



**Università degli Studi Mediterranea di Reggio Calabria**  
Archivio Istituzionale dei prodotti della ricerca

A new and simplified approach to assess the pavement surface micro- and macrotexture

This is the peer reviewed version of the following article:

*Original*

A new and simplified approach to assess the pavement surface micro- and macrotexture / Pratico', F.G., Astolfi, A.. - In: CONSTRUCTION AND BUILDING MATERIALS. - ISSN 0950-0618. - 148:(2017), pp. 476-483. [10.1016/j.conbuildmat.2017.05.050]

*Availability:*

This version is available at: <https://hdl.handle.net/20.500.12318/3370> since: 2020-12-04T10:41:05Z

*Published*

DOI: <http://doi.org/10.1016/j.conbuildmat.2017.05.050>

The final published version is available online at: <https://www.sciencedirect>.

*Terms of use:*

The terms and conditions for the reuse of this version of the manuscript are specified in the publishing policy. For all terms of use and more information see the publisher's website

*Publisher copyright*

This item was downloaded from IRIS Università Mediterranea di Reggio Calabria (<https://iris.unirc.it/>) When citing, please refer to the published version.

(Article begins on next page)

1 **A New and Simplified Approach to Assess the Pavement Surface micro- and**  
2 **macrotecture**

3 Filippo G. Praticò<sup>a</sup>, Armando Astolfi<sup>b</sup>

4 *<sup>a</sup>DIIES Department, University Mediterranea of Reggio Calabria*

5 *<sup>b</sup>DICAM Department, University of Palermo*

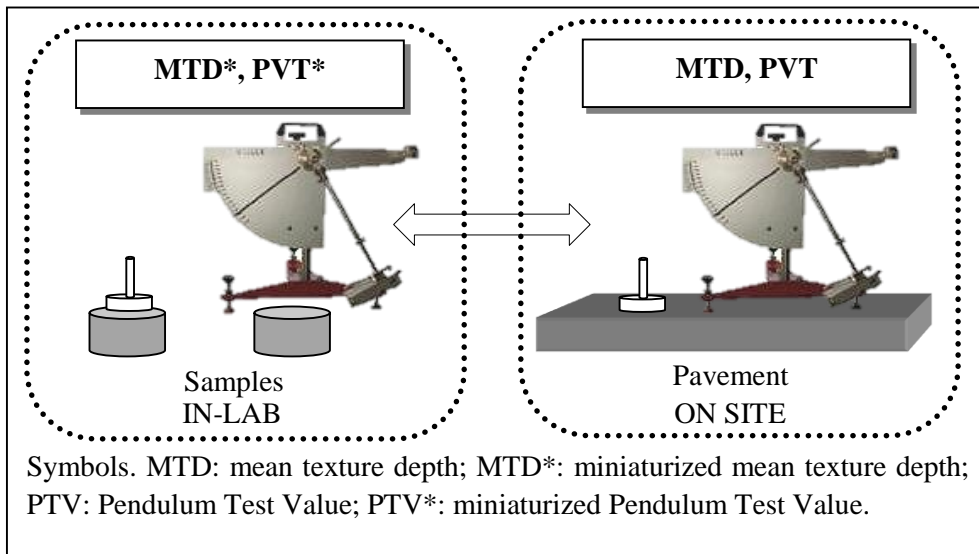
6

7 **ABSTRACT**

8 Road safety depends on pavement skid resistance and surface texture. Skid resistance mainly depends on  
9 micro-texture and macrotecture. Skid and texture measurements on samples, in the laboratory, at the  
10 preliminary stage of the design, would enhance the design in terms of timing, costs, and reliability.  
11 Consequently, this study aims at setting up and validating simple methods for assessing surface texture and  
12 skid resistance based on core/sample measurements. Experiments were carried out and predictive  
13 relationships were set up to explain and predict results. Under given conditions, miniaturised macro-and  
14 microtexture tests (modified EN 13036-1 and modified EN 13036-4, respectively) prove to be a reliable tool  
15 to optimise texture design. Results highlight the suitability of the proposed methodology and can benefit both  
16 researchers and practitioners.

17 **Keywords:** Pavement Surface Properties, Road Safety, Macrotecture, Micro-texture.

## Graphical abstract



## 20 1. Introduction

21 Pavement texture is a continuum which includes different scales, as a function of the wavelength: micro,  
 22 macro, mega-texture and unevenness [1], [2], [3], [4]. Micro-texture refers to wavelengths,  $\lambda$ , lower than 0.5  
 23 mm and peak-to-peak amplitudes,  $A$ , in the range 10–3mm–0.5 mm. Macrottexture refers to  $\lambda = 0.5–50$  mm  
 24 and  $A = 0.1$  mm–20 mm.

25

26 Macrottexture can be assessed through laser-based methods [5], [6], [7], [8], [9], sand-patch-like methods  
 27 [10], [11], [12], [13], [14], or other extrinsic methods [15]. Methods above differ based on a number of  
 28 parameters: the “material-method” used to “fill” the texture (sand, glass beads, or laser), the number of  
 29 points on the surface investigated (1–10), and the number of diameters measured per point (2–4) [11]. The  
 30 mean texture depth (MTD, [10]) pertains to the macrottexture domain. It usually ranges from 0.3 mm to 0.7  
 31 mm for dense-graded friction courses (DGFC) and from 1 mm to 6 mm for porous asphalt concretes (PA)  
 32 and it requires a surface diameter that is usually between 50 mm and 300 mm [16].

33

34 Micro-texture pertains to the roughness of the surface of the exposed aggregate chips that can be felt by  
 35 one’s fingertips. It interacts with the tire rubber on a molecular scale and provide adhesion (one out of the

36 two key mechanisms of tire-pavement friction, cf. [17]. Research shows that the evolution of the asperity-  
37 peak curvature of micro-texture follows that of the surface friction coefficient [18].

38

39 Micro-texture values are indirectly estimated in terms of pendulum test value (termed PTV in the standard  
40 EN and termed BPN in ASTM and CNR standards), using low speed friction measurement devices such as  
41 the British Portable Tester [19], [20]. PVT values usually have to be greater than 45–65 (based on pavement  
42 type and road relevance), with measurements baselines which are about 125 mm [21], [22]. Furthermore,  
43 surface texture affects friction, in terms of both macrotexture and micro-texture [23], [24], [25], [26], [19].

44

45 Pavement micro- and macrotexture are a vital requirement of a pavement because they impact road safety,  
46 [1], [17], [27], [28], [29], [30], [31], [32] and greatly affect the state of play of the transportation  
47 infrastructure [33]. It turns out that the design of pavement texture at an early stage, in the laboratory, is  
48 crucial because of many reasons: i) concurrent requirements have to be satisfied: volumetric properties [34],  
49 “premium” properties [35], variations over time [17], [36], [37], [38], and production requirements [39]; ii)  
50 the ability of laboratory specimens to reproduce real pavements may be sometimes controversial (cf. [40],  
51 [41], [42]) and methods and studies are needed to link field and laboratory results; iii) laboratory experiments  
52 enforce scientific control by testing hypotheses in the artificial and highly controlled setting of a laboratory  
53 and imply considerable savings. Unfortunately, MTD and PTV measurements require extended surface areas  
54 and this hinders from having MTD and PTV estimates based on laboratory samples.

55

56 Understanding and deriving relationships between MTD (/PTV) tests carried out on samples and on real  
57 pavements is crucial: 1) to assess if mixes with identical volumetrics and components may have surface  
58 properties which are significantly different based on on-site vs. in-lab compaction [43], [44]; 2) given the  
59 above, to help carry out a realistic design of surface characteristics during the so-called prequalification of  
60 the mix friction course. This research gap calls for research and investigation.

## 61        **2. Objectives**

62        The main objective of the study described in this paper is to provide a theoretical and practical framework to  
63        carry out micro- and macrottexture measurements at the design stage, on samples or small slabs, in the  
64        laboratory. In more detail: i) standardized measurements were carried out on several friction courses  
65        according to the sand patch method [10] and to the British Pendulum Method [21]; ii) both dense-graded and  
66        open-graded friction courses were considered; iii) in-lab and on-site tests were carried out; iv) the tests were  
67        both modelled. Algorithms were set up and finally applied to explain results and predict further  
68        developments. This paper illustrates the results obtained in terms of miniaturization of macrottexture  
69        measurements and micro-texture measurements. Section 3 refers to experiments while a Section 4 focuses on  
70        modelling, calibration, and validation. Finally, in Section 5, conclusion are drawn and main contributions are  
71        pointed out.

## 72        **3. Experiments**

73        In task 1, in the aim of gathering practical information and data about the potential of the two tests to be used  
74        in the laboratory, experiments were carried out on pavements and on cores extracted. Six reference friction  
75        courses were considered: three dense-graded friction courses (DGFC), herein termed DG1-DG3, and three  
76        porous asphalt concretes (PA), herein termed PA1-PA3. On average, for DGFCs, specific gravity was 2.32  
77        and asphalt binder content was 5.1% (by weight of mix), while for PAs, specific gravity was 2.11 and asphalt  
78        binder content was 5.0% (by weight of mix). Two types of indicators were derived: Mean Texture Depth  
79        (MTD, [10]) and Pendulum Test Value (PVT, [21]). The volume used to measure MTD and the length of the  
80        contact path were the ones set up in the concerned standards (UNI EN 13036-1 [10] and UNI EN 13036-4  
81        [21]) and the ones needed in order to make it possible to perform them on samples, in the laboratory.

### 82        **3.1. Macrottexture**

83        For macrottexture, note that a volume of 25,000 mm<sup>3</sup> is required by the traditional, current methods [1], [11],  
84        [12], while a smaller volume (4500 mm<sup>3</sup>, [45]) is required by the diameter of Marshall [46] or gyratory  
85        specimens [47]. By referring to the miniaturization of the MTD test, it appears relevant to observe that when  
86        sample, sand patch, and spreading tool are considered: the sample diameter varies from “infinity”

87 (pavement), to about 100 mm (Marshall specimen), while the spreading tool has a constant diameter of 63.5  
88 mm, and the sand patch diameter varies based on mix type, compaction and volume.

89 In each point of each surface (e.g., point B of surface DG1), multiple repetitions of the MTD measurement  
90 were carried-out (up to 31, Table 1). For  $V = 4500 \text{ mm}^3$ , note that each measurement was followed by  
91 compressed air jet blasting in order to clean the surface and that this procedure is not usually required  
92 because both CNR and EN-ASTM standards do not require to repeat the measurement in the same point of  
93 the surface. Table 1 illustrates the averages obtained for the six pavements under analysis. Values in the  
94 range 0.5 mm–1.9 mm were obtained for DGFCs. On the contrary, values between 1.6 mm and 2.9 mm were  
95 obtained for PAs. Note that the standard deviation ranged from 0.01 mm to 0.22 mm for DGFCs, while it  
96 ranged from 0.00 mm to 0.10 mm for PAs. Note that DG1 differs from DG2 and DG3 and this may be due to  
97 the fact that DG1 corresponds to a dense-grade friction course that is older than DG2 and DG3. This partly  
98 complies with Iuele [43] and Do [48] and refers to the fact that surface texture deterioration is greater than  
99 for the other two types of surface. Many factors, including aggregate properties, binder properties, aggregate-  
100 binder combination, road geometry, traffic, weather, rainfall, and environmental conditions can be  
101 responsible for this [43], [48], [49], [50], [51], [52]. Table 1 also illustrates the coefficients of variation (CV,  
102 ratio of standard deviation to mean) for each mix (with  $V = 4500 \text{ mm}^3$  and  $V = 25,000 \text{ mm}^3$ ). DGFCs have  
103 CVs lower than 14%, while PAs have CVs lower than 4%. It is possible to observe that:

- 104 • the higher the volume is, the higher the MTD becomes;
- 105 • the standard deviation decreases when the volume used increases from  $4500 \text{ mm}^3$  to  $25,000 \text{ mm}^3$ ;
- 106 • the coefficient of variation (CV) decreases when the volume increases;

107 RMTD is the ratio  $\text{MTD}_{25}/\text{MTD}_{4.5}$ , i.e., the ratio between the value of MTD obtained when using a volume  
108 of  $25,000 \text{ mm}^3$  or  $4500 \text{ mm}^3$ . By referring to  $\text{RMTD} = \text{MTD}_{25}/\text{MTD}_{4.5}$  (Table 1), note that this ratio  
109 ranges from 103% to 121% for the dense-graded friction courses considered, while it ranges from 102% to  
110 123% for porous asphalt concretes.

111 It is noted that high values of MTD (e.g. PA2) may be linked to sand percolation into the interconnected  
112 pores “under the surface”, which may imply higher variances for MTD and RMTD and non-linearities in  
113 MPD-MTD relationship [53].

114

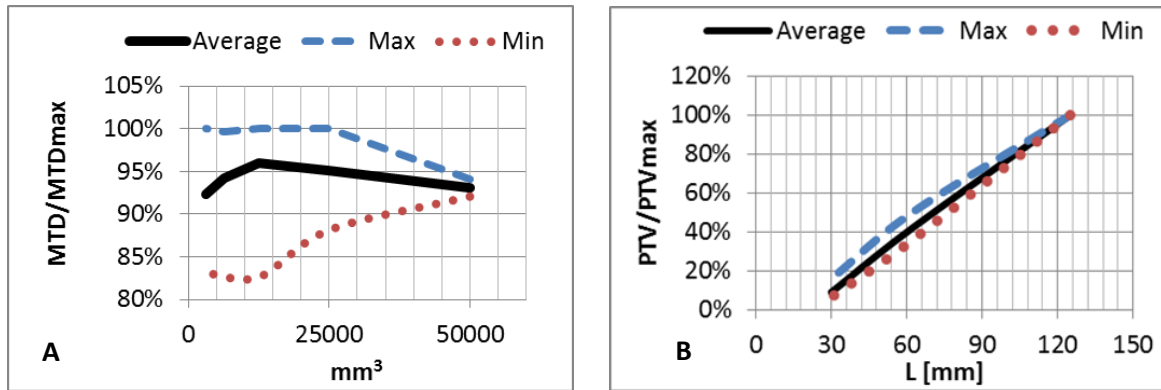
115 **Table 1:** MTD values obtained according to the UNI EN 13036-1 [**Errore. L'origine riferimento non è stata trovata.**]

Sample	DG1		DG2		DG3		PA1		PA2		PA3	
V	25000	4500	25000	4500	25000	4500	25000	4500	25000	4500	25000	4500
MTD	1.90	1.57	0.50	0.46	0.50	0.48	2.02	1.64	2.89	2.83	1.76	1.60
$R_{MTD}$	-	1.21	-	1.09	-	1.03	-	1.23	-	1.02	-	1.10
$1/R_{MTD}$	-	0.83	-	0.91	-	0.97	-	0.81	-	0.98	-	0.91
S.D.	0.06	0.22	0.01	0.03	0.01	0.03	0.06	0.03	0.00	0.10	0.05	0.07
CV	3%	14%	2%	6%	2%	7%	3%	2%	0%	4%	3%	4%

Symbols. V: Volume of sand [mm<sup>3</sup>]; MTD: Mean Texture Depth, mm [**Errore. L'origine riferimento non è stata trovata.**];  $R_{MTD}$ : ratio  $MTD_{25}/MTD_{4.5}$ ;  $MTD_{25}$ : Mean Texture Depth corresponding to  $V=25000$  mm<sup>3</sup>;  $MTD_{4.5}$ : Mean Texture Depth corresponding to  $V=4500$  mm<sup>3</sup>; S.D.: Standard Deviation [mm]; CV: Coefficient of Variation [%]; DG1-DG3: dense-graded friction courses; PA1-PA3: porous asphalt concretes.

116

117



118

119 **Figure 1:** Preliminary tests performed (example: left/A: MTD as a percentage of the maximum value; right/B: PTV).

120 **4.2 Skid resistance**

121 For skid resistance, preliminary tests were carried out in order to explore for different slide lengths (cf. Fig.  
122 1B). For both PTV and MTD, note that the smaller the lengths/surfaces are, the higher the variability is.

123 Table 2 refers the results (PTV) obtained for dense-graded mixtures (DG1-DG3) and porous asphalt  
124 concretes (PA1-PA3), when using the slide length as per standard ( $L = 125$  mm) or reducing it in the pursuit  
125 of miniaturization ( $L = 62.5$  mm).

126 Each result (e.g.,  $PTV = 76$ ) refers to a given sample and is the average of 6 values. In turn, each of these six  
127 values is the average of 5 “swings”. In summarising, each results derives from 30 “swings”. The coefficient  
128 of variation (CV,%) is derived starting from the standard deviation and the average (PTV).

129  $1/R$  refers to the ratio  $PTV_{62.5}/PTV_{125}$  (same mixture, e.g., DG2). Note that  $PTV_{125}/PTV_{62.5}$  ranges from  
130 1.99 to 2.77 (all the samples) and its average is 2.40. In contrast,  $PTV_{125}/PTV_{62.5}$  ranges from 1.99 to 2.22

131 and its average is 2.14 for porous concretes (PAs), while PTV<sub>125</sub>/PTV<sub>62.5</sub> ranges from 2.48 to 2.77 and its  
 132 average is 2.66 for dense-graded friction courses (DGs).

133 Note that: i) PTV ranges from 59 to 76 for DGs and from 59 to 61 for PAs (L = 125 mm); ii) If the contact  
 134 path is halved then the results obtained decrease and the standard deviation increase; iii) RPVT ranges from  
 135 1.9 to 2.2 for DGs and from 2.4 to 2.7 for PAs; iv) 1/RPTV ranges from 36 to 50%.

136

137 **Table 2:** PTV values obtained according to UNI EN 13036-4 [Errore. L'origine riferimento non è stata trovata.]

Sample	DG1		DG2		DG3		PA1		PA2		PA3	
L	125.0	62.5	125.0	62.5	125.0	62.5	125.0	62.5	125.0	62.5	125.0	62.5
PTV	76	34	59	29	64	29	59	21	59	24	61	22
CFT	-3	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2	-2
R <sub>PVT</sub>	-	2.20	-	1.99	-	2.22	-	2.77	-	2.48	-	2.74
1/R <sub>PVT</sub>	-	0.45	-	0.50	-	0.45	-	0.36	-	0.40	-	0.37
S.D.	1.53	1.11	1.09	1.23	1.00	0.72	1.27	1.16	1.12	0.84	2.06	0.76
CV	2%	3%	2%	4%	2%	2%	2%	5%	2%	3%	3%	3%

Symbols. L: Slide length [mm]; PTV: Pendulum Test Value [Errore. L'origine riferimento non è stata trovata.]; R<sub>PVT</sub>: ratio PTV<sub>125</sub>/PTV<sub>62.5</sub>; PTV<sub>125</sub>: Pendulum Test Value corresponding to L=125 mm; PTV<sub>62.5</sub>: Pendulum Test Value corresponding to L=62.5 mm; S.D.: Standard Deviation; CV: Coefficient of Variation [%]; DG1-DG3: dense-graded friction courses; PA1-PA3: porous asphalt concretes; CFT correction factor for temperature.

138

#### 139 4. Modelling, calibration, and validation

140 In order to explain the rationale behind the results obtained, attention was focused on modelling both tests. In  
 141 both cases, analyses were carried out to simulate what happens when small surfaces are used, in the aim of  
 142 providing insights and explanations.

##### 143 4.1. MTD modelling

144 As is well known, MTD is the ratio between a given volume, V (e.g. V<sub>25</sub>= 25000 mm<sup>3</sup> or V<sub>4.5</sub>= 4500 mm<sup>3</sup>),  
 145 and the corresponding area ( $\pi D_{25}^2/4$  or  $\pi D_{4.5}^2/4$ , respectively):

$$146 \quad MTD = \frac{4 \cdot V}{\pi \cdot D^2} \quad (\text{Eq. 1})$$

147 Where D (e.g., D<sub>25</sub>) is the diameter of sand patch. If R is the ratio between MTD<sub>25</sub> (volume=25000 mm<sup>3</sup>) and  
 148 MTD<sub>4.5</sub> (volume=4500 mm<sup>3</sup>), for the diameters of sand patch, D<sub>4.5</sub> and D<sub>25</sub>, it follows:

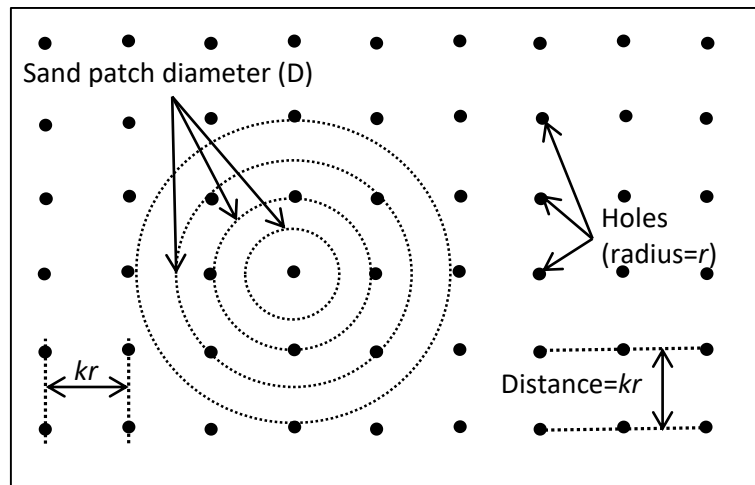
149 
$$\frac{D_{25}^2}{25} = \frac{1}{R} \frac{D_{4.5}^2}{4.5} \quad (\text{Eq. 2})$$

150 Under the hypothesis that  $R > 1$ , it follows:

151 
$$\frac{D_{25}^2}{25} < \frac{D_{4.5}^2}{4.5} \quad (\text{Eq. 3})$$

152 By referring to the reasons for having such a relationship (as observed in the experiments), different  
 153 hypotheses might be formulated, among which the following: i) Results are affected by spreading procedure  
 154 and by the ratio DST/DV, where DST is the diameter of the spreading tool (63.5 mm), while DV is the  
 155 diameter of the sand patch for the given volume (V); ii) when smaller quantities of sands are investigated, for  
 156 the relationship between MTD (dependent variable) and the volume of sand used (V, independent variable),  
 157 there are local domains of V in which the first derivative changes sign.

158 In order to provide explanations, let us model surface texture in terms of spherical holes on a flat surface (see  
 159 Fig. 2).



160  
 161 **Figure 2:** Modelling sand patch test in an ideal surface.

162 Let us suppose that the volume of each hole is:

163 
$$V_H = \frac{2\pi \cdot r^3}{3} \quad (\text{Eq. 4})$$

164 Where  $V_H$  ( $\text{mm}^3$ ) is the volume of the given hole and  $r$  (mm) is the radius of the semi-sphere. Let us suppose  
 165 that the distance (centre to centre) between two adjacent spheres is  $k \cdot r$  on both the x-axis and the y-axis  
 166 ( $k \geq 2$ ). For  $D \gg 2r$ , the number of semi-spheres is approximately given by:

167 
$$N \cong \left( \frac{(D - 2 \cdot r)}{k \cdot r \cdot \sqrt{2}} + 1 \right)^2 \quad (\text{Eq. 5})$$

168 Consequently it results approximately that:

169 for  $\frac{(D - 2 \cdot r)}{k \cdot r \cdot \sqrt{2}} \geq 1$  
$$MTD \cong \left[ \frac{(D - 2 \cdot r)}{k \cdot r \cdot \sqrt{2}} + 1 \right]^2 \cdot \frac{\frac{2}{3} \pi \cdot r^3}{\pi D^2} + 0.2 \quad [\text{mm}] \quad (\text{Eq. 6})$$

170 and

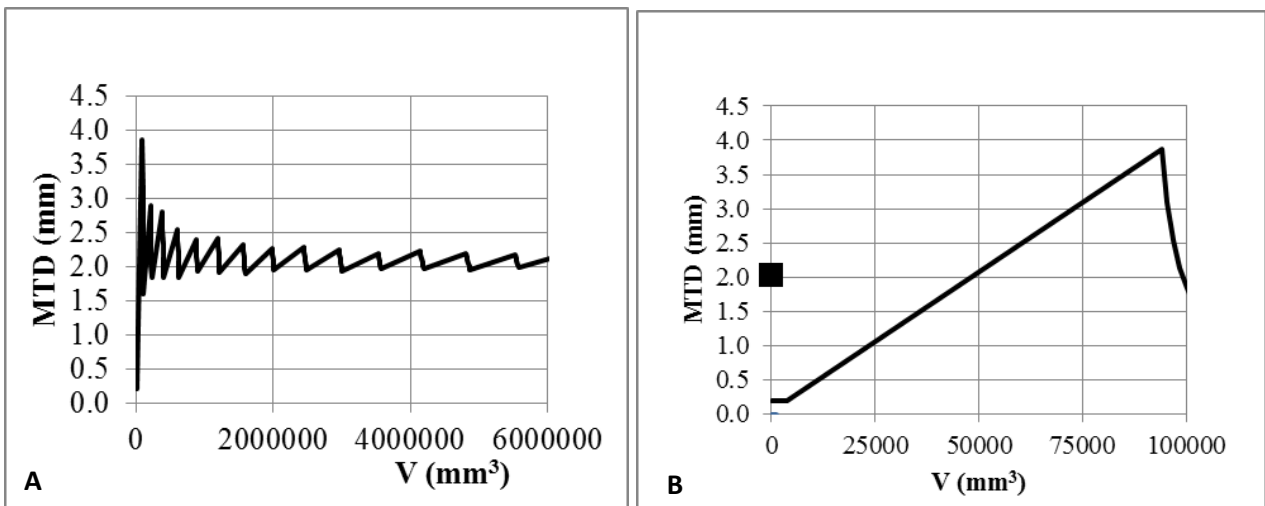
171 for  $\frac{(D - 2 \cdot r)}{k \cdot r \cdot \sqrt{2}} < 1$  
$$MTD \cong 0.2 \quad [\text{mm}] \quad (\text{Eq. 7})$$

172 when D approaches infinity, then it results:

173 
$$\lim_{D \rightarrow \infty} (MTD) \cong \frac{4 \cdot r}{3k^2} + 0.2 \quad (\text{Eq. 8})$$

174 Based on the algorithms herein set up (Eqs. (5), (6), (7), (8)) it follows that:

- 175 • The lowest value depends on sand diameter (0.2 mm);
- 176 • The highest value depends on hole geometry;
- 177 • The higher D becomes, the lower the variability of MTD is (cf. Fig. 3-A). The asymptotic value
- 178 depends on the geometric model.



179 **Figure 3:** MTD predicted through the model.

181

182 The rationale behind Eq. (6) is that MTD is given by 0.2 mm (i.e., sand diameter) plus 1, 9, 25 times the  
 183 volume of a semisphere divided by the overall surface area covered. The multiplier is in square brackets.

184

185 Fig. 3 refers to how MTD (y-axis, Eq. (6)) varies based on the volume of sand (x-axis). It appears evident  
186 that the model confirms that there are contexts in which the first derivative may be positive and, vice versa,  
187 there are situations in which the first derivative may be negative.

188 Model predictions (see Fig. 3) confirm that the first derivative undergoes different values (positive and  
189 negative), due to the fact that sand can be spread over sags, crests, or flat surfaces.

190 For the number of repetitions, note that based on the dependence of the standard deviation of the mean  
191 (SDOM) on the number of repetitions, for a volume of 4500 mm<sup>3</sup>, 4 repetitions are needed in order to have a  
192 standard deviation-to-average ratio of 2% (as per EN and ASTM standards).

193 Table 3 summarises the main characteristics of the proposed method for the miniaturization of MTD test.

194 By referring to test repeatability and reproducibility (CV% s.o. and CV% d.o., respectively, cf. Table 3), it  
195 appears noteworthy to highlight that in ASTM E 965 [11] and UNI EN 13036-1 [10] it is reported that “The  
196 standard deviation of the site-to-site measurements may be as large as 27% of the average texture depth”,  
197 where site “defines a randomly selected location within a nominally homogeneous pavement section”. In  
198 contrast, fixed-site CV is about 1–2%.

199 **Table 3:** Characteristics of the proposed method.

Standard	CNR BU 94/83	UNI EN 13036-1	ASTM E 965	Proposed
Points	5 + 5	4	4	1
Diameters	2	2	2	2
Distribution	2A	Random	Random	COS
CV% s.o.	N.A.	1% (*)	1% (*)	2%
CV% d.o.	N.A.	2% (*)	2% (*)	2%
Repetitions	1	1	1	4
Cleaning	N.A.	N.A.	N.A.	CA

Symbols. (\*): Macrottexture depth of 0.5 to 1.2 mm; N.A.: not available; s.o.: same operator; d.o.: different operator; Points: number of points for the given surface; Diameters: number of diameters per point; Distribution: distribution of points on the surface; CV%: Precision in terms of coefficient of variation in percentage; Repetitions: number of repetitions in the same point; 2A: two alignments (quasi-deterministic); CV%: coefficient of variation in percentage. CA: compressed air. COS: centre of specimen [**Errore. L'origine riferimento non è stata trovata.**].

200

#### 201 **4.2. PTV modelling**

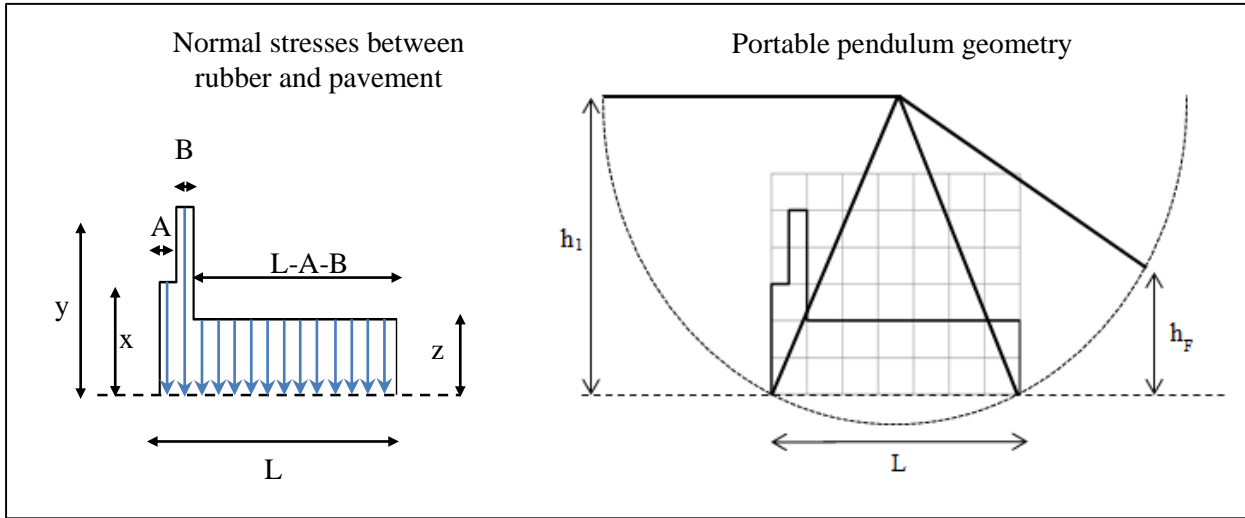
202 As is well known, following da Vinci observations, Amontons' laws states that the ratio of the friction force  
203 to the loading force (friction coefficient) does not depend on the loading force or the apparent contact area.

204

205 When an object begins to slide, it is often considered that a shear force greater than the maximum static  
206 friction force is needed. This notwithstanding, according to Otsuki & Matsukawa [54], precursors appear as  
207 local slips at the interface under shear forces quite below before the maximum static friction force, and this  
208 force corresponds to the onset of bulk sliding. According to Tuononen [55], the onset of the frictional sliding  
209 (i.e., when the phenomenon commences) depends on the state of the surfaces between the two sliding  
210 materials. In more detail, Tuononen [55] focuses on rubber–glass contact under dry and lubricated conditions  
211 and obtained different curves. For rubber on dry glass, the force curve over time undergoes a smooth  
212 transition from the static situation (friction coefficient zero) to sliding (friction coefficient quasi-constant),  
213 without any identifiable peak value, and with no precursors of sliding. For rubber on wet glass, the force  
214 curve over time shows a clear peak value (which would traditionally be the static friction coefficient),  
215 involved phenomena are more complex, and after the peak a quasi-constant value is approached (over time).

216

217 Based on theory and based on preliminary experiments, an equation in which the sliding force varies over  
218 space according to a three-step model is formulated in this paper. In order to derive information about the  
219 expected variation of PTV when different lengths of contact path are considered, let us consider that the  
220 pendulum motion starts from a given height ( $h_1$ ) and ends at a given height ( $h_F$ ), due to two main classes of  
221 energy losses (Fig. 4): i) friction losses ( $W$ ) in the contact path between pavement/core and the pendulum  
222 rubber shoe (slider assembly), based on friction coefficient ( $\mu$ ), on reference orthogonal force ( $F_{ort}$ ) and on  
223 contact length ( $L = A + B + (L - A - B)$ ); ii) friction losses in the hinge of the device, which refer to  $h_{piv}$   
224 (see below) and  $h^*$  (zero reading below the horizontal, [56], [57], [58]).



225

226 **Figure 4:** PTV stress distribution (left) and test geometry (right)

227 The main algorithms herein set up are summarised in Eqs (9), (10), (11), (12), (13), (14).

228 The relationship between  $PTV_{ob125}$  (PTV observed,  $L=125$  mm) and the friction coefficient is as follows:

229 
$$\mu = \frac{PTV_{ob125}}{100} \quad (\text{Eq. 9})$$

230 Three stretches (A, B, L-A-B) in the contact path L are supposed to exist, with a contact force which  
 231 undergoes corresponding changes ( $x F_{ort}$  in A,  $y F_{ort}$  in B,  $z F_{ort}$  afterwards):

232 
$$W = F_{ort} \cdot \mu \cdot [Ax + By + (L - A - B)z] \quad (\text{Eq. 10})$$

233 The final height (no friction at hinge) is as follows:

234 
$$h_2 = \frac{1}{mg} \left[ \left( \frac{1}{2} m \cdot 2h_1 \cdot g \right) - W \right] \quad (\text{Eq. 11})$$

235 where  $m \cong 1.5 \pm 0.03$  kg [**Errore. L'origine riferimento non è stata trovata.**],  $g = 9.81 \text{ m/s}^2$ ,  $h_1 \cong 0.512 \text{ m}$ ,  $F_{ort} \cong$   
 236  $22.5 \text{ N}$ .

237 The final height results:

238 
$$h_F = h_2 - h_{piv} = h_2 - \frac{h_2}{h_1} h^* \quad (\text{Eq. 12})$$

239 where  $h^* = 0.01016 \text{ m}$ .

240 Based on the as-built characteristics of the British Pendulum, the relationship between the final height ( $h_F$ )  
 241 and the value of PTV is here estimated as follows:

242  $PTV_e = -0.7013 \cdot h_F + 352.06$  (Eq. 13)

243 Overall, based on tests, the calibration of the proposed model is carried out through the following error  
244 function (objective function):

245  $\Phi = \sum (PTV_e - PTV_{ob})^2$  (Eq. 14)

246 where  $PTV_{ob}$  is the value observed, while  $PTV_e$  is the value estimated through the equation above.

### 247 **4.3. Calibration and validation**

248 PTV model calibration was carried out based on equations above. Based on results it is possible to observe  
249 that, for the cases under analysis: i) on average there are three different steps/phases in rubber vs. pavement  
250 sliding. In the first phase (length A < 15 mm) there is a force which is less than 1% of the reference force set  
251 up on the standard (22.5 N). In the second phase (length B < 0.3 mm), there may be an increase of the  
252 reciprocal, orthogonal force. This supplementary phase (B), if existing, accounts for less than 1 cm of sliding  
253 path. In the third phase (L-A-B), which corresponds to almost the entire sliding length (L), the force is close  
254 to 100% of the reference force; ii) overall an average error of 1–3 PTV points was obtained, as a function of  
255 the minimization process chosen; iii) Fort resulted to range from 17 to 23 N; iv) in all the optimizations  
256 attempts, PTV62.5/PTV125 resulted close to 44%.

257

258 In summarising, based on modelling it appears that the results obtained and the relationship between contact  
259 length and results are well explained by the physical model set up herein.

260

261 By referring to the number of repetitions and to the precision of the proposed and miniaturised method (see  
262 Table 4), note that: i) the EN 13036-4 [21] states that the precision is 1 PTV, uncorrected for temperature and  
263 on a fine-textured, plane surface. At the same time, it mentions that coarse textured or very smooth surfaces  
264 will reduce the precision and it warns about porous surfaces on which the test may give erroneous results.  
265 Furthermore, the same standard states that (Note 2) the use of the temperature correction will reduce the

266 precision of the test and that (10.3) the number of samples necessary to obtain the PTV of an area will be  
 267 dependent upon the variability of the surface; ii) experiments prove that the miniaturised method has a  
 268 standard deviation which is close to 1 PTV (0.7 for the tests under investigation); iii) the EN precision in  
 269 terms of standard deviation corresponds to a precision in terms of coefficient of variation of about 1.6%; iv)  
 270 based on the above, it is suggested to perform at least six tests (each test consisting of five swings) for dense-  
 271 graded friction courses and at least nine tests (each test consisting of five swings) for porous asphalt  
 272 concretes. These repetitions (e.g., 1·6·5 for DGFCs) make the standard deviation of the miniaturised test  
 273 consistent with the one of the EN standard for both DGFCs and PAs.

274 Based on the above, Table 4 summarises the characteristics of the proposed method.

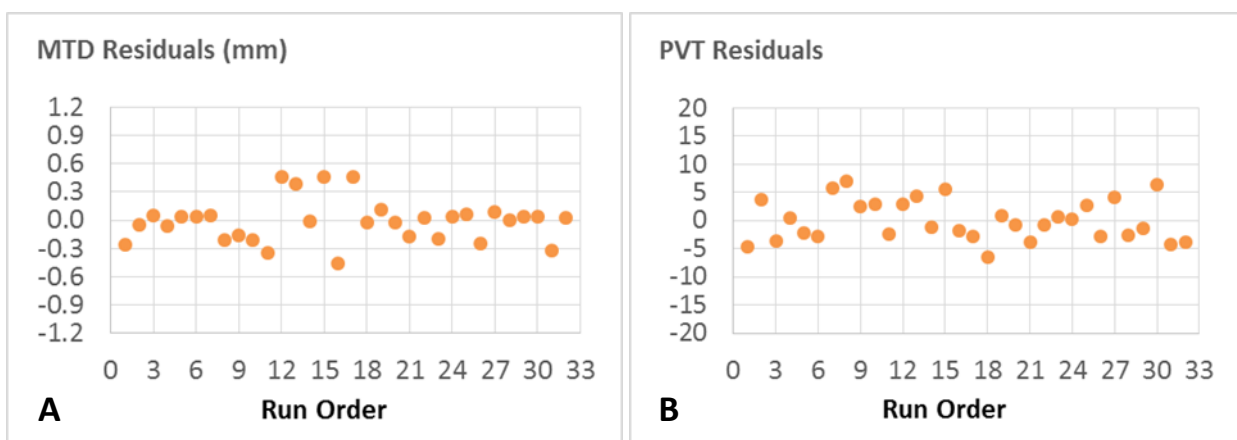
275 **Table 4:** Characteristics of the proposed method (PTV-BPN).

Standard	ASTM E 303	UNI EN 13036-4	CNR 105/85	Proposed
Points	4-5	≥3	5·3	1
Measures <i>per</i> point	1	1	1	6-9 (*)
Swings <i>per</i> point	>4	5	5	5
Distribution of points	N.A.	Random	3A	COS
S.D.	1-1.2 BPN unit	1 PTV	1.2 BPN unit	1 PTV

Symbols. 3A: three alignments (quasi-deterministic) in areas more stressed by traffic; COS: centre of specimen; S.D.: Standard Deviation; N.A.: not available; (\*): 6·5 swings for DGFCs, 9·5 swings for PAs.

276

277 Figure 5 summarizes model validation. Validation data were independently measured from the calibration  
 278 data.



279

280 **Figure 5:** Run sequence plot for the residuals (MTD: Fig.5A; PTV: Fig.5B).

281

282 Fig. 5A (left) focuses on MTD. Note that R-square is 0.93 while the residual scatter plot shows no systematic  
283 patterns apparent. This indicates that the model fits the data well. Fig. 5B (right) refers to PVT. This plot  
284 shows that there is only random scatter in the relationship between the observed PTV and the order in which  
285 the data were collected. Note that in this case the R-square is only 0.4. This fact may be due to the high  
286 standard deviation of PAs and calls for further study and research.

## 287 **5. Conclusions and contribution**

288 Based on the results shown above it may be observed that for macrotexture:

289 4500 mm<sup>3</sup> are appropriate for Marshall/Giratory specimens and for different types of mixes, included  
290 DGFCs and PAs;

291 The miniaturised MTD ( $V = 4500 \text{ mm}^3$ ) is approximately 10% less than the one obtained according to  
292 in-situ tests (for both PAs and DGFCs). This implies that the results should be consequently corrected ( $R$   
293  $= 1.02\text{--}1.23$ );

294 Four measurements are needed in order to have a  $\sigma$ /MTD ratio complying with the one stated in the  
295 ASTM-EN standards;

296 Due to the small quantity of sand and to the complexity of surface texture, modelling explains that MTD  
297 measurements are affected by the volume of sand used.

298 At the same time, for skid resistance:

- 299 • A contact path of 62.5 mm is appropriate for Marshall/Giratory specimens of different types of  
300 mixes, including DGFCs and PAs;
- 301 • The value of PTV which is obtained when using a length of 62.5 mm is approximately 58% less  
302 than the one obtained according to in-situ tests (for both PAs and DGFCs). This implies that the  
303 results should be consequently corrected ( $R = 1.99\text{--}2.77$ );
- 304 • Based on the dispersion indicators obtained, 6–9 measures per point are needed in order to have  
305 a precision complying with the one stated in the ASTM E 303 [59] and in the EN 13036-4 [21];
- 306 • Test model set up and calibrated explains that lower contact paths correspond to lower PTVs and  
307 quantifies the difference with a fair precision (44% versus 42%, on average).

308

309

310 Based on the above, it seems possible to point out that this paper makes several contributions to the  
311 literature. First, this study adds to the relatively small amount of research that examines whether  
312 macrotexture and pendulum test can be explained and predicted based on simple physical and geometric  
313 models.

314 Second, the results of this study help provide a better understanding of the importance and the  
315 criticalities of assessing macro- and micro-texture at an early stage and on small samples.

316 Whereas previous research provides evidence that small samples may provide valuable information  
317 about texture, this study reveals that such measures can be related to the corresponding measures on real  
318 pavements.

319 Finally, evidence of methods to limit the uncertainties in texture prediction may be of interest to  
320 practitioners and researchers.

## 321 **6. References**

322 [1] M.B. Snyder, Current Perspectives on Pavement Surface Characteristics, ACPA publication EB235P  
323 Pavement Surface Characteristics: A Synthesis and Guide. R&T Update, Concrete Pavement Research &  
324 Technology, Number 8.02, 2007.

325 [2] Chengyi Huang, Shunqi Mei, Investigation of Road Surface Texture Wavelengths, New Tribological  
326 Ways, Dr. Taher Ghrib (Ed.), ISBN: 978-953-307-206-7, 2011.

327 [3] L.G. Andersen, J.K. Larsen, E.S. Fraser, B. Schmidt, J.C. Dyre  
328 Rolling resistance measurement and model development  
329 J. Transp. Eng., 141 (2) (2015), p. 04014075

330 [4] A. Dunford  
331 Friction and the Texture of Aggregate Particles Used in the Road Surface Course  
332 (Ph.D thesis)  
333 University of Nottingham, UK (2013)

334 [5] E. Astm  
335 Standard Practice for Calculating Pavement Macrotexture Mean Profile Depth

336 ASTM International, West Conshohocken, PA (1845), p. 2015

337 [6] ISO 13473-1, Characterization of Pavement Texture by use of Surface Profiles. Part 1: De-  
338 termination of Mean Profile Depth, 2013.

339 [7] ASTM E 2157  
340 Standard Test Method for Measuring Pavement Macrotexture Properties Using the Circular Track Meter  
341 ASTM International, West Conshohocken, PA (2015)

342 [8] ISO 13473-2  
343 Characterization of Pavement Texture by Use of Sur-face Profiles – Part 2: Terminology and Basic  
344 Requirements Related to Pavement Texture Profile Analysis  
345 (2002)

346 [9] ISO 13473-3  
347 Characterization of Pavement Texture by Use of Sur-face Profiles. Part3: Specifications and  
348 Classification Of Profilometers  
349 (2002)

350 [10] UNI EN 13036-1  
351 Road and Airfield Surface Characteristics - Test Methods - Part 1: Measurement of Pavement Surface  
352 Macrotexture Depth Using a Volumetric Patch Technique  
353 Ente Nazionale Italiano di Unificazione, Milano, Italia (2010)

354 [11] ASTM E 965  
355 Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique  
356 ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959,  
357 United States (2006)

358 [12] CNR B.U. 94/1983, Norme per la misura delle caratteristiche superficiali delle pavimentazioni –  
359 Metodo di prova per la misura della macro-rugosità superficiale con il sistema della altezza di sabbia,  
360 Consiglio Nazionale delle Ricerche Anno XVII, pt. IV, n.94 (1983), pp. 3–20.

361 [13] Colorado Procedure 77-09, Determination of Macro-Texture of Planed Hot Mix Asphalt Pavement,  
362 2009.

363 [14] Colorado Procedure 77-14, Determination of Macro-Texture of a Pavement Surface, 2014.

364 [15] ASTM E 2380/E 2380M  
365 Standard Test Method for Measuring Pavement Texture Drainage Using an Outflow Meter  
366 ASTM International, West Conshohocken, PA (2015)

367 [16] ANAS, Capitolato Speciale d'Appalto – Parte 2a Norme Tecniche Pavimentazioni  
368 stradali/autostradali, Ministero delle Infrastrutture e dei Trasporti – Ispettorato per la Circolazione e la  
369 Sicurezza Stradale – CIRS, Centro Sperimentale Interuniversitario di Ricerca Stradale, 2009.

370 [17] R.B. Kogbara, E.A. Masada, E. Kassem, A. Scarpas, K. Anupam  
371 A state-of-the-art review of parameters influencing measurement and modeling of skid resistance of  
372 asphalt pavements  
373 Constr. Build. Mater., 114 (1) (July 2016), pp. 602-617

374 [18] A.D. Nataadmadja, M.T. Do, D.J. Wilson, S.B. Costello, Quantifying aggregate microtexture with  
375 respect to wear—Case of New Zealand aggregates, Wear, Volumes 332–333, May–June 2015, pp. 907–  
376 917.

377 [19] J.N. Meegoda, S. Gao  
378 Evaluation of pavement skid resistance using high speed texture measurement  
379 J. Traffic Transp. Eng. (English Edition), 2 (6) (2015), pp. 382-390

380 [20] J.C. Wambold, J.J. Henry  
381 International PIARC experiment to compare and harmonize texture and skid resistance measurements  
382 Nordic Road Transp. Res., 6 (2) (1995), pp. 28-31

383 [21] UNI EN 13036-4, Road and airfield surface characteristics – Test methods – Part 4: Method for  
384 measurement of slip/skid resistance of a surface: The pendulum test, 2011.

385 [22] CNR B.U. 105/1985, Norme per la misura delle caratteristiche superficiali delle pavimentazioni -  
386 Metodo di prova per la misura della resistenza di attrito radente con l'apparecchio portatile a pendolo,  
387 1985.

388 [23] G.G. Balmer  
389 Pavement texture: its significance and development  
390 Transp. Res. Board Res. Rec., 666 (1979), pp. 1-6

391 [24] M. Ergun, S. Lyinam, A.F. Lyinam

392 Prediction of road surface friction coefficient using only macro- and micro-texture measurements  
393 J. Transp. Eng., 131 (4) (2005), pp. 311-319

394 [25] N.M. Jackson, B. Choubane, C.R. Holzschuher  
395 Measuring Pavement Friction Characteristics at Variable Speeds for Added Safety Pavement Surface  
396 Condition/Performance Assessment: Reliability and Relevancy of Procedures and Technologies  
397 ASTM, West Conshohocken (2007)  
398 STP 1486

399 [26] M.A. Khasawneh, R.Y. Liang, Correlation study between locked-wheel skid trailer and dynamic  
400 friction tester, TRB 87th Annual Meeting, Washington DC, 2008.

401 [27] D. Woodward, P. Millar, C. Lantieri, C. Sangiorgi, V. Vignali  
402 The wear of Stone Mastic Asphalt due to slow speed high stress simulated laboratory trafficking  
403 Constr. Build. Mater., 110 (2016), pp. 270-277

404 [28] V.M.C. Araujo, I.S. Bessa, V.T.F. Casteli Branco  
405 Measuring skid resistance of hot mix asphalt using the aggregate image measurement system (AIMS)  
406 Constr. Build. Mater., 98 (2015), pp. 476-481

407 [29] D.A. Noyce, H.U. Bahia, J.M. Yambò, G. Kim, Incorporating road safety into pavement  
408 management: Maximizing asphalt pavement surface friction for road safety improvements, Draft  
409 Literature Review & State Surveys, Midwest Regional University transportation Center Traffic  
410 Operations and Safety (TOPS) Laboratory, 2005.

411 [30] U. Sandberg, Influence of road surface texture on traffic characteristics related to environment,  
412 economy and safety: A state-of-the-art study regarding measures and measuring methods, Swedish  
413 National Road and Transport Research Institute. Road Maintenance and Operation, Project n. 20229,  
414 Measurement of road surface texture, Swedish, 1998.

415 [31] F.R. Zhao, T.J. Qiu, H. Zhang  
416 Effect of macro-texture features on anti-sliding characteristics of cement concrete pavement  
417 Zhongguo Gonglu Xuebao/China J. Highway Transport, 29 (7) (2016), pp. 15-21

418 [32] L.J. Chu, T.F. Fwa, K.H. Tan  
419 Considering Aggregate Polishing Effect in Prediction of Pavement Skid Resistance

420 Proc. of the Eighth Intl. Conf. on Maintenance and Rehabilitation of Pavements, Research Publishing,  
421 Singapore (2016), 10.3850/978-981-11-0449-7-238-cd  
422 ISBN: 978-981-11-0449-7  
423 [33] M.N. Postorino, F.G. Praticò  
424 An application of the multi-criteria decision-making analysis to a regional multi-airport system  
425 Res. Transp. Bus. Manage., 4 (2012), pp. 44-52  
426 [34] F.G. Praticò, A. Moro  
427 In-lab and on-site measurements of hot mix asphalt density: convergence and divergence hypotheses  
428 Constr. Build. Mater., 25 (2) (2011), pp. 1065-1071  
429 [35] K.P. Biligiri  
430 Tyre/road noise damping characteristics using nomographs and fundamental vibroacoustical  
431 relationships  
432 Transp. Res. Part D: Transp. Environ. (2016)  
433 [36] F.G. Praticò, R. Ammendola, A. Moro  
434 Factors affecting the environmental impact of pavement wear  
435 Transp. Res. Part D: Transp. Environ., 15 (3) (2010), pp. 127-133, 10.1016/j.trd  
436 ISSN 1361–9209  
437 ArticleDownload PDFView Record in ScopusGoogle Scholar  
438 [37] F.G. Praticò, R. Vaiana  
439 Improving infrastructure sustainability in suburban and urban areas: is Porous asphalt the right answer?  
440 And how?  
441 C.A. Brebbia, J.W.S. Longhurst (Eds.), Urban Transport: Urban Transport and the Environment in the  
442 21st Century, WIT Transactions on Ecology and the Environment, WIT Press (2012), pp. 673-684  
443 ISBN: 9781845645809  
444 [38] F.G. Praticò, A. Casciano  
445 Variability of HMA characteristics and its influence on pay adjustment  
446 J. Civil Eng. Manage., 21 (1) (2015), pp. 119-130  
447 [39] F.G. Praticò

448 Metrics for management of asphalt plant sustainability  
449 J. Constr. Eng. Manage. (2017), 10.1061/(ASCE)CO.1943-7862. 00012  
450 [40] P. Georgiou, A. Loizos  
451 A laboratory compaction approach to characterize asphalt pavement surface friction performance  
452 Wear, 311 (2014), pp. 114-122  
453 [41] S.N. Goodman, Y. Hassan, A.O. AbdElHalim  
454 Preliminary estimation of asphalt pavement frictional properties from Superpave gyratory specimen and  
455 mix parameters  
456 Transp. Res. Rec., 2006 (1949), pp. 173-180  
457 [42] G. Boscaino, B. Celauro, C. Celauro, A. Amadore  
458 Evaluation of the laboratory prediction of surface properties of bituminous mixtures  
459 Constr. Build. Mater., 23 (2) (2009), pp. 943-952  
460 [43] T. Iuele  
461 Road surface micro - and macrotexture evolution in relation to asphalt mix composition  
462 Hu (Ed.), Advanced Materials and Structural Engineering, Taylor & Francis Group, London (2016)  
463 ISBN 978-1-138-02786-2  
464 [44] F.G. Praticò, R. Vaiana  
465 A study on volumetric versus surface properties of wearing courses  
466 Constr. Build. Mater., 38 (2013), pp. 766-775, 10.1016/j.conbuildmat.2012.09.021  
467 [45] F.G. Praticò, S. Noto, A. Astolfi, In-lab versus on-site measurement of surface performance of  
468 flexible pavements, in: Tenth International Conference on the Bearing Capacity of Roads, Railways and  
469 Airfields, 2017.  
470 [46] UNI EN 12697-30  
471 Bituminous Mixtures – Test Methods for Hot Mix Asphalt – Part 30: Specimen Preparation by Impact  
472 Compactor  
473 Ente Nazionale Italiano di Unificazione, Milano, Italia (2012)  
474 [47] UNI EN 12697-31

475 Bituminous Mixtures - Test Methods for Hot Mix Asphalt - Part 31: Specimen Preparation by Gyratory  
476 Compactor  
477 Ente Nazionale Italiano di Unificazione, Milano, Italia (2007)

478 [48] M.T. Do, L.P. Kerzreho, J.M. Balay, M. Gothie, Full Scale Tests for the Assessment of Wear of  
479 Pavement Surfaces, TRB 82nd Annual Meeting (Transportation Research Board), 2013.

480 [49] S. Li, D. Harris, T. Wells  
481 Surface texture and friction characteristics of diamond-ground concrete and asphalt pavements  
482 J. Traffic Transp. Eng. (Engl. Ed.), 3 (5) (2016), pp. 475-482

483 [50] R. Vaiana, G.F. Capiluppi, V. Gallelli, T. Iuele, V. Minani  
484 Pavement surface performances evolution: an experimental application, SIIV – 5th International  
485 Congress – Sustainability of Road Infrastructures  
486 Procedia – Social and Behavioral Sciences, 53 (2012), pp. 1151-1162

487 [51] R. Roque, A. Ravanshad, G. Lopp  
488 Use of Aggregate Image Measurement System (AIMS) to Evaluate Aggregate Polishing in Friction  
489 Surfaces, Florida Department of Transportation Research Management Center  
490 University of Florida Department of Civil and Coastal Engineering (2013)  
491 Final Report

492 [52] R.M. Larson, T.E. Hoerner, K.D. Smith, A.S. Wolters, Relationship between Skid Resistance  
493 Numbers Measured with Ribbed and Smooth Tire and Wet Accident Locations, Final Report – State Job  
494 Number 134323, 2008.

495 [53] F.G. Praticò, R. Vaiana  
496 A study on the relationship between mean texture depth and mean profile depth of asphalt pavements  
497 Constr. Build. Mater., 101 (2015), pp. 72-79, 10.1016/j.conbuildmat.2015.10.021

498 [54] M. Otsuki, H. Matsukawa, Systematic Breakdown of Amontons' Law of Friction for an Elastic  
499 Object Locally Obeying Amontons' Law, Scientific Reports 3, Article number: 1586, 2013,  
500 doi:<http://dx.doi.org/10.1038/srep01586>.

501 [55] A.J. Tuononen  
502 Onset of frictional sliding of rubber-glass contact under dry and lubricated conditions

503 Sci. Rep., 6 (2016), p. 27951, 10.1038/srep27951

504 [56] K. Hallas, G. Hunwin, A study of pendulum slider dimensions for use on profiled surfaces, RR726

505 Research Report, Health and Safety Executive 2009, Health and Safety Laboratory, 2009.

506 [57] S.G. Kim, K.W. Kim

507 Influence of pad–pivot friction on tilting pad journal bearing

508 Tribol. Int., 41 (2008), pp. 694-703, 10.1016/j.triboint.2007.12.003

509 [58] G. Inturri, Cenni di meccanica della locomozione: aderenza e resistenza al moto, Corso di

510 Fondamenti di Trasporti, Corso di laurea Ingegneria Civile, Università di Catania, 2012.

511 [59] ASTM E 303

512 Standard Test for Measuring Surface Frictional Properties Using the British Pendulum Tester

513 (2008)