CORRELATING FIELD AND LAB MEASUREMENTS OF SKID RESISTANCE BY SKIDDOMETER AND WEHNER/SCHULZE DEVICE

Bernhard Hofko, PhD (Corresponding Author)
University of California Pavement Research Center
Department of Civil and Environmental Engineering
University of California, Davis
One Shields Avenue, Davis, CA, 95616
Tel: (530) 760-6951 Email: bhofko@ucdavis.edu

Hannes Kugler, PhD
TPA Gesellschaft für Qualitätssicherung und Innovation GmbH
Polgarstrasse 30, 1220 Vienna, Austria,
Tel: +43-664-8101260; Email: hannes.kugler@tpaqi.com

Georgi Chankov
Vienna University of Technology, Institute of Transportation
Gusshausstrasse 28/E230-3, 1040 Vienna, Austria
Tel: +43-1-58801-23353; Email: georgi.chankov@tuwien.ac.at

Roland Spielhofer
AIT Austrian Institute of Technology
Donau-City-Strasse 1, 1220 Vienna, Austria
Tel.: +43-50-5500; Email: roland.spielhofer@ait.ac.at

Word count: 4,226 words text + 6 tables/figures x 250 words (each) = 5,726 words

Submission Date: June 16th 2016

ABSTRACT

The skid resistance of road surfaces is an important parameter for road safety. Decreasing skid resistance correlates with increasing number of road accidents. This paper presents outcomes of a study that aims for a correlation between skid resistance measurement in the lab and in the field. Therefore, representative test section on the highway network with stone mastic asphalt (SMA) and exposed aggregate concrete surface (EACS) were selected in a first step. High resolution skid resistance measurements were carried out on these test sections by a monitoring vehicle (RoadSTAR) equipped with a skiddometer. Based on these field measurements, spots with a homogeneous skid resistance were chosen and cores were taken. Skid resistance measurements were run on these cores in the lab on the Wehner/Schulze device. It was found by regression analysis that data from field and lab correlated in a linear way with high coefficient of determination ($R^2 = 0.89$). The correlation is independent of the type of surface layer and is valid for a range of friction coefficients from 0.52 to 0.97. With this correlation at hand, extensive field measurements carried out for acceptance testing can be substituted by efficient and economic lab tests based on the Wehner/Schulze device.

Keywords: skid resistance, asphalt mixture, concrete pavement, Wehner/Schulze

INTRODUCTION

The skid resistance of road surfaces has a crucial impact on road safety in general (1, 2). Various studies show significant correlations between the skid resistance of surface layers and the number of road accidents (3-5). This brings the need for providing road surfaces with both, a high initial skid resistance and resistance to polishing due to climate and traffic to ensure long-lasting friction values on roads and therefore, sufficient safety for users.

Continuous monitoring of the skid resistance in the field can be carried out by different devices. Commonly used are the SCRIM (Side force Coefficient Routine Investigatory Machine) (6, 7), the Skiddometer (8), or the GripTester (9-11). For the assessment of the polishing and skid resistance in the laboratory, the polished stone value (PSV) method has been in use for decades (12-17). However, the PSV method is limited to the coarse aggregate fraction and does not take into account the actual surface texture of a road pavement including the binder component, filler and fine aggregates. The Wehner/Schulze device, developed in the 1960s in Germany (18, 19), is a combined test stand for simulating polishing and skid resistance measurement on flat, circular specimens and can thus be employed for studying arbitrary surfaces, including aggregates, but also actual road surface layers from field cores or lab produced samples. The Wehner/Schulze device has been increasingly used in research in recent years to study skid resistance of aggregates, surface layers and correlations between lab and field measurements (20-26).

In recent years, research studies tend to work towards correlation between laboratory assessment of skid and polishing resistance and the actual skid resistance situation in the field incorporating information on aggregate mineralogy, surface texture, traffic and climate situation into the studies (20, 27-29). The main objectives of these studies are to understand the impact of employed materials and field conditions on the evolution of the skid resistance on the one hand, and how to simulate these conditions in a realistic way in the laboratory on the other hand.

The study presented in this paper aims to contribute to the work on correlating laboratory and field measurements of skid resistance based on the Wehner/Schulze device and Skiddometer measurements in the field.

OBJECTIVES

The present situation in many road design guidelines, e.g. (30), is to set requirements regarding the skid and polishing resistance of the coarse and/or fine aggregate fraction of a surface layer in identification testing, mostly by PSV testing. For acceptance testing, the actual skid resistance of the surface layer in the field is measured. In addition, a minimum remaining skid resistance at the end of the warranty period required to ensure sufficient polishing resistance. However, skid resistance quality of the aggregate fraction in the lab does not necessarily correlate with the skid resistance of a surface layer in the field. This is especially true for more recently developed materials, e.g. high rate use of recycling material for asphalt mixtures.

To overcome this obstacle, a recently completed research project (31) worked towards two main objectives:

- Analyze correlations between skid resistance measurements of road surfaces in the lab by the Wehner/Schulze device and in the field using RoadSTAR. The RoadSTAR is a skid resistance measurement device for routine monitoring on network level used in Austria (32) based on a measurement wheel with fixed slip.
- Develop a lab procedure based on the Wehner/Schulze device to predict the evolution of the skid resistance under traffic in the lab and calibrate it to field data.

This paper concentrates on the first objective of the study. The outcomes of the study allow for a realistic prediction of the skid resistance on lab scale. Compared to full scale measurements on the road, the correlation provides is a quick and easy way to determine skid resistance in the lab.

For the study, the following steps were taken:

- Selection of 14 representative test sections (asphalt and cement bound surface layers) on the high level road network
- High resolution skid resistance measurements in the field by RoadSTAR
- Sampling of the test sections by coring
- Skid resistance measurements in the lab by the Wehner/Schulze device
- Correlation analysis between both measurement principles

MATERIALS AND TEST DEVICES

Surface Layers

The Austrian highway network consists of a total length of about 2,200 km, one third of the network is constructed with concrete pavement structures, the other two thirds with asphalt mixtures. Regarding surface layers, the majority of the asphalt bound surface layers is made of stone mastic asphalt with a maximum nominal aggregate size of 11 mm (SMA 11) and a nominal void content ranging from 3 Vol.% to 6 Vol.%. Concrete pavements have been carried out as exposed aggregate concrete surface with a maximum nominal aggregate size of 8 mm or 11 mm (EACS 8 and EACS 11) exclusively since the early 1990s. For these reasons, the study concentrated on SMA 11 and EACS 8.

Skid resistance measurement in the field – RoadSTAR

The RoadSTAR skid resistance measurement device (FIGURE 1) measures the longitudinal skid resistance of a pavement in the right wheel path using a modified Stuttgarter skiddometer. It uses a PIARC ribbed tire with a controlled vertical load of 3500 N (33). The skid resistance is determined using a fixed slip of 18% and a water film of 0.5 mm. Measurements are carried out in fluent traffic with a standard speed of 60 km/h. For the speed range of 30 to 60 km/h, the measurement results can be converted to the standard speed to allow for speed variation due to traffic. The braking torque and vertical load are recorded in intervals of 0.1 m travelled distance and the skid resistance coefficient μ_{field} is calculated as follows:

$$\mu_{field} = \frac{M_B}{r} \cdot \frac{1}{F_N} \qquad (1)$$

with

μ_{field}	Skid resistance coefficient [-]
M_B	Braking torque [Nm]
r	radius of measurement tire [m]
F_N	vertical load [N]

The measurement simulates a full braking of a passenger car (similar slip and vertical load) on a wet pavement. From the measured skid resistance, achievable decelerations of braking passenger cars and thus braking distances can be calculated (34).

FIGURE 1 Monitoring device RoadSTAR (left); detail of the skid resistance measurement unit (right)

Skid resistance measurement in the lab – Wehner/Schulze device

The Wehner/Schulze device (FIGURE 2) combines polishing and skid resistance measurement in one test stand. Any flat, circular surface with a diameter of 225 mm can be tested. The polishing is carried out by a rotating head with three rubber covered conical rollers rotating at 500 rpm on the specimen surface (left inFIGURE 2). Thus, 90,000 polishing passes can be applied per hour. To increase the polishing effect, a water-quartz powder slurry is added. After any user-defined number of polishing passes, the polishing can be stopped, the test specimen is washed to remove remaining quartz powder and the skid resistance is measured using a measurement head with three testing rubbers (right in FIGURE 2). For the skid resistance measurement, the rotating head is accelerated to a tangential speed of 100 km/h in a first step. Subsequently, water is sprayed onto the specimen surface before the rotating head is lowered onto the surface. As the test head decelerates the friction coefficient μ is recorded. According to the European standard procedure (35), the friction value at 60 km/h is reported as the μ_{PWS}. This value is used within this study as well to describe the skid resistance of lab tested specimens.

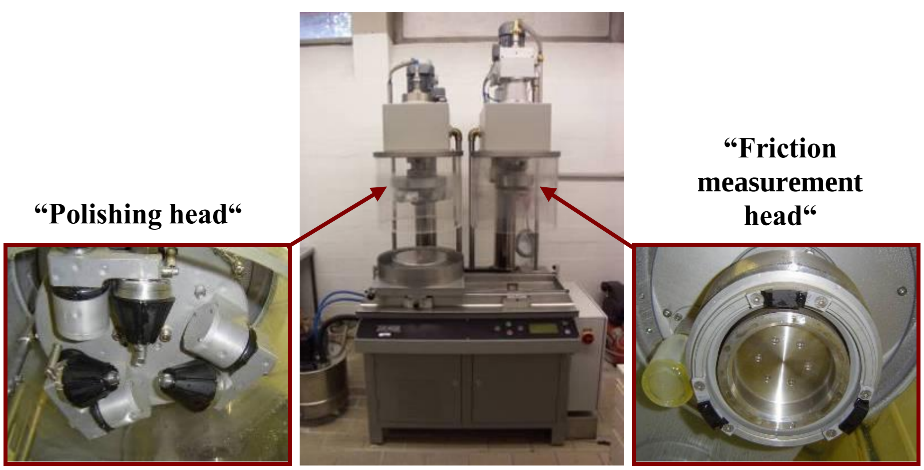

FIGURE 2 Wehner/Schulze device

APPROACH

Test sections

Since 1999, routine skid resistance surveys are carried out on the Austrian highway network in 5-year intervals. In addition, acceptance testing and testing at the end of the warranty period is carried out on all newly constructed or resurfaced sections since 2004. From these measurements, a total of 4,000 data sets with a total length of measurement of 13,000 km are available. They were the basis for selecting suitable test sections for the presented study. For pre-filtering, only sections meeting the following requirements were taken into consideration:

- Surface layer SMA 11 or EACS 8
- Average annual daily traffic (AADT) > 20,000 and share of heavy goods vehicles (HGV) > 14% of AADT
- Linearity of the road axis: no horizontal curvature, max. slope ± 1%
- Homogeneity of the skid resistance derived from RoadSTAR data to avoid outliers when sampling

From this pre-filtering, 60 sections remained to be considered for sampling. Taking into consideration additional criteria for the test sections, i.e. age of the surface layer and evolution of the skid resistance with time, 14 test sections were finally selected, seven of them being SMA 11 and seven EACS 8. The year of construction or resurfacing varies from 1994 to 2012.

Skid resistance measurements on the test sections

The standard resolution of skid resistance measurements by the RoadSTAR are 50 m values. To ensure that all samples are cored from a homogeneous region regarding the skid resistance, high resolution measurements were carried out using 1 m values for all 14 test sections. The measurements were run on the right wheel path of the main lane, as well as on the emergency lane to receive skid resistance data for the polished, as well as for the non-polished part of the surface layer. Based on the skid resistance data, optimal spots for coring were determined. An example of skid resistance measurement in the field is given in FIGURE 3. It shows two test runs for the polished and non-polished section in the upper part of the diagram and information on where cores for lab testing were taken.

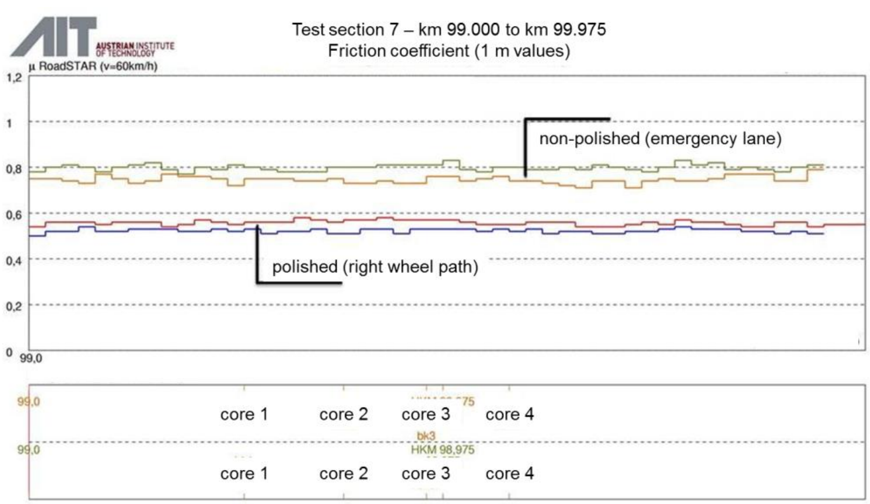

FIGURE 3 Example of skid resistance measurement in the field (test section 7)

Sampling

Cores were taken from the right wheel path of the main lane to receive polished samples. In addition, unpolished samples were taken either from the emergency lane or, for those sections, where the emergency lane was not constructed with the same surface layer as the main lane, from between the wheel paths of the main lane. From each test section, 4 polished and 4 non-polished samples were cored for further analysis in the lab.

Skid resistance measurements in the lab

Testing of polished and non-polished cores in lab was carried out by the Wehner-Schulze device. For testing purposes the cores were mounted in the test machine. Both, the sample and the sliding rubbers of the test head were conditioned by rinsing them with water with a temperature of 10°C±0,5°C for 5 min to ensure that the viscoelastic properties of the core and the sliding rubbers were repeatable for each test. μ_{PWS} was determined at 60 km/h for three times on each core. From each test section at least three cores were tested. Results given in the further course of this paper represent mean values (MV) of skid resistance measurements on three cores with triple replication. An example of a skid resistance measurement by the Wehner/Schulze device is given in FIGURE 4. It shows the recorded raw data, which is the ratio of friction force vs. vertical loading on the sliding rubbers. According to (35) these raw data are fitted by a polynomial of 6th order between 95 km/h and 5 km/h. μ_{PWS} is taken as the value at 60 km/h.

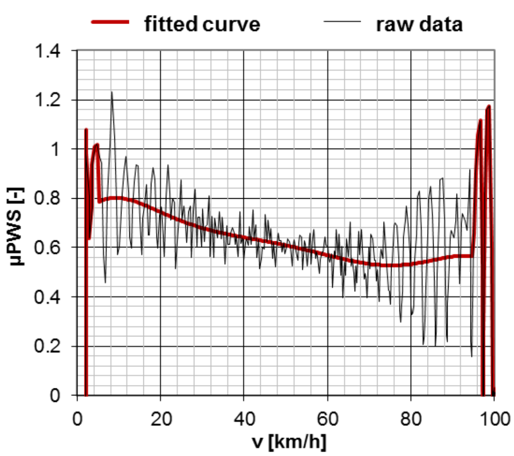

FIGURE 4 Example of skid resistance measurement in the lab

RESULTS AND DISCUSSION

TABLE 1 presents results of all skid resistance measurements in the field and in the lab. It shows the 1 m friction coefficient recorded by the RoadSTAR (μ_{RS}) from the spot where the cores for lab testing were taken. The friction coefficient recorded by the Wehner/Schulze (μ_{PWS}) device is also given for each test section. For these lab measurements, the MV as well as the standard deviation (SD) are given from tests on three cores and triple replication. The skid resistance obtained from the field covers a large range from 0.52 to 0.97, whereas the skid resistance derived in the lab ranges from 0.26 to 0.71. Although the absolute values of lab and field measurement differ, both methods record skid resistance values that cover a spectrum of 0.45. The hypothesis that a polished part and a non-polished part of a road cross section can be distinguished in terms of difference in skid resistance seems to be valid. All friction values of the non-polished sections and cores are on a higher level than those of the polished sections and cores.

TABLE 1 Results of skid resistance measurements

# of test section	surface type	µRS (Field) [-] section		µPWS (Lab) [-] core			
		polished	non-polished	polished		non-polished	
		MV	MV	MV	SD	MV	SD
2	EACS	0.57	0.69	0.319	0.011	0.439	0.009
7	EACS	0.54	0.77	0.333	0.012	0.488	0.003
29	EACS	0.74	0.75	0.393	0.006	0.451	0.008
42	SMA	0.66	0.85	0.380	0.002	0.544	0.026
51	SMA	0.64	0.89	0.383	0.006	0.611	0.009
63	EACS	0.52	0.59	0.258	0.006	0.343	0.005
65	EACS	0.58	0.69	0.337	0.007	0.451	0.001
67	SMA	0.75	0.83	0.420	0.006	0.526	0.017
67a	SMA	0.67	0.81	0.426	0.011	0.622	0.015
68	EACS	0.58	0.64	0.352	0.004	0.422	0.019
77	EACS	0.61	0.63	0.371	0.016	0.427	0.018
108	SMA	0.64	0.9	0.364	0.018	0.624	0.013
109	SMA	0.67	0.97	0.397	0.009	0.599	0.047
110	SMA	0.64	0.94	0.379	0.002	0.706	0.033

FIGURE 5 shows the correlation analysis of skid resistance measurements in the field and in the lab. It contains the single mean values from each of the four groups: the SMA and EACS surfaces from the polished and non-polished sections and cores. From these single values it becomes obvious that SMA surface layers result in significantly higher initial skid resistance values than EACS surface layers. However, looking at the values from polished specimens, both surface layer types result in quite similar friction values after being in-service under traffic loading. The decrease in skid resistance over time is therefore much higher for SMA surface layers than for EACS surface layers.

In addition, FIGURE 5 contains a linear regression that correlates skid resistance measurements in the lab by the Wehner/Schulze device to the respective measurements in the field by the Skiddometer. The regression reveals that the friction coefficient received in the lab are generally on a lower level than those from the field. This fact can be explained by the different measurement principles: the Wehner/Schulze device simulates friction under a locked wheel with no slip, whereas the Skiddometer produces a fixed slip of 18% which simulates a wheel with anti-lock break system (ABS). This leads to higher friction coefficients derived from field measurements. However, the regression shows a good coefficient of correlation R^2 of 0.89. The linear regression includes all data from SMA and EACS surfaces. From the presented data is seems that the correlation between both measuring principles is independent of the type of surface layer and also, whether it is in a non-polished or polished state.

FIGURE 5 also contains the 95% projection interval for the linear regression represented by the dotted lines. This interval provides information on the confidence interval for any point within the linear regression.

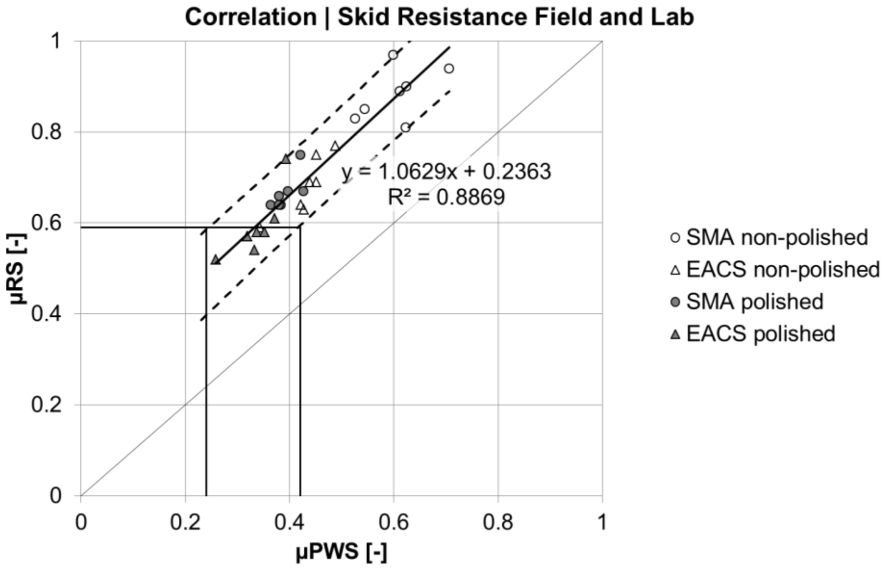

FIGURE 5 Correlation of skid resistance measurement in the field and in the lab

Application

The results of this study and the obtained correlation can be used in different ways:

- Many countries include some kind of skid resistance testing for acceptance testing of surface layers to ensure sufficient friction and therefore, safety for road users. Usually, these measurements are carried out by field testing. However, to ensure reliable results, field testing can only be carried out at very specific weather conditions. Also, field testing of short road sections can be inefficient. With the developed correlation at hand, field testing can be substituted by lab testing on cores taken from the road. FIGURE 5 shows an example: If the minimum allowed skid resistance in acceptance testing by field measurement is 0.59, a core that delivers a μ_{PWS} in the lab of 0.42 or higher ensures sufficient friction with 95% probability. On the other hand, if the core shows a μ_{PWS} of 0.23 or lower, the friction value is below the field limit of 0.59 with a 95% certainty. For cases in between 0.23 and 0.42 a field measurement is needed for clarification. The same principle can be applied for testing at the end of the warranty period.
- The correlation can be used for mix design optimization for the producer. New mix designs or a new aggregate sources can be tested on skid resistance performance at low costs and reduce the risk before large scale use on project level.
- In condition assessment on project level, cores can be tested on remaining skid resistance in the lab rather than running extensive field measurements with the same weather constraints as mentioned above.

SUMMARY AND CONCLUSIONS

A recently completed study analyzed correlations between measurement of skid resistance in the field and in the lab by different methods. 14 test sections on the highway network were selected. The selection was based on the type of surface layer (SMA 11 or EACS 8), the traffic volume, linearity of the road axis and homogeneity of the skid resistance. Skid resistance was measured on these test sections by a monitoring vehicle (RoadSTAR) equipped with a skiddometer. Based on the field data, spots for coring were determined. From each test section, cores from the polished part of the cross section (wheel path) and the non-polished part were taken. These cores were tested for skid resistance in the lab by the Wehner/Schulze device. It was found that a linear regression links μ_{RS} from the field with μ_{PWS} from the lab with a high correlation ($R^2 = 0.89$). The following conclusions can be drawn:

- Friction coefficients derived from the field (μ_{RS}) are generally on a higher level than those derived from the lab (μ_{PWS}). This can be explained by the fact that the skiddometer works with a fixed slip (18%) whereas the Wehner/Schulze device simulates a locked slip.
- Both measurement devices correlate well since they are based on the same principle.
- The correlation is independent of the type of surface and of the state of the surface (polished or non-polished) for a range of friction coefficients from 0.52 to 0.97. At the present stage, the correlation is limited to stone mastic asphalt (SMA) and exposed aggregate concrete surfaces (EACS).

The outcomes of the study can be used for quick and efficient testing of cores instead of extensive and time consuming field measurements, which have tight weather constraints to ensure reliable data. It can be used as a tool for identification and acceptance testing, as well as for mix design optimization and pavement monitoring in terms of skid resistance.

AKNOWLEDGEMENTS

The authors would like to express their gratitude to ASFINAG, the Austrian ministry of transportation (BMVIT), Gestrata, VOEZ, OEBA and OEBV for financing significant parts of this study.

REFERENCES

1. Hatherly, L.W., J.H. Mahaffy, and A. Tweddle, *Skid Resistance of City Streets and Road Safety.* Journal of the Institution of Highway Engineers, 1969. **16**(4): p. 7-&.
2. Wu, H., Z.M. Zhang, K. Long, and M.R. Murphy, *Considering Safety Impacts of Skid Resistance in Decision-Making Processes for Pavement Management.* Transportation Research Record, 2014(2455): p. 19-27.
3. Kuttesch, J.S., *Quantifying the Relationship between Skid Resistance and Wet Weather Accidents for Virginia Data*. 2004, Virginia Polytechnic Institute and State University: Blacksburg, VA.
4. Davies, R.B., P.D. Cenek, and R.J. Henderson, *The effect of skid resistance and texture on crash risk.* International Surface Friction Conference, Christchurch, New Zealand, 2005.
5. Kudrna, J., A. Vojtesek, I. Malis, and I. Neukla, *Road skid resistance influence on the number of crash accidents.* International Conference on Safe Roads, Budapest, Hungary, 2006.
6. Oliver, J.W.H., *Factors affecting the correlation of skid-testing machines and a proposed correlation framework.* Road & Transport Research, 2009. **18**(2): p. 39-48.
7. Echaveguren, T., H. de Solminihac, and A. Chamorro, *Long-term behaviour model of skid resistance for asphalt roadway surfaces.* Canadian Journal of Civil Engineering, 2010. **37**(5): p. 719-727.
8. Leandri, P. and M. Losa, *Peak Friction Prediction Model Based on Surface Texture Characteristics.* Transportation Research Record, 2015(2525): p. 91-99.
9. Yut, I., J.W. Henault, and J. Mahoney, *Friction Study of Long-Term Pavement Performance Special Pavement Study SA Sections in Connecticut.* Transportation Research Record, 2014(2446): p. 29-36.
10. Flintsch, G.W., E.D. Izeppi, K.K. McGhee, and J.A. Roa, *Evaluation of International*

Friction Index Coefficients for Various Devices. Transportation Research Record, 2009(2094): p. 136-143.

11. Najafi, S., G.W. Flintsch, and K.K. McGhee, *Assessment of operational characteristics of continuous friction measuring equipment (CFME).* International Journal of Pavement Engineering, 2013. **14**(8): p. 706-714.
12. Perry, M.J., A.R. Woodside, and W.D.H. Woodward, *Observations on aspects of skid-resistance of greywacke aggregate.* Quarterly Journal of Engineering Geology and Hydrogeology, 2001. **34**: p. 347-352.
13. Erichsen, E., *Relationship between PSV and in situ friction: a Norwegian case study.* Bulletin of Engineering Geology and the Environment, 2009. **68**(3): p. 339-343.
14. Shabani, S., M. Ahmadinejad, and M. Ameri, *Developing a model for estimation of polished stone value (PSV) of road surface aggregates based on petrographic parameters.* International Journal of Pavement Engineering, 2013. **14**(3): p. 242-255.
15. Perry, M.J., *Role of aggregate petrography in micro-texture retention of greywacke surfacing aggregate.* Road Materials and Pavement Design, 2014. **15**(4): p. 791-803.
16. Dokic, O., V. Matovic, S. Eric, and K. Saric, *Influence of engineering properties on Polished Stone Value (PSV): A case study on basic igneous rocks from Serbia.* Construction and Building Materials, 2015. **101**: p. 1088-1096.
17. Wang, G., R.G. Thompson, and Y.H. Wang, *Hot-Mix Asphalt That Contains Nickel Slag Aggregate Laboratory Evaluation of Use in Highway Construction.* Transportation Research Record, 2011(2208): p. 1-8.
18. Wehner, B., *Strassengriffigkeit und Verkehrssicherheit bei Nässe.* Internationales Colloquium über Straßengriffigkeit und Verkehrssicherheit bei Nässe, Berlin, Germany, 1968.
19. Schulze, K.-H., *Typen der Oberflächenfeingestalt und ihre Wirkung auf den Reibungswiderstand bei Nässe.* Internationales Colloquium über Straßengriffigkeit und Verkehrssicherheit bei Nässe, Berlin, Germany, 1968.
20. Do, M.T., Z. Tang, M. Kane, and F. de Larrard, *Pavement polishing - Development of a dedicated laboratory test and its correlation with road results.* Wear, 2007. **263**: p. 36-42.
21. Kane, M., M.T. Do, and J.M. Piau, *Modeling of the Road Surface Polishing Based on Contact-mechanics Approach.* Road Materials and Pavement Design, 2008. **9**: p. 305-318.
22. Wang, D.W., C.E. Yin, X.H. Chen, and B. Steinauer, *Evaluating on the skid resistance of the aggregates based on mineralogy.* Advanced Building Materials, Pts 1-4, 2011. **250-253**(1-4): p. 3646-3651.
23. Wang, D.W., X.H. Chen, X.G. Xie, H. Stanjek, M. Oeser, and B. Steinauer, *A study of the laboratory polishing behavior of granite as road surfacing aggregate.* Construction and Building Materials, 2015. **89**: p. 25-35.
24. Wang, D.W., X.G. Xie, M. Oeser, and B. Steinauer, *Influence of the gritting material applied during the winter services on the asphalt surface performance.* Cold Regions Science and Technology, 2015. **112**: p. 39-44.
25. Kane, M., I. Artamendi, and T. Scarpas, *Long-term skid resistance of asphalt surfacings: Correlation between Wehner-Schulze friction values and the mineralogical composition of the aggregates.* Wear, 2013. **303**(1-2): p. 235-243.
26. Nataadmadja, A.D., D.J. Wilson, S.B. Costello, and M.T. Do, *Correlating Laboratory Test Methodologies to Measure Skid Resistance of Pavement Surfaces.* Transportation Research Record, 2015(2506): p. 107-115.
27. Panagouli, O.K. and A.G. Kokkalis, *Skid resistance and fractal structure of pavement*

surface. Chaos Solitons & Fractals, 1998. **9**(3): p. 493-505.
28. Asi, I.M., *Evaluating skid resistance of different asphalt concrete mixes.* Building and Environment, 2007. **42**(1): p. 325-329.
29. Seneviratne, H.N., M.P.N. Rajapakshe, and M. Gunaratne, *Field Calibration of an Analytical Model for Pavement Friction Testing Applications.* Journal of Testing and Evaluation, 2009. **37**(1): p. 21-30.
30. FSV, *RVS 08.97.05: Technical Contract Conditions, Requirements for Bituminous Mixtures*. 2015: Vienna, Austria.
31. Kugler, H., B. Hofko, and R. Spielhofer, *Prognose der Griffigkeit von Fahrbahnoberflächen* - *Entwicklung eines Labor-Verfahrens* - *PROGRIP*. 2015: Vienna, Austria.
32. FSV, *RVS 11.06.65: Skid Resistance Measurement by RoadSTAR*. 2004: Vienna, Austria.
33. CEN, *TS15901-1: Road and airfield surface characteristics* - *Part 1: Procedure for determining the skid resistance of a pavement surface using a device with longitudinal fixed slip ratio (LFCS): RoadSTAR*. 2009: Brussels, Belgium.
34. Maurer, P., *The new Austrian skid resistance evaluation background based on the correlation of skid resistance values µRoadSTAR and braking decleration of passenger cars.* 6th Symposium on pavement surface characteristics: SURF 2008, Portoroz, Slovenia, 2008.
35. CEN, *EN 12697-49: Bituminous mixtures* - *Test methods for hot mix asphalt* - *Part 49: Determination of friction after polishing*. 2014: Brussels.