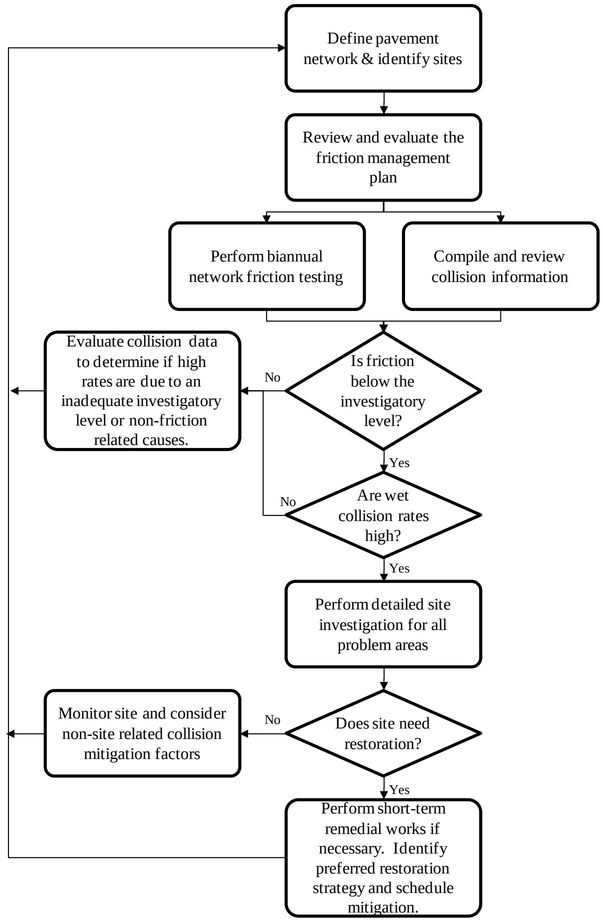

Figure 1 Example of Pavement Friction Management Plan

SURFACE TEXTURE

Surface texture is characterized by the asperities present in a pavement surface. Those asperities range from the micro-level roughness contained in individual aggregate particles to a variable span length of unevenness. The feature of the road surface that ultimately determines most of the tire/road interaction including wet friction, noise, splash and spray, rolling resistance, and tire wear is pavement surface texture. Pavement texture is typically divided into categories of microtexture, macrotexture, and megatexture based on wavelength and vertical amplitude characteristics. The two levels of texture that predominantly affect friction are microtexture and macrotexture.

In simple terms, microtexture is the roughness of individual pieces of aggregate. Essentially, the resistance to skidding on a road surface is determined by the microtexture of the surface aggregate, as demonstrated in Figure 2. The wavelength of microtexture ranges from 0.5 to 1.0 mm with a vertical amplitude ranging between 0.2 and 1.0 mm. This level of texture makes it possible to characterize a surface which is more or less rough, but is generally too small to be observed with the naked eye.

Macrotexture is the overall texture of the pavement which is generally controlled by coarse aggregate type and size in flexible pavements and by surface finish in rigid pavements. The wavelength of macrotexture ranges from 0.5 mm to 50 mm with a vertical amplitude ranging between 0.1 mm and 20 mm. This level of texture gives wavelengths of the same order of magnitude as those of the rubber strips of the tread of the tires which intervene in the tire-pavement contact.

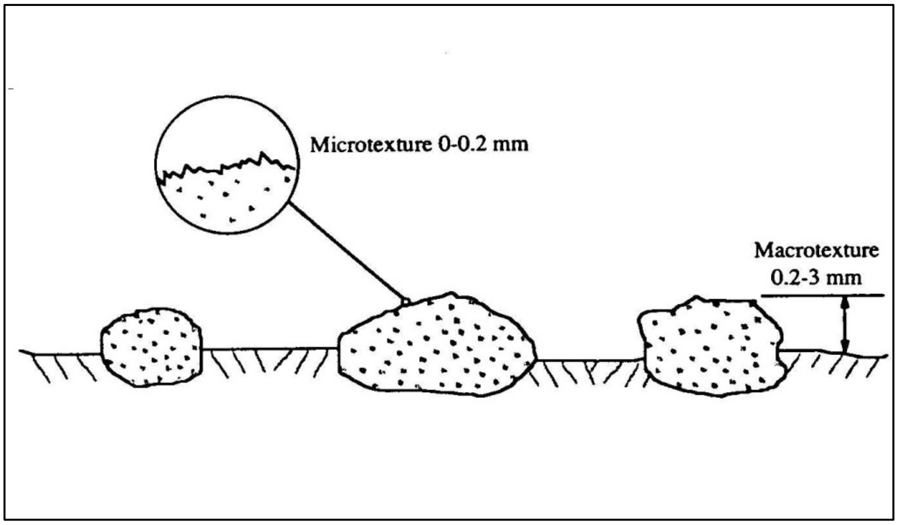

Figure 2. Illustration of the microtexture and macrotexture of the road surface
(Source: TAC Pavement Design and Management Guide, 1997. Transportation Association of Canada)

These two textures in any pavement are greatly associated in reducing wet weather related accidents. A clean and dry road surface has a high frictional resistance because tires can keep in close contact with the road surface. However, when the surface is wet, a “film” is created between the tire and the surface, which reduces the bond with vehicle tires. In such situation, an escape channel is provided by macrotexture to help get rid of surface water at the pavement-tire interface. But penetration of the remaining film of water is only possible if there is sufficient microtexture. There are various factors affecting pavement surface texture for asphalt and rigid pavements. Table 1 provides a summary of the factors and how these factors influence microtexture and macrotexture

Table 1. Factors affecting pavement microtexture and macrotexture
(Source: NCHRP Web –Only Document 108: Guide for Pavement Friction, February 2009)

Pavement Surface Type	Factor	Micro-Texture	Macro-Texture
Asphalt	Maximum aggregate dimensions		X
	Coarse aggregate types	X	X
	Fine aggregate types		X
	Mix gradation		X
	Mix air content		X
	Mix binder		X
Concrete	Coarse aggregate type	X (for exposed agg. PCC)	X (for exposed agg. PCC)
	Fine aggregate type	X	
	Mix gradation		X (for exposed agg. PCC)
	Texture dimensions and spacing		X
	Texture orientation		X
	Texture skew		X

EQUIPMENT

There are mainly four different kinds of friction survey measurement equipment types. All the devices explained below do not measure texture.

- Locked Wheel Testers: The most common method of friction measurement used in North America is the locked wheel trailer in accordance with ASTM E 274. In this procedure, a truck carrying water tank deposits a known film thickness of water on the surface ahead of a locked-wheel trailer it is towing. The operator “locks” the wheel of the trailer and the friction between the tire and pavement surface is measured at a speed of 65 km/h. General output of the locked-wheel tester is a “skid number.”

- Side Force Devices: These devices are designed to simulate a vehicle’s ability to maintain control in curves. They function by maintaining a test wheel in a plane at an angle (the yaw angle) to the direction of motion, while the wheel is allowed to roll freely (i.e., a 0 percent slip condition). The developed side force (cornering force) is then measured perpendicular to the plane of rotation. An advantage of these devices is that they can measure continuously through the test section while locked wheel devices usually sample the friction over the distance corresponding to one second of the vehicle travel after which the brake is applied. Examples of specific side force testing equipment include the MuMeter and the Sideway-force Coefficient Routine Investigation Machine (SCRIM). The MuMeter is the only side force device that has been used in North America (primarily at airports) but with only limited use in the past on highways. The results of a 1999 survey indicated that side force devices are more frequently used by foreign agencies than in the United States. In that survey, 9 of 21 responding foreign agencies reported using the side force method with a smooth tire to measure wet pavement friction.

- Fixed Slip Devices: These devices are used to simulate a vehicle's ability to brake while using antilock brakes. Fixed slip devices operate at a constant slip, usually between 10 and 20 percent slip (i.e., the test wheel is driven at a lower angular velocity than its free rolling velocity). As with the side force devices, the largest advantage of using fixed slip devices is that these testers can also be operated continuously over the test section without excessive wear of the test tire. An example of a specific fixed slip testing device is the GripTester. Although most fixed slip devices are designed to operate at only one slip ratio, some fixed slip devices have been designed to allow the slip ratio to be varied (these are termed "Variable Fixed Slip" devices). Although fixed slip devices are not commonly used in the North America, 8 of 21 foreign agencies responding to the previously mentioned 1999 survey indicated using a fixed slip device with a smooth test tire to measure wet pavement friction.

- Variable slip testers: These are similar to fixed slip devices, except that instead of using one constant slip ratio during a test, the variable slip devices sweep through a predetermined set of slip ratios (in accordance with ASTM Standard E 1859). An example of a specific variable slip device is the Norsemeter ROAR (ROad Analyzer and Recorder).

ASTM Brakeforce Trailer

The ASTM Brakeforce Trailer (Figure 3) requirements are described in ASTM E-274 and consist of a tow vehicle, a skid trailer with actuation controls for the brake of the test wheel (standard ribbed pavement test tire as per ASTM E 501-06), a transducer, instrumentation, and a water supply with a dispensing system to control the thickness of the water film . The ASTM Brakeforce Trailer has been used by many U.S. State Highway Departments and two Canadian Provinces to measure pavement surface friction. The testing equipment sprays water on the pavement surface at a pre-determined depth and the wheels of the trailer are locked and dragged over the surface of the pavement on top of the water. The force needed to drag the wheels is measured and converted into a friction number (SN). Tests are taken typically at intervals of about 3 per kilometre.

ASTM E-274 specifies a standard test speed of 65 km/hr. However, the standard practice in Ontario is to test at the posted highway speed limit for Ontario, which is 100 km/hr. Prior to performing the skid testing, the vehicle is brought up to the test speed of 100 km/hr. Water is delivered ahead of the test tire, while the braking system was actuated to lock the test tire. The resulting friction force acting between the test tire and the pavement surface, along with the test speed and temperature is recorded at each test location.

Figure 3. Vehicle and Testing Trailer Used to Complete the Skid Testing

Findlay Irvine GripTester

In light of the installation of anti-lock brake systems in most vehicles, the industry has been moving towards equipment that more closely represents this braking motion and has introduced variable slip type devices like the GripTester (GT). The Findlay Irvine Mark 2 GripTester is a variable slip friction testing device as shown in Figure 4. The GripTester is much smaller than the ASTM Brakeforce Trailer and uses a small wheel to continuously measure pavement surface friction using variable slip. An onboard computer performs self-calibration and operates the equipment during testing. The friction value is expressed as a GripNumber (GN). It is simple to operate and can test more than 80 km on a single tank of water.

Figure 4. Findlay Irvine Mark 2 GripTester

CORRELATION PROGRAM

The objective of this program was to compare friction data measured by the ASTM Brake force trailer and the Findlay Irvine GripTester outlined above. An Ontario highway was selected for the purpose of this study. Approximately 100 km was tested on the Eastbound and Westbound Direction. Two basic assumptions were used for the purpose of this analysis.

- The correlation between friction measurements between the two types of equipment may change with the test speed and with type of surface (ASTM E2793 - 10e1 Standard Guide for the Evaluation, Calibration, and Correlation of E274 Friction Measurement Systems and Equipment).

- For a similar speed and type of surface, all data can be combined as long as the pairs of data for same location are maintained

During the field testing, approximately 600 SN and over 200,000 GN values were measured. GPS coordinates were included for each measurement. The first step in the data processing was to 'clean' the data and to develop a database for each of the test runs. The GPS position of each SN value was used to determine the closest GN value to that specific test so that a correlation of individual values could be completed.

A summary of the SN and GN data are provided in Figure 5 for the eastbound lanes and Figure 6 for the westbound lanes. From the figures, it can be seen that, in general, the data shows some patterns as follows:

- The SN and GN values in the asphalt surfaced sections are similar.
- The GN values are typically lower than the SN values in the concrete surfaced sections.
- The variability of both the SN and GN values is higher in the concrete surfaced sections.

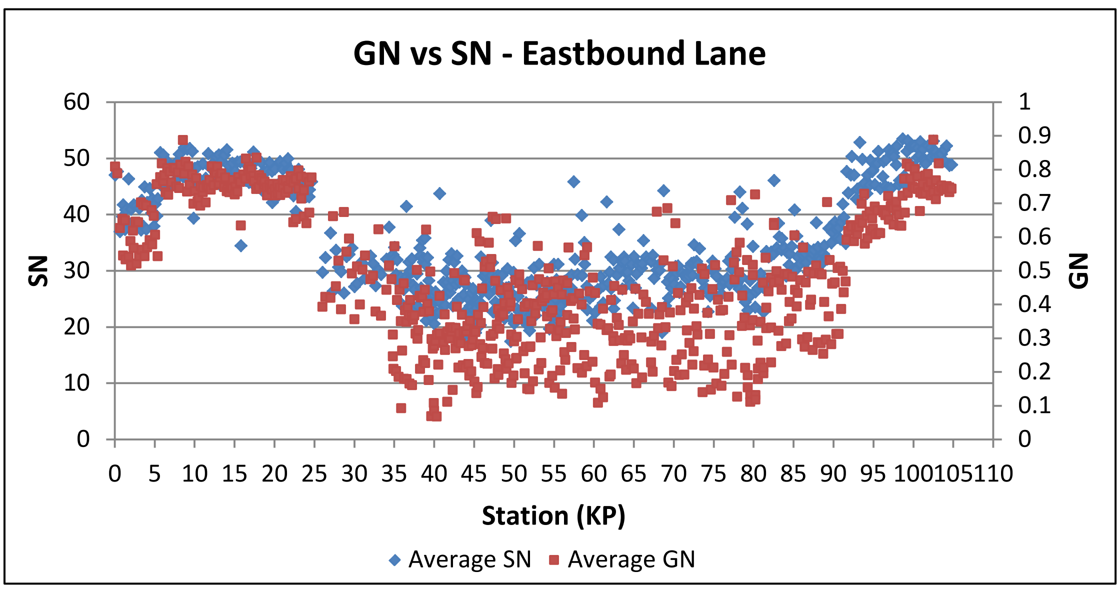

Figure 5. Friction Measurement Values – Eastbound Lanes

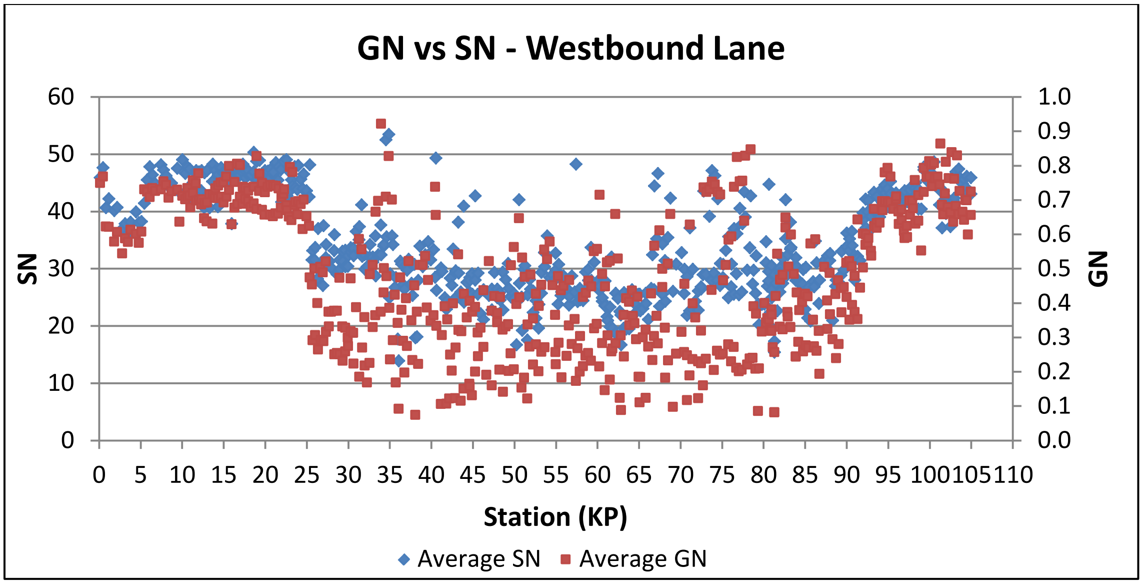

Figure 6. Friction Measurement Values – Westbound Lanes

The general correlation for the concrete and asphalt surfaced pavement are shown in Figure 7 and Figure 8 below. The correlation coefficient (R^2) for the concrete section is 0.16 while the correlation coefficient of the asphalt section is 0.25. These coefficient values are considered to be poor. Part of this is due to the fact that there were only two types of surface course asphalt on this section of highway. In this case, there is a dominant effect of certain sources of variation not associated with different friction levels, particularly the errors associated with equipment precision. This type of error is random and reduces the correlation between the equipment.

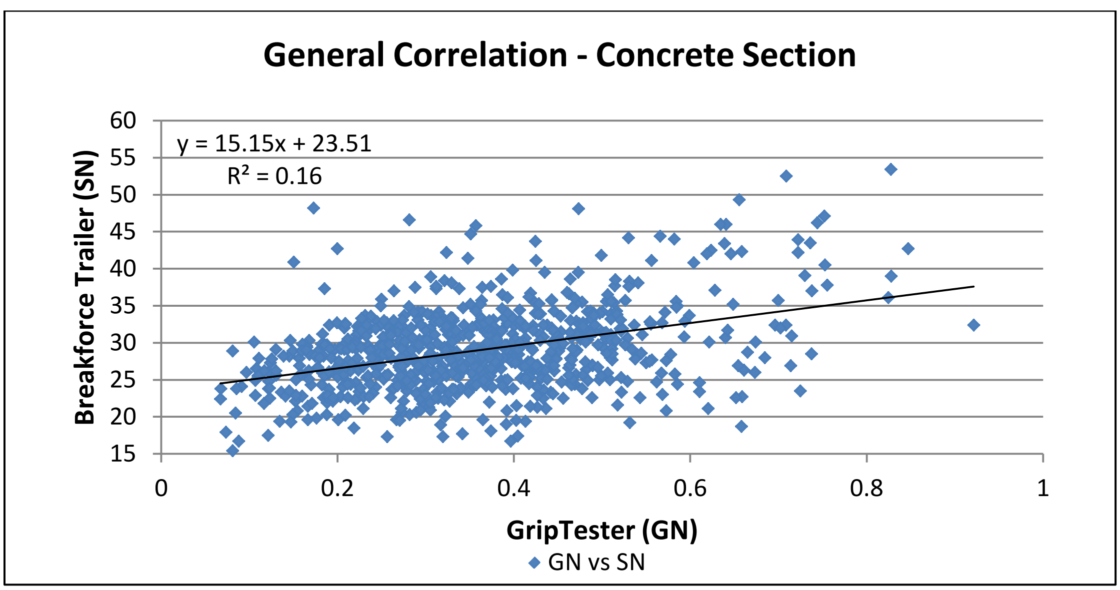

Figure 7. General Correlation for Concrete Surfaced Pavement

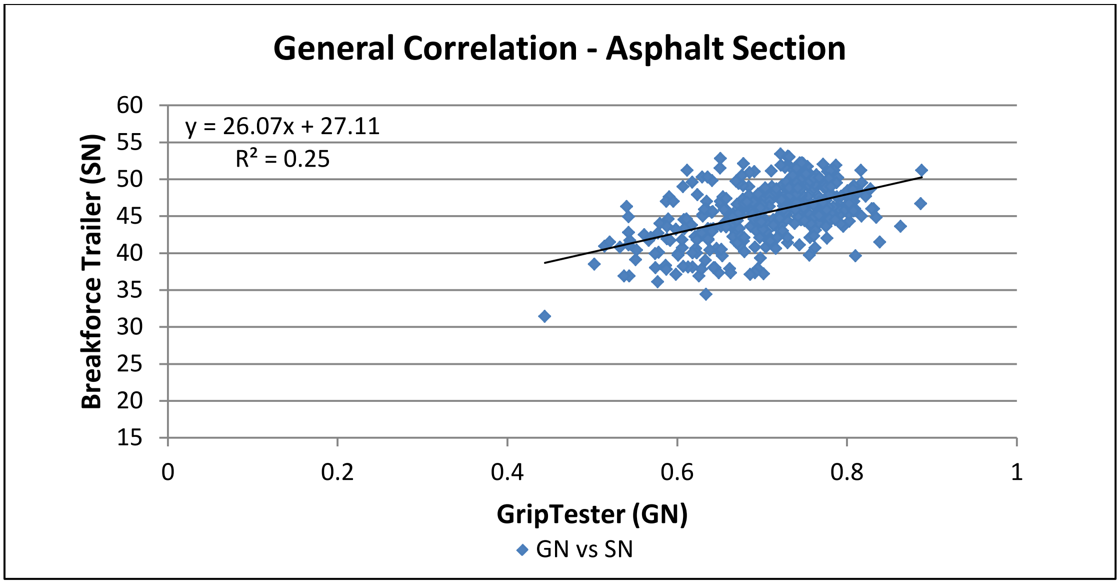

Figure 8. General Correlation for Asphalt Surfaced Pavement

The skid data for both the concrete and asphalt pavement surfaces were pooled together and a general correlation was examined. The correlation coefficient in this case was 0.65 as shown in Figure 9. This is a significant improvement and considered to be fairly reasonable.

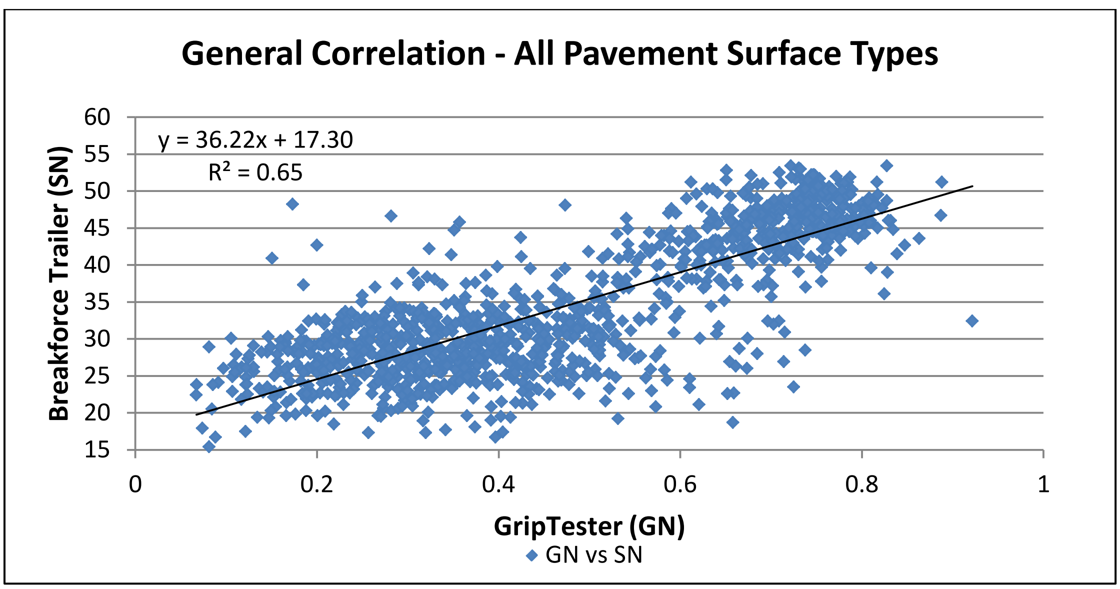

Figure 9. General Correlation – All Pavement Surface Types

A comparison of measurement between the Brakeforce Trailer and GripTester equipment was performed and the results are tabulated in Table 2 below. For each type of pavement the maximum error (difference between measurements) expected with 95 percent confidence is presented. In other words, in 95 percent of the measurements the difference between GT and E274 measurements are expected to be lower than the given value. It is noted that the measurement differences were larger in the concrete surface sections compared to the asphalt surfaced pavement. However the range of friction levels was also larger in the concrete sections compared to the asphalt sections.

Table 2. Summary of Maximum Error for 95 Percent Confidence

Pavement Type	Number of Samples	Maximum Error for 95 Percent Confidence
Asphalt	400	14.4 %
Concrete	788	35.7 %
Combined	1188	38.0 %

In summary, equipment precision for both the Brakeforce Trailer and the GripTester were relatively small for the asphalt surfaced sections with maximum errors for 95 percent confidence in the range of 5 to 22 percent, with the Brakeforce Trailer having better precision in most of the cases. In the concrete sections, measurements in the outside lane led to larger errors for the GripTester with maximum errors greater than 70 percent. For the type of conditions found in the outside lane, the Brakeforce Trailer had consistently better measurement precision. This may be due to higher roughness in the outside lane (truck lane) causing more vertical movement of the GripTester causing higher error values.

Correlations for the asphalt surfaced pavement were satisfactory; however the friction level was fairly constant and a better assessment could be obtained if the experiment covered a larger range of friction levels for this type of pavement. In the concrete sections the correlations were lower and most likely there were two reasons for this occurrence. The concrete pavement has a higher level of roughness than the asphalt sections. The rougher concrete surface appears to cause the relatively light GripTester to "bounce" more resulting in higher measured roughness compared to the heavier ASTM Brakeforce Trailer.

CONCLUSION

Surface friction is a very important aspect of pavement to provide a safe and reliable travelling experience for the public. It is very important to monitor the pavement friction in any given highway. This paper has provided an overview of friction including the factors that primarily affect the friction, micro texture and macro texture. Amongst the wide range of methods to collect friction number, two dominant methods are explained and correlated with an example case study conducted in an Ontario highway. The results of the friction testing correlation program showed a reasonable correlation between the Brakeforce Trailer and the GripTester when the data from both the asphalt and concrete sections is combined. Additional specific testing of pavements with a wider range in friction values would likely further improve the correlation between the equipment.

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