



HAL
open science

Encouraging Results of International Friction Measurement Harmonization through Quality Assurance and Calibration

Véronique Cerezo, Zoltan Rado, Malal Kane

► **To cite this version:**

Véronique Cerezo, Zoltan Rado, Malal Kane. Encouraging Results of International Friction Measurement Harmonization through Quality Assurance and Calibration. 98th Annual Meeting Transportation Research Board, Jan 2019, WASHINGTON, United States. hal-02065905

HAL Id: hal-02065905

<https://hal.science/hal-02065905>

Submitted on 13 Mar 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

1 **ENCOURAGING RESULTS OF INTERNATIONAL FRICTION MEASUREMENT**
2 **HARMONIZATION THROUGH QUALITY ASSURANCE AND CALIBRATION**

3
4
5
6 **Veronique Cerezo, Corresponding Author**

7 IFSTTAR, AME-EASE

8 Allée des Ponts et Chaussées, CS5004, 44340 Bouguenais, France

9 Tel: (+33)2 40 84 59 37 Email: veronique.cerezo@ifsttar.fr

10
11 **Zoltan Rado**

12 Aviation Safety Technologies LTD.

13 222 S. Riverside Plaza, 28th Floor, Chicago IL 60606, USA

14 Tel: +1 312 332 1900, Email: zoltanr@avsafetech.com

15
16 **Malal Kane**

17 IFSTTAR, AME-EASE

18 Allée des Ponts et Chaussées, CS5004, 44340 Bouguenais, France

19 Tel: (+33)2 40 84 58 39 Email: malal.kane@ifsttar.fr

20
21
22
23
24
25
26 Word count: 4339 words text + 8 tables x 250 words (each) = 6339 words

27
28
29
30
31
32
33 Submission Date: 31/07/2018; revision: 31/10/2018

1 ABSTRACT

2 The friction measurement devices being used today in accordance with various international
3 standards for the assessment of surface conditions on highways and runways are numerous.
4 Although among the different equipment designs there are only a few substantially different
5 measurement principles, they all have a significant number of design and operational differences.
6 The difficulty of correlation and harmonization between the friction measurement systems due to
7 these design variations has led to operator and regulatory governmental concerns regarding the
8 viability of high-quality harmonized measurements collected by the large array of devices.

9
10 This paper presents the work performed and the results obtained in the 1st European Pavement
11 Friction Workshop to overcome the differences of designs and technical specifications of device
12 subcomponents using unified standardization practice and uniform requirement/compliance
13 checks and quality assessment of devices. The work also evaluated, analyzed and validated the
14 European and US developed methodologies and technical solutions for standardization and the
15 practical procedures for calibration and quality assessment to ensure reliable, quality data from all
16 devices in a common scale.

17
18 Keywords: friction, harmonization, macrotexture, round robin tests
19

1 INTRODUCTION

2 The variety and number of friction measurement devices in use all around the world for the
3 assessment of pavement surface characteristics is quite large. These devices are using different
4 principles of measurement and can highly differ regarding their design or operating conditions.
5 Regarding the range of variation of these operating conditions (load, slip ratio, pressure, etc.), it is
6 very difficult to obtain a robust correlation between the measured friction coefficients. The scale
7 correction requested to use more advanced modelisation.

8 In the past twenty years, some research projects tried to tackle this issue (Hermes, PIARC
9 International Experiment (1), Tyrosafe, Rosanne). These projects highlighted the need of quality
10 controlled, reliable and accurate calibration/checking process of the devices prior to round robin
11 tests and proposed several methodologies for harmonization processes. Additionally, a skid
12 resistance index (SRI) was proposed to harmonize friction coefficient measurements at the
13 European scale. Despite the progress, work remains to confirm the robustness and the effectiveness
14 of the common scale.

15 Therefore, IFSTTAR (France) organized the 1st annual European Pavement Friction
16 Workshop hosted at the IFSTTAR facility in Nantes, France. The program included improved
17 checking processes, new unified component level calibration processes of the participating devices
18 and a well-controlled comparison trial on the IFSTTAR test surfaces. The results were analysed
19 both according to the harmonization method developed in the framework of FP7 European
20 Research project ROSANNE (2013-2016) and according the method used in the United States
21 (International Friction Index “two steps approach”). The first methodology uses an average friction
22 value from all measurement devices as the reference of the common scale whereas the US method
23 uses a two-step approach utilizing a laboratory scale reference surface and a pair of unique
24 laboratory and field useable devices to establish time stable universal check standards for friction
25 harmonization.

26 This paper describes the first European Pavement Friction Workshop and the application
27 of the two harmonization processes. After describing the common scale and its calibration, the
28 results obtained by the two approaches are discussed.

29

30 EXPERIMENTS

31

32 Devices

33 The 1st European Pavement Friction Workshop incorporated high-speed friction measuring
34 devices (both at low and high speeds) and stationary friction measuring devices.

35

36 *Longitudinal Friction measuring devices*

37 Ten devices measuring Longitudinal Friction Coefficient (LFC) attended the trials. These devices
38 operated on the principle of a vertically loaded wheel rotating at a lower speed than the forward
39 vehicle speed. The slip ratio of the devices ranged from 10 to 25%. The static vertical load ranged
40 from 105 to 180 kg. Three different smooth tires were used depending on the device: PIARC (2),
41 ASTM E1551-16 (3) and ASTM E1844-96 (4). The theoretical water film thickness was 0.5 or 1
42 mm depending the device.

43

44 *Side force friction measuring devices*

45 Five devices measuring Sideway-Force Friction Coefficient (SFC) attended the trials. These devices
46 operated on the principle of a sideway-force generated by a free rotating wheel, which is set at an
47 angle with respect to the driving direction. All the five SFC devices had the same measurement

1 wheel angle of 20°, which generated a slip ratio of 34%. The static vertical load was 200 kg and
2 water film thickness spread on the surface was 0.5 mm.

3 *Stationary measurement devices*

4 Five Dynamic Friction Tester (DFT) stationary measurement devices attended the trials. The DFT
5 device is composed of a measuring unit and a control unit. The measuring unit operates a motor
6 driven horizontal disc. Three rubber sliders are attached to the disc and a watering system allow
7 maintaining a constant waterflow during the measurement process. Once the set speed of the
8 rotating disc is reached, the electric motor is switched off and the disc with the measurement pads
9 is lowered into contact with the surface with a constant vertical load. The speed of the pads
10 decreases to a full stop due to the generated friction. Friction values at different speeds (mostly 40
11 and 60 km/h) are extracted from the recorded braking curve. For the tests, all the devices were
12 equipped with new rubber pads from the same batch provided by the machine supplier. Tests were
13 conducted according to ASTM standard E1911-09ae1 (5).

14 *Macrotexture measurements*

15
16 Macro-texture measurements were performed with the Circular Track-texture Meter (CTM)
17 according to the ASTM E2157-15 (6) standard and the ISO EN 13473-1 (7) standard for Mean
18 Profile Depth (MPD) calculation. The CTM device uses a laser sensor attached to a rotating arm,
19 measuring texture profile along a circle of 142 mm radius. The obtained profile is composed of
20 1024 data points spaced at 0.87 mm intervals, meaning a total profile length of 892 mm (8). CTM
21 measures profile in the exact same circular track where DFT measures friction.
22

23 **Tested surfaces**

24 The IFSTTAR test track located in Nantes (France) is composed of straight lane parallel test track
25 surfaces incorporating various pavement surfaces arranged in several longitudinal tracks (Figure
26 1).
27
28



29 **FIGURE 1 Test track (Ifsttar, France)**

30
31
32 These test surfaces cover a wide range of micro-texture and macro-texture levels (Table 1).
33 Regular pavement surface monitoring is done on test track (at least every six months). Macro-
34 texture is assessed using longitudinal laser profilometer measurements. The MPD values were
35 calculated on each test track following ISO EN 13473-1 (7). Micro-texture was estimated through
36 British Pendulum measurements according to EN 13036-4 (9).
37

1 **TABLE 1 Pavement surfaces characteristics on test tracks**
 2

Surface	Pavement mix	Grains size	MPD (mm)	DFT20
A	Porous asphalt concrete	0/6	2.90	0.29
C1	Asphalt concrete	0/10	0.35	0.61
E1	Semi - coarse asphalt concrete	0/10	0.66	0.34
E3	Stone Mastic Asphalt	0/10	1.19	0.40
L2	Sand asphalt	0/4	0.50	0.38
M2	Very thin asphalt concrete	0/6	1.10	0.30
G0	Asphalt concrete	-	0.83	0.34
G1	Painted surface (low microtexture)	-	0.60	0.25
G2	Painted surface with glass balls	-	0.59	0.26
G22	Painted surface with glass balls	-	0.67	0.35

3
 4 **Test program**
 5

6 Tests were performed during one week and were divided into two phases (10). In the first phase, a
 7 calibration exercise was conducted to ensure that devices are working properly. In a second phase,
 8 the round robin tests were performed by all the participating devices. Each device provided five
 9 valid measurements on ten different pavement surfaces at three speeds (40, 60 and 80 km/h). A
 10 measurement was considered as valid when it was realized in the 0.50 m centre strip of the test
 11 lane. An orange mark at the beginning of each test track indicated the valid measurement strip.
 12 Within each test track white points every 20m indicated the valid measurement strip. In parallel,
 13 continuous macrotexture measurements were performed with laser profilometers in order to
 14 provide MPD (Mean Profile Depth) values on the same test tracks according to ISO EN 13473-1.
 15
 16



17
 18 **FIGURE 2 Marks on the test sections**
 19

20 Then, static friction measurements were performed with Dynamic Friction Tester on the
 21 same test tracks. For each test surface, measurement points were defined every twenty meters. For
 22 each location, two measurements were obtained and average values were calculated to characterize

1 each test section. Three test speeds were used for the analysis: 20, 40 and 60 km/h. Static
2 macrotexture values with CTM were also collected on the same locations as the DFT
3 measurements.

4
5 Thus, a database containing 2250 average friction values for high-speed devices, 1230 DFT
6 values and 41 macro-texture values obtained with CTM was built for the analysis.

7
8 **CALIBRATION EXERCICE**
9 Checking process was conducted only on dynamic friction measuring devices. The DFT devices
10 were directly calibrated by the manufacturer at the beginning of the friction workshop to ensure
11 they were working properly.

12
13 Checking process of dynamic devices focused on those main parameters, that can have an
14 influence on friction measurements:

- 15 • Tire (pressure, cleanness, wear, Shore hardness),
- 16 • Measuring system (static vertical load, wheel angle),
- 17 • Speed,
- 18 • Water flow (nominal magnitude, film thickness distribution under the tire).

19 Participants were also requested to have a calibration certificate of the force sensor and to
20 use a new or honed tire, without visible defects.

21
22 **Tires checking**
23 Five different tires were used during the trials depending on the device: ASTM 1551, Piarç smooth,
24 Trelleborg T49, Avon and SKM. Checking were based on European, American, national
25 specifications or existing standards.

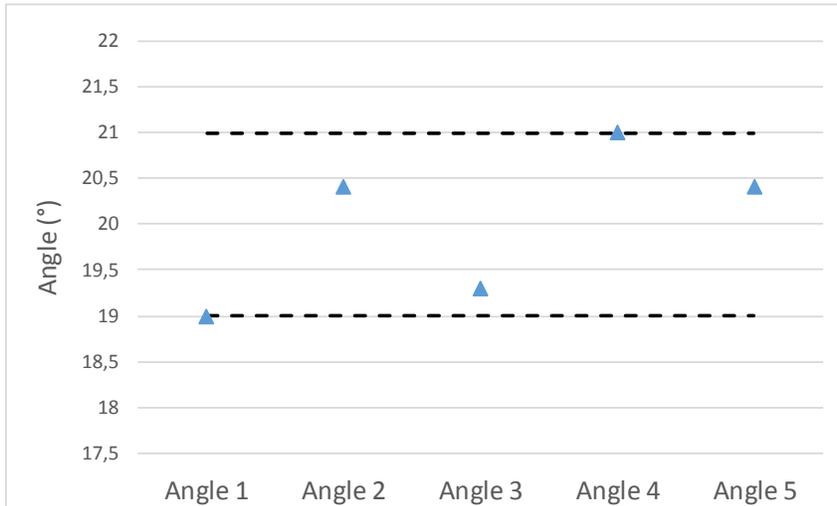
26
27 **TABLE 2 Checking results for the tires**
28

Device	Tire state		Tire pressure (bars)		Tire Shore hardness	
	Wear	Cleaness (Y/N)	Reference value	Measured value	Reference value	Measured value
1	New	Y	2,0	2,1	58±2	58,8
2	New	Y	2,0	2,0	58±2	58,5
3	New	Y	2,1	2,3	58±2	62,8
4	Honed	Y	2,0	2,0	58±2	59,1
5	New	Y	2,1	2,1	58±2	59,1
6	Honed	Y	1,5	1,5	63,0	59,9
7	Honed	Y	2,1	2,1	58±2	62,1
8	Honed	Y	1,5	1,5	63,0	59,5
9	New	Y	2,1	2,1	58±2	59,8
10	Honed	Y	2,1	2,1	66,0	64,0
11	New	Y	3,5	3,5	64±5	66,5
12	New	Y	3,5	3,5	66-67	68,5
13	Honed	Y	3,5	3,5	60-65	64,1
14	Honed	Y	3,5	3,5	64±5	64,6
15	New	Y	3,5	3,5	65-69	66,4

Note: Tire pressures were set to comply with European, American, national specifications or existing standards. The measured Shore hardness values, stayed within the required range of acceptable values.

Angles

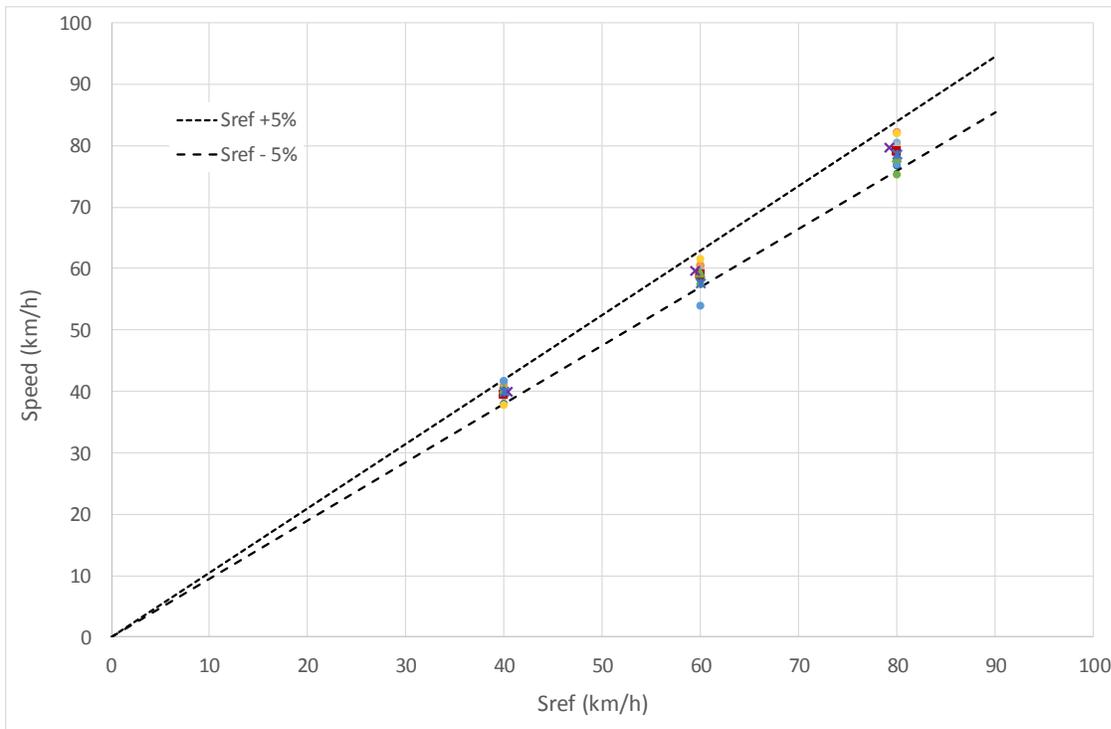
Five devices were working on the SFC friction measurement principle. The theoretical side-ways angle value was $20^{\circ} \pm 1^{\circ}$ regarding European standards. Two measurements were conducted and the test wheel angle value was determined to be the average of these two measured values. Figure 3 shows that all the devices complied with the requirements.



1
2 **FIGURE 3 Measured wheel angle**

3
4 **Speed**

5 The measurement speed of each device was checked by a calibrated radar. The radar was set up on
6 the side of the test track. Devices drove at constant speed on straight line along the test track and
7 the radar recorded value was compared to the on-board speed measured on the friction devices.
8 The speeds 40, 60 and 80 km/h were tested. The results shall be within $\pm 5\%$ of the reference speed.
9 Figure 4 presents the results obtained for the fifteen vehicles. Only, one value at 60 km/h was
10 outside the requested range. Further analysis showed that this lower speed value can be explained
11 by a small braking manoeuver during the checking process.
12



13
14 **FIGURE 4 Measured speeds**

15
16

1 Vertical load

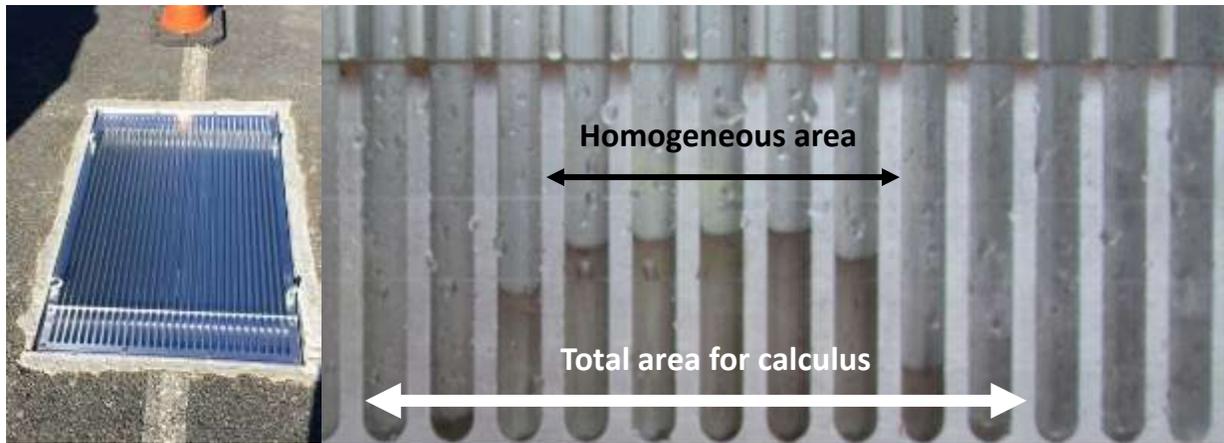
2 The static vertical load was checked by using a calibrated weigh pad, readable and accurate to 0.5
 3 kg. The test vehicle was positioned on a level surface such that the test wheel could be lowered,
 4 when required, on to the weigh pad. The weigh pad was constructed to ensure that a device's
 5 measurement wheel when lowered to the weigh pad positioned at it's normal measurement place.
 6 During the calibration the measured and reference load values were used to ensure compliance to
 7 the standards EN TS 15901-1 to 15 (11) (12) (13) (14) or existing national procedures. Two
 8 measurements were performed and the static load was determined to be the average of the two
 9 measured values. Table 3 shows that static load values complied with European, American or
 10 national specifications or existing standards.

11 **TABLE 3 Checking results for the vertical load**

Device	Reference value (kg)	Measured value (kg)	Difference (%)
1	148,0	146,5	1%
2	135,0	128,3	5%
3	135,0	128,8	5%
4	100,0	96,8	3%
5	90,0	87,8	3%
6	120 [110-130]	123,0	-3%
7	180,0	178,5	1%
8	120,0	133,8	-11%
9	185,0	183,5	1%
10	106,8	107,5	-1%
11	200,0	-	-
12	200,0	199,0	1%
13	200,0	209,3	-5%
14	200,0	200,0	0%
15	200,0	201,0	-1%

17 Water film thickness

18 Water film thickness was checked using a special aluminium tray composed of small channels.
 19 The platform was embedded in the pavement such that the top of the platform was level with the
 20 pavement surface. The vehicles drove over the platform at 40, 60 and 80 km/h in normal
 21 measurement mode. The amount of water spread in the channels of the platform was measured
 22 using digital high-resolution pictures taken after the vehicles have passed. A special purpose
 23 software allowed a semi-automatic analysis of each photo. Two criteria were analysed: a) the
 24 homogeneity and width of the water distribution in the tubes; b) the average nominal water film
 25 thickness under the tire.



1 **FIGURE 5 Grid (a) and method used to analyze pictures (b)**

2

3 Table 4 presents the results of the water film thickness checking. The total width of water
4 dispersal under the tire was generally sufficient, but when only the width of the homogeneous area
5 was considered results were different. In half of the cases, the water-film thickness under the
6 tire was not uniform and not provided the required niminal water depth.

7 Even though the average water-film thickness for most of the devices was close to the
8 required, under the tire in the homogeneous area for the majority of devices, it was significantly
9 smaller. This fact can be explained by the calibration process employed for numerous devices,
10 which is based on the weighing the amount of water delivered during a given time.

11 Only the average water-film thickness measurement was considered to accept devices
12 (distribution and below tire water-film thicknesses were not included), due to the fact that
13 standards and specifications generally consider an average water-film thickness value in their
14 requirements. All the devices were compliant with these specifications.

15 Three devices (2 side-forces devices and 1 longitudinal friction device) were not able to
16 perform this check due to the shape of their water delivery system. However, these devices
17 contained electronic closed-loop controlled water delivery systems to ensure a regular and correct
18 water flow.

1 **TABLE 4 Checking results for the water film thickness**

Device	Speed (km/h)	Tire Width (mm)	Theoretical number of tubes under the tire	Theoretical water film thickness (mm)	All tubes			Homogeneous area			Homogeneous wetting width sufficient (Y/N)	Wetting width sufficient (Y/N)	ΔWD (%) (homogeneous area)	ΔWD (%) (total)
					Average water film thickness (mm)	Standard deviation (mm)	Number of tubes filled in	Average water film thickness (mm)	Standard deviation (mm)	Number of tubes filled in				
1	40	61	5	1,0	1,04	0,23	5	1,16	0,10	4	N	Y	16%	4%
	60	61	5	1,0	0,95	0,34	6	1,20	0,06	4	N	Y	20%	-5%
	80	61	5	1,0	1,04	0,33	6	1,29	0,08	4	N	Y	29%	4%
2	40	61	5	1,0	1,11	0,55	6	1,45	0,34	4	N	Y	45%	11%
	60	61	5	1,0	1,14	0,31	6	1,27	0,24	5	Y	Y	27%	14%
	80	61	5	1,0	1,28	0,47	8	1,65	0,10	5	Y	Y	65%	28%
4	40	61	5	0,5	0,42	0,21	5	0,50	0,03	2	N	Y	-1%	-16%
	60	61	5	0,5	0,36	0,11	4	0,43	0,05	3	N	N	-14%	-28%
	80	61	5	0,5	0,26	0,10	4	0,24	0,02	2	N	N	-53%	-48%
5	40	61	5	1,0	0,37	0,13	6	0,46	0,08	4	N	Y	-54%	-64%
	60	61	5	1,0	0,28	0,09	8	0,36	0,07	5	Y	Y	-64%	-72%
	80	61	5	1,0	0,35	0,13	8	0,45	0,12	5	Y	Y	-55%	-65%
6	40	61	5	1,0	0,97	0,06	5	0,97	0,06	5	Y	Y	-3%	-3%
	60	61	5	1,0	0,90	0,25	6	1,05	0,08	5	Y	Y	5%	-10%
	80	61	5	1,0	0,59	0,12	6	0,67	0,04	5	Y	Y	-33%	-41%
7	40	100	8	1,0	1,01	0,38	8	1,26	0,10	6	N	Y	26%	1%
	60	100	8	1,0	0,97	0,34	8	1,19	0,11	6	N	Y	19%	-3%
	80	100	8	1,0	1,01	0,21	7	1,15	0,06	5	N	N	15%	1%
8	40	61	5	1,0	0,83	0,58	7	1,51	0,05	3	N	Y	51%	-17%
	60	61	5	1,0	0,64	0,32	7	1,01	0,11	3	N	Y	1%	-36%
	80	61	5	1,0	0,68	0,35	7	0,80	0,09	3	N	Y	-20%	-32%
9	40	100	8	1,0	0,94	0,53	10	1,38	0,10	6	N	Y	38%	-7%
	60	100	8	1,0	0,77	0,35	9	1,08	0,05	5	N	Y	8%	-23%
	80	100	8	1,0	0,74	0,37	9	1,07	0,07	5	N	Y	7%	-26%
10	40	61	5	0,5	0,57	0,30	8	0,87	0,11	6	Y	Y	73%	14%
	60	61	5	0,5	0,33	0,15	6	0,53	0,18	2	N	Y	5%	-34%
	80	61	5	0,5	0,26	0,13	8	0,39	0,06	4	N	Y	-22%	-48%
11	40	76	6	0,5	0,25	0,15	9	0,57	0,07	2	N	Y	13%	-50%
	60	76	6	0,5	0,33	0,22	10	0,56	0,11	5	N	Y	11%	-33%
	80	76	6	0,5	0,29	0,16	9	0,53	0,04	3	N	Y	7%	-42%
13	40	76	6	0,5	0,42	0,33	10	0,83	0,27	4	N	Y	67%	-17%
	60	76	6	0,5	0,39	0,21	15	0,62	0,16	7	Y	Y	23%	-23%
	80	76	6	0,5	0,28	0,18	15	0,51	0,19	6	Y	Y	1%	-45%
15	40	76	6	0,5	0,38	0,22	6	0,60	0,15	3	N	Y	20%	-24%
	60	76	6	0,5	0,30	0,17	8	0,48	0,11	4	N	Y	-5%	-40%
	80	76	6	0,5	0,36	0,21	7	0,55	0,14	4	N	Y	10%	-27%

1 METHODOLOGY FOR ROUND ROBIN TESTS ANALYSIS

2 Two different harmonization methodologies were examined using the friction workshop's database.
 3 The first one was based on the Skid Resistance Index (CEN/TS 13036-2) (15) which was improved
 4 during FP7 EU ROSANNE project funded between 2013 and 2016 (16) (17) (18). The second one
 5 according to the methodology developed in the US used a two-step method utilizing a laboratory
 6 scale reference surface and a pair of unique laboratory and field useable devices (DFT and CTM)
 7 to establish time stable check standards for friction harmonization (19).

8 9 **Common scale principle (SRI)**

10 The concept is to transform measured friction values provided by an individual device under its
 11 particular test conditions (speed, load, tire) to equivalent friction values under reference conditions.
 12 This transformation is based on the following formula defining the SRI (Skid Resistance Index):
 13

$$14 \quad SRI = B \cdot F \cdot e^{\frac{S - S_{Ref}}{S_0}}$$

15 (1)

$$17 \quad S_0 = a \cdot MPD^b \quad (2)$$

18
 19 Where SRI is the skid resistance value reported against the common scale
 20 a, b, and B are device-specific calibration parameters to be determined
 21 F is the measured skid resistance value
 22 S is the vehicle operating speed (in km/h)
 23 S_{Ref} is the reference speed at which SRI values are reported (in km/h)
 24 S_0 represents speed gradient of skid resistance values related to the surface texture
 25 MPD is the Mean Profile Depth (in mm)
 26

27 To determine the device-specific calibration factors (a, b and B), the value of the common
 28 scale for each test surface must be fixed. Based on former research work, the reference value is set
 29 to be the average value of friction coefficients measured on a given surface by a group of devices
 30 operating on the same measuring principle (i.e. 10 devices for longitudinal friction and 5 devices
 31 for sideways-force friction). Data scattering for each group on each surface was checked with
 32 statistical tests to detect outliers, outliers were excluded from the calculation of the reference
 33 values (20) (21). When the reference value is defined, parameters a, b and B are adjusted with least
 34 squares method.
 35

36 **Check-standard IFI “two-steps approach”**

37 The process embodies the use of a pair of macro-texture and friction measurement equipment that
 38 can be used both in the laboratory and on field and have good reproducibility and high precision.
 39 It also uses a set of small highly reproducible manufactured standard surfaces for dynamic
 40 laboratory calibration. Thus, the calibration and harmonization of any high-speed continuous
 41 friction measurement equipment or locked wheel tester can be accomplished.
 42

43 The implementation of check-standard IFI method requires the following steps:

- 44 • Calibration of DFT and CTM according to manufacturer's specifications: static
 45 calibration of each individual part of the devices and dynamical tests on two

1 laboratory reference surfaces manufactured from special aluminium alloy and highly
2 wear resistant ceramic (Figure 6).

- 3 • Use the calibrated DFT and CTM devices on the test sections to establish the “check
4 standard” friction and macro-texture values for each of the test surfaces.

5 The F60 and Sp values of each surface were thus calculated using:

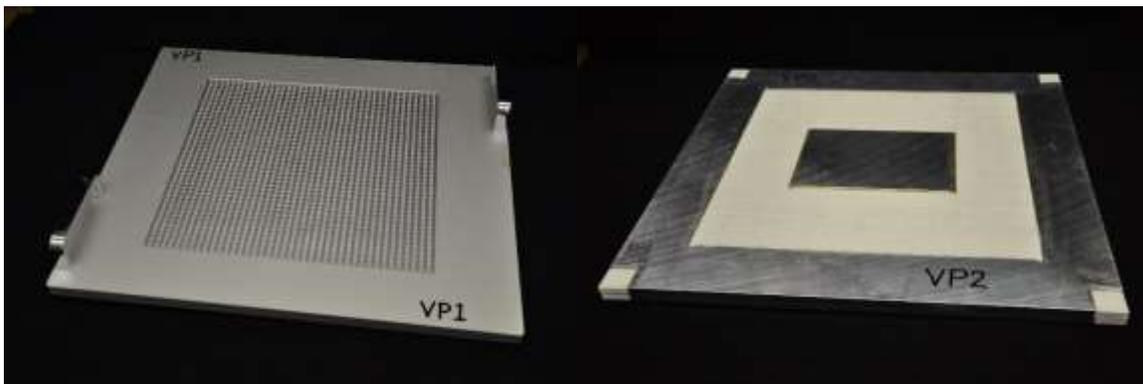
$$6 \quad F_{60} = 0.081 + .732 * DFT_{20} * e^{\frac{(20-60)}{S_p}} \quad (3)$$

$$7 \quad S_p = 14.2 + 89.7 * MPD \quad (4)$$

8 Where DFT20 is the skid resistance measured at 20 km/h with DFT

9 MPD is the Mean Profile Depth (in mm)

10



11

12 **FIGURE 6 Small-scale laboratory standard friction surfaces**

13

14

15

16

17

18

19

20

21

22

23

24

25

26

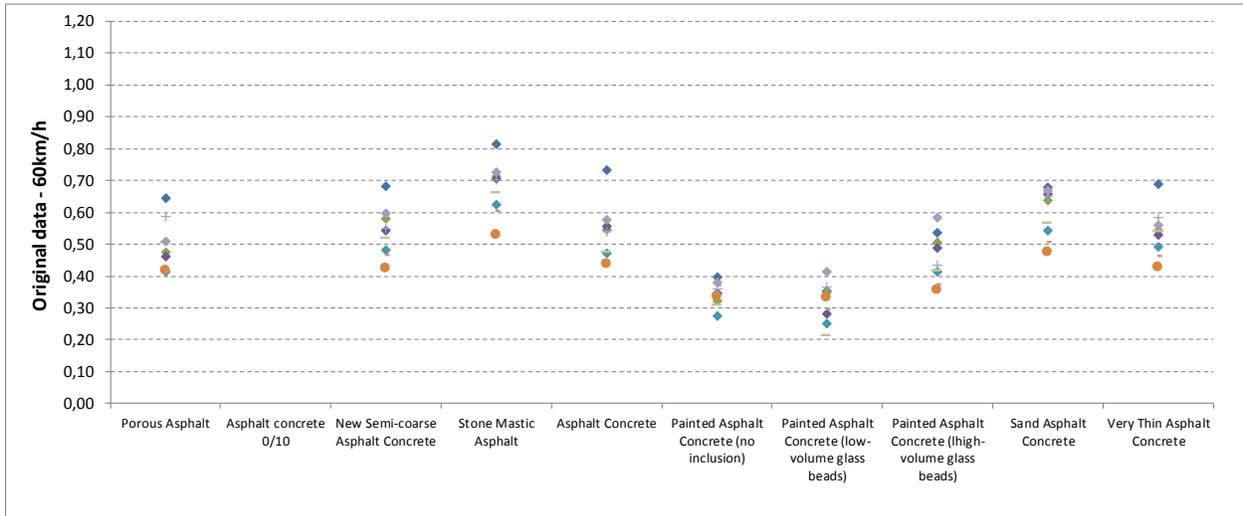
27

RESULTS

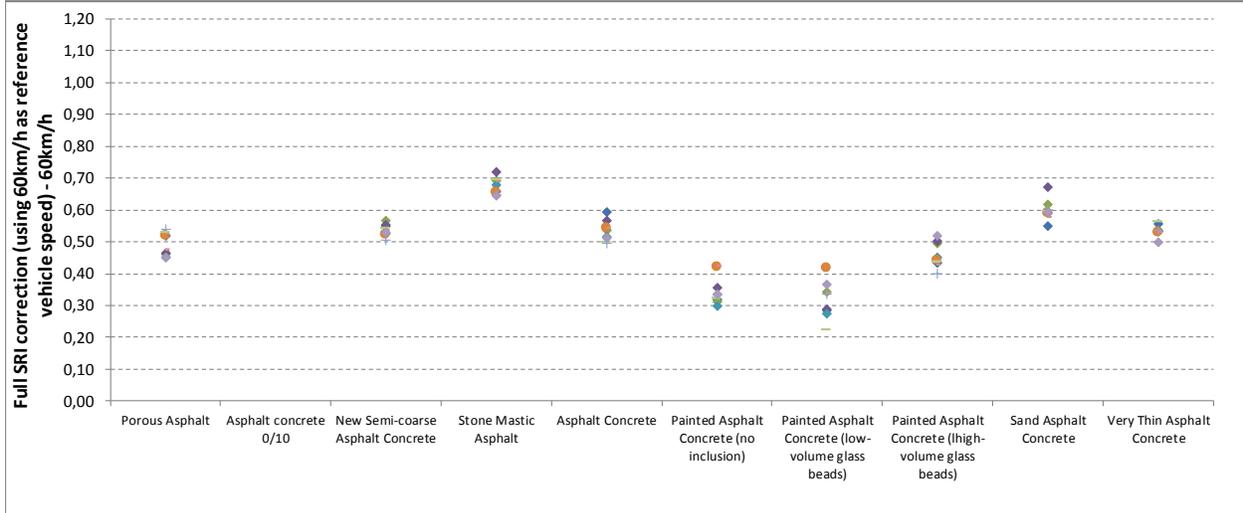
Application of common scale (SRI)

The database was split into two sub-bases, one for longitudinal friction devices and the other for transversal friction devices. Each sub-database was analyzed by using 60 km/h as a reference speed. The set of parameters (a, b, B) was calculated for each operating device.

Figures 7 and 8 present examples of results for both types of devices with raw data and calibrated data when the SRI approach is used. The SRI approach effectively reduces the distribution range of friction values. The same trend was observed for all the speeds and both groups of devices.



1



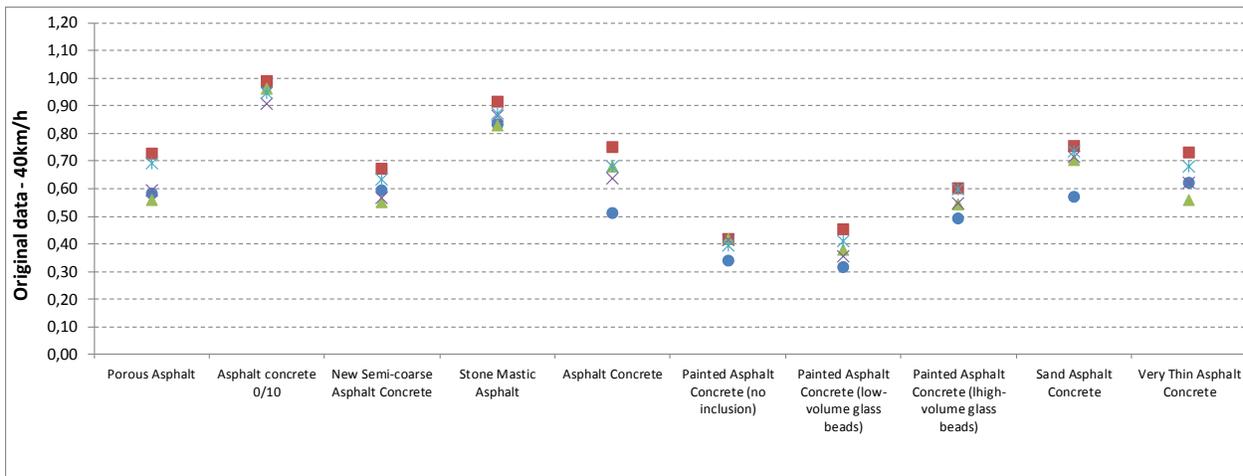
2

3

FIGURE 7 Raw data measured at 60 km/h and SRI correction (Ref. speed = 60 km/h) for longitudinal friction measuring devices (22)

4

5



6

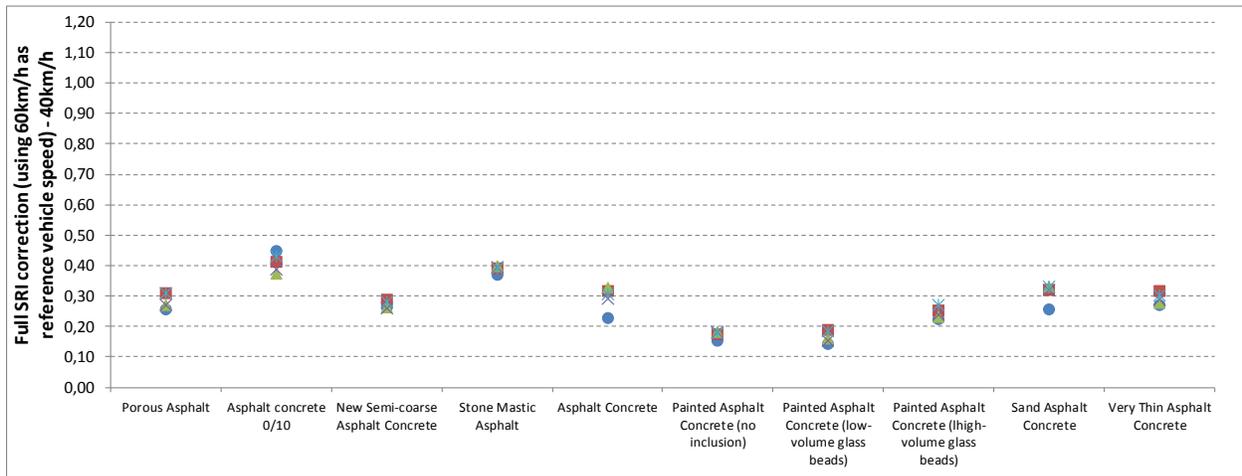


FIGURE 8 Raw data measured at 40 km/h and SRI correction (Ref. speed = 60 km/h) for transversal friction measuring devices (22)

The repeatability and reproducibility of the devices were also estimated before and after SRI implementation. Regarding longitudinal friction devices (Table 5), the standard deviation of repeatability of raw data was 0.020, is considered very good considering the variety of devices included in the analysis and the SRI correction did not improve this. By contrast, standard deviation of reproducibility was reduced by a factor of two (0.039 vs 0.078). This level is comparable with results obtained within a family of the same devices (between 0.030 and 0.040 obtained during round robin tests), which demonstrates the benefits of the SRI approach when applied to a group of different devices.

TABLE 5 Repeatability and reproducibility for SRI correction (longitudinal friction devices)

		40	60	80	All
Repeatability	Original data	0,022	0,020	0,019	0,020
	Full SRI correction (using 60km/h as reference vehicle speed)	0,019	0,019	0,022	0,020
Reproducibility	Original data	0,074	0,075	0,085	0,078
	Full SRI correction (using 60km/h as reference vehicle speed)	0,039	0,038	0,041	0,039

TABLE 6 Repeatability and reproducibility for SRI correction (transversal friction devices)

		40	60	80	All
Repeatability	Original data	0,069	0,019	0,020	0,036
	Full SRI correction (using 60km/h as reference vehicle speed)	0,031	0,009	0,011	0,017
Reproducibility	Original data	0,089	0,031	0,033	0,051
	Full SRI correction (using 60km/h as reference vehicle speed)	0,038	0,013	0,020	0,024

For side-force friction devices, both repeatability and reproducibility were reduced to 50% of the original values by applying the full SRI correction (Table 6). The results are better than the one obtained in ROSANNE project (17).

TABLE 7 Disagreement of Measurement Devices after SRI implementation

	Longitudinal Friction devices		Transversal Friction devices	
	Average of absolute differences (Disagreement of devices) of different equipment	STD of absolute differences of different equipment	Average of absolute differences (Disagreement of devices) of different equipment	STD of absolute differences of different equipment
Porous Asphalt	0,03	0,016	0,01	0,006
New Semi-coarse Asphalt Concrete	0,01	0,009	0,01	0,006
Stone Mastic Asphalt	0,02	0,014	0,01	0,003
Asphalt Concrete	0,01	0,012	0,01	0,013
Painted Asphalt Concrete (no inclusion)	0,03	0,023	0,00	0,002
Painted Asphalt Concrete (low-volume glass beads)	0,04	0,016	0,01	0,003
Painted Asphalt Concrete (high-volume glass beads)	0,03	0,023	0,01	0,005
Sand Asphalt Concrete	0,02	0,011	0,01	0,007
Very Thin Asphalt Concrete	0,02	0,012	0,01	0,007

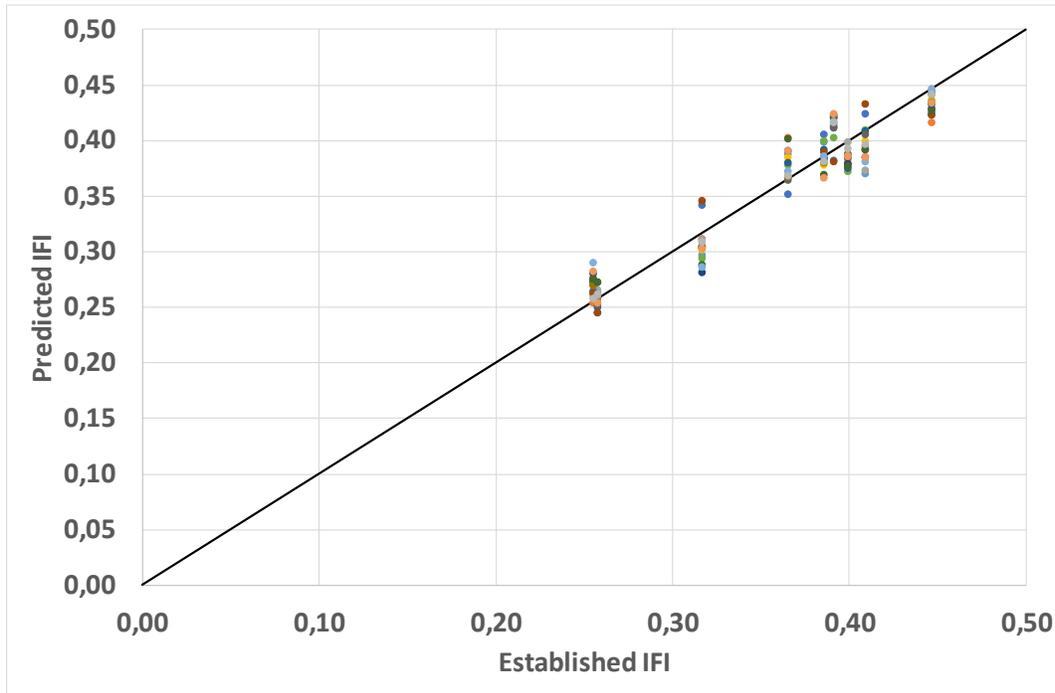
The SRI approach was completed by calculating the error between the harmonized values of friction and the reference values for all the devices (Table 7). Very good agreement between the SRI harmonized values of all the side-force devices can be observed. Considering longitudinal friction devices, the agreement remains reasonable except on painted surfaces, which exhibited some in-homogeneities.

Additionally, effect of temperature was explored. Friction measurements were corrected by using linear temperature correction laws. It appears that no significant improvement was observed since the range of air and water temperatures in this study was small. Thus, the friction coefficient variation was inferior to the repeatability of the devices.

Application of the two steps approach (Check-standard IFI)

As observed on Figures 7 and 8, raw data are widely scattered for the various surfaces. As this two-steps approach consider DFT and CTM values as references, all the participating devices (i.e. longitudinal and transversal friction devices) were calibrated with an identical procedure, as

1 described in the section “Methodology”. Figure 9 presents results obtained for all the devices after
 2 harmonization process. The data scatter among different measurement equipment was reduced and
 3 the agreement between the different devices and the established check standard had been moved
 4 to a very good agreement with the line of equality.
 5



6
 7 **FIGURE 9 Harmonized Friction Measurement of All Devices by IFI approach**
 8

9 This approach was completed by calculating the error between the harmonized values of
 10 friction and the reference for all the devices (Table 8). Good agreement between harmonized
 11 friction values on the various test sections is observed. Moreover, the results are comparable to the
 12 ones obtained with the “common scale (SRI)” approach.
 13

14 **TABLE 8 Disagreement of Measurement Devices after IFI implementation**
 15

	Average of absolute differences (Disagreement of devices) of different equipment	STD of absolute differences of different equipment
Porous Asphalt	0,02	0,012
New Semi-coarse Asphalt Concrete	0,01	0,006
Stone Mastic Asphalt	0,01	0,009
Asphalt Concrete	0,01	0,007
Painted Asphalt Concrete (no inclusion)	0,02	0,009
Painted Asphalt Concrete (low-volume glass beads)	0,01	0,005
Painted Asphalt Concrete (high-volume glass beads)	0,02	0,009
Sand Asphalt Concrete	0,02	0,011
Very Thin Asphalt Concrete	0,02	0,008

CONCLUSION

The friction workshop was aimed at testing and improving the harmonization processes for devices measuring longitudinal and sideways-force friction coefficients. During the workshop, both the SRI common scale developed in Europe and the two-steps harmonization process (IFI) used in the United States were implemented, to check the robustness and applicability of these methodologies.

Calibration is always of paramount importance for friction measuring devices since friction strongly depends on operating conditions (load, slip ratio, speed, pressure), on surface characteristics (micro and macrotexture) and on environmental conditions (water film thickness, cleanness of the surface). That is the reason why the trials were preceded by checking/calibration of the devices based on the experience gained during ROSANNE project and Penn State Friction workshops. This checking exercise led to the conclusion that the devices were fulfilling the existing European and international standards requirements or applicable national requirements.

The round robin test analysis demonstrated that both harmonization procedures led to an improvement of the results and to a good agreement of the friction values measured by very different devices.

The SRI approach in fact achieved a standard deviation value of repeatability around 0.0017 for side-force devices and 0.0020 for longitudinal friction devices, which proved to be very satisfying. The standard deviation values of reproducibility calculated with SRI approach were 0.0024 for side-force devices and 0.0039 for longitudinal devices. These results were even better than the ones obtained during the ROSANNE project's trials.

ACKNOWLEDGEMENT

The authors want to thank members of Laboratory EASE at IFSTTAR who helped in the organization and the realization of the 1st European Pavement Friction Workshop.

AUTHOR CONTRIBUTION STATEMENT

1 The authors confirm contribution to the paper as follows: study conception and design: V. Cerezo,
2 Z. Rado, M. Kane; data collection: V. Cerezo, Z. Rado; analysis and interpretation of results: V.
3 Cerezo, Z. Rado; draft manuscript preparation: V. Cerezo, Z. Rado, M. Kane. All authors reviewed
4 the results and approved the final version of the manuscript.
5

6 REFERENCES

- 7 1. Wambold, J. C., C. E. Antle, J. J. Henry, and Z. Rado. (1995) International PIARC
8 Experiment to Compare and Harmonize Texture and Skid Resistance
9 Measurements. Final report submitted to the Permanent International Association
10 of Road Congresses (PIARC), State College, Pa.
- 11 2. PIARC (2004), Specification for a standard test tyre for friction coefficient
12 measurement of a pavement surface: SmooTh TeS TyRe, Technical Committee 1
13 Surfaces characteristics, 13 pages.
- 14 3. ASTM E1551-16 (2016), Standard Specification for a Size 4.00-8 Smooth Tread
15 Friction Test Tire, ASTM International, West Conshohocken, PA, 2016,
16 www.astm.org.
- 17 4. ASTM E1844-96 (1996), Standard Specification for A Size 10 x 4-5 Smooth-Tread
18 Friction Test Tire, ASTM International, West Conshohocken, PA, 1996,
19 www.astm.org.
- 20 5. ASTM E1911-09ae1 (2009), Standard Test Method for Measuring Paved Surface
21 Frictional Properties Using the Dynamic Friction Tester, ASTM International, West
22 Conshohocken, PA, 2009, www.astm.org.
- 23 6. ASTM E2157-15 (2015), Standard Test Method for Measuring Pavement Macro-
24 texture Properties Using the Circular Track Meter, ASTM International, West
25 Conshohocken, PA, 2015, www.astm.org.
- 26 7. ISO 13473-1 (2005), Characterisation of pavement texture by use of surface profiles
27 —Part 1: Determination of Mean Profile Depth, January.
- 28 8. Hanson D. and B. Prowel, B (2004), Evaluation of Circular Track Meter for
29 measuring surface texture of Pavements, NCAT Report 04-05, 26 pages,
30 September.
- 31 9. CEN (2011), DD CEN/TS 13036-4: Road and airfield surface characteristics – test
32 methods. Part 4: Method for measurement of slip/skid resistance of a surface: The
33 pendulum test.
- 34 10. Cerezo V. and Dauvergne, S. (2017), 1st European Pavement Friction Workshop -
35 experimental program, 1st European Pavement Friction Workshop, 31 pages, May.
- 36 11. CEN (2009), CEN TS 15901-4: Road and airfield surface characteristics — Part 4:
37 Procedure for determining the skid resistance of a pavement surface using a device
38 with longitudinal controlled slip (LFCT): Tatra Runway Tester (TRT).
- 39 12. CEN (2009), CEN/TS 15901-6: Road and airfield surface characteristics — Part 6:
40 Procedure for determining the skid resistance of a pavement surface by
41 measurement of the sideway force coefficient (SFCS): SCRIM ®.
- 42 13. CEN (2009), CEN/TS 15901-8: Road and airfield surface characteristics — Part 8:
43 Procedure for determining the skid resistance of a pavement surface by
44 measurement of the sideway force coefficient (SFCD): SKM.
- 45 14. CEN (2013), CEN/TS 15901-15: Road and airfield surface characteristics — Part
46 15: Procedure for determining the skid resistance of a pavement surface using a
47 device with longitudinal controlled slip (LFCT): The IMAG.

- 1 15. CEN (2010), DD CEN/TS 13036-2: Road and airfield surface characteristics – test
2 methods. Part 2: Assessment of the skid resistance of a road pavement surface by
3 the use of dynamic measuring systems.
- 4 16. Greene M J, Viner H, Cerezo v, Kokot D and Schmidt B (2014), Deliverable D1.1:
5 Definition of boundaries and requirements for the common scale for harmonisation
6 of skid resistance measurements, Collaborative Project FP7- Rolling resistance,
7 Skid resistance, ANd Noise Emission measurement standards for road surfaces
8 (ROSANNE), 79 pages, May.
- 9 17. Greene M., Viner H., Cerezo V., Brittain S. (2016), Deliverable 1.3: Analysis of
10 data from the second round of tests and further development of the common scale,
11 Collaborative Project FP7- Rolling resistance, Skid resistance, ANd Noise
12 Emission measurement standards for road surfaces (ROSANNE), 89 pages,
13 November.
- 14 18. Greene, M. Viner, H. Cerezo, V. Schmidt, B. Scharnigg, K. (2015), Deliverable
15 D1.2: Analysis of data from the first round of tests and initial development of the
16 common scale, Collaborative Project FP7- Rolling resistance, Skid resistance, ANd
17 Noise Emission measurement standards for road surfaces (ROSANNE), 63 pages,
18 May.
- 19 19. ASTM E1960-07 (2015), Standard Practice for Calculating International Friction
20 Index of a Pavement Surface, ASTM International, West Conshohocken, PA, 2015,
21 www.astm.org.
- 22 20. ISO 5725-1 (1994), Application of statistics: accuracy (trueness and precision) of
23 measurements methods and results – part 1: General principles and definition,
24 December.
- 25 21. ISO 5725-5 (1998), Application of statistics: accuracy (trueness and precision) of
26 measurements methods and results – part 5: Alternative methods for the
27 determination of the precision of a standard measurement method, October.
- 28 22. Cerezo V. and Rado, Z. (2017), 1st European Pavement Friction Workshop – round
29 robin tests analysis, 1st European Pavement Friction Workshop, 59 pages,
30 December.
- 31