Analysis of Test Methods for Texture Depth Evaluation Applied in Portugal

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ABSTRACT: Texture is a surface characteristic which has a very wide influence on pavements functional quality. It is currently assessed by a number of test methods. Road Administrations face the problems of dealing with data acquired by different methods and, in addition to that, the repeatability and reproducibility of the results. This paper presents an analysis of test methods used for texture depth evaluation in Portugal: the volumetric patch method and two methods based on surface profiles. Hence, three roads with low (dense asphalt), medium ("open texture asphalt") and high (porous asphalt) texture depths were selected, where five profilometers made five runs. Two subsections of 150 m length were also selected to carry out the volumetric patch test. The texture indicators analysed were: the mean texture depth, the mean profile depth and the sensor measured texture depth. The average and the standard deviation were the statistical parameters used for the analysis. The results obtained for each method are significantly different and a good correlation between the mean profile depth and the sensor measured texture depth was established.

KEY WORDS: Texture, evaluation, mean profile depth, mean texture depth, sensor measured texture depth.

1. INTRODUCTION

Factors such as safety (influenced by tyre/road friction) (NCHRP 291, 2000), noise emission caused by tyre/road interaction (SILVIA, 2006), driving comfort (Delanne et al., 1999), rolling resistance, wear of tyres (Domenichini et al., 2004) and other operating costs are influenced, to a great extent, by pavement surface irregularities and therefore by surface texture and unevenness.

Pavement irregularities are currently surveyed at network level and the pavement condition is assessed through appropriate indicators that are related to one or more factors referred above. Considering the need for evaluating texture at network level, there has been an effort to standardize texture measurement methods at travelling speeds, based on surface profiles. This has already been achieved for macro-texture. For microtexture, there are still some technical issues that are expected to be overcome shortly through research on friction prediction based on microtexture profiles, what is being carried out at present (Do et al., 2004).

This paper is the result of the undeniable need to analyse the methods used by Portuguese public and private institutions that are currently involved in surveying pavement irregularities and other pavement condition parameters.

The objective of the work presented hereafter is the analysis of the test methods used in Portugal for macrotexture depth evaluation carried out under ordinary testing conditions, having the European standards related to surface characteristics as background.

2. MACROTEXTURE INDICATORS

The volumetric technique has been widely used in the past for the assessment of surface macrotexture. This simple method consists of spreading a known volume of material (sand, glass beads or grease) on the pavement surface and measure the area covered. The macrotexture depth is obtained by dividing the volume by the area (Mean Texture Depth - MTD).

More recently, systems that can measure macrotexture at traffic speeds have become available. The profiles produced by these devices can be used to compute various profile statistics, such as the Mean Profile Depth (MPD) and the Sensor Measured Texture Depth (SMTD).

2.1. Mean Texture Depth

Originally the sand patch method required spreading a specified volume of sand with a specific grading (100 % of the material passing the Nº 50 ASTM sieve and retained on the Nº 100 sieve). The sand was spread on the pavement surface with a spreading tool in a circular motion. The area of the roughly circular sand patch is calculated by using the average of four equally spaced diameters (Figure 1).

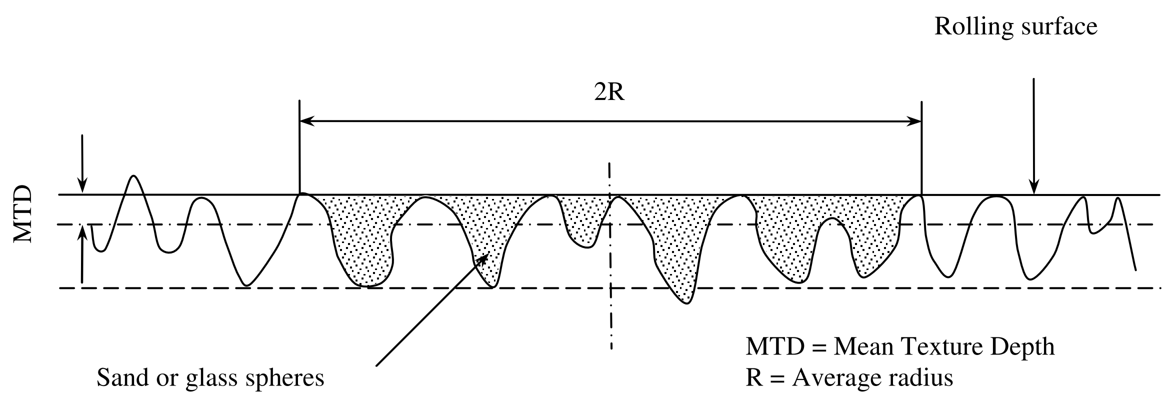


Figure 1: Illustration of the MTD

The current standard EN 13036-1, which is largely based on ASTM E 965, requires the use of glass spheres instead of sand. The material was changed for two reasons: 1. glass spheres can be spread more uniformly than sand, which has an irregular shape; 2. very low yields are usually obtained when bags of sand are sieved, whereas glass spheres that meet the size specification are commercially available and the need to sieve the material is avoided (Abe et al., 2001).

2.2. Mean Profile Depth

The MPD is calculated by dividing the measured profile into segments of 100 mm length (recommended base line). The slope of each segment is suppressed by subtracting a linear regression of the segment, providing a zero mean profile. The MPD is determined as shown in Figure 2. The MTD may be estimated through a conversion equation (also presented in Figure 2). In this case the MTD is indicated as Estimated Texture Depth (ETD).

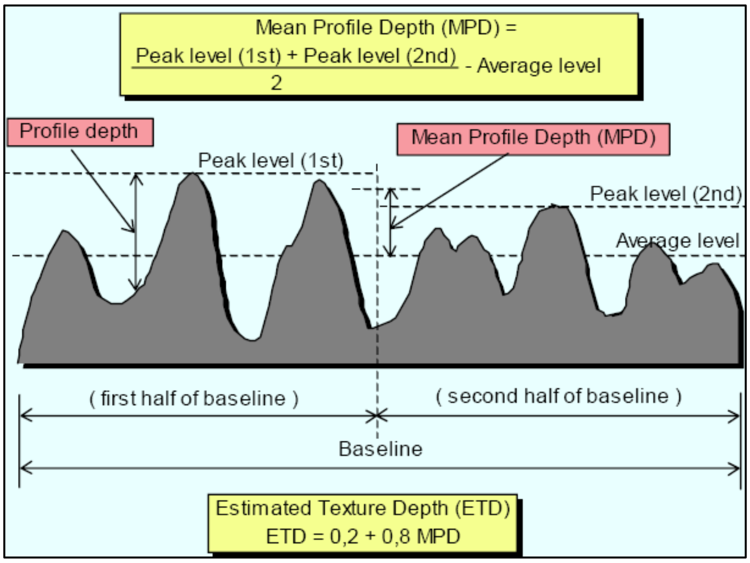
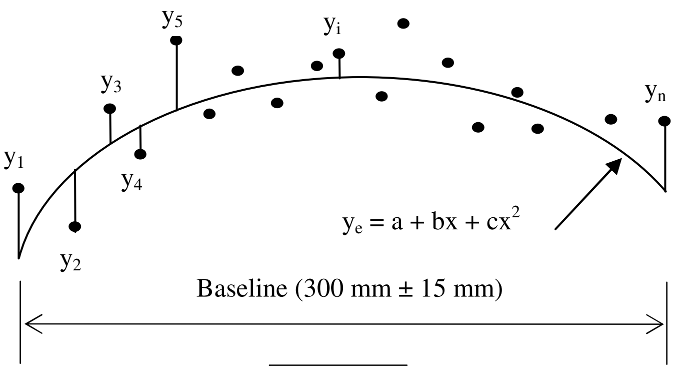


Figure 2: Illustration of the concepts of base line, profile depth and the texture indicators mean profile depth and estimated texture depth (in millimetres) (ISO 13473-1)

2.3. Sensor Measured Texture Depth

The Sensor Measured Texture Depth is the standard deviation of the profile amplitudes, measured by a sensor over a 300 mm ± 15 mm length of road. The effect of vehicle bounce is removed by applying a best-fit parabolic trend curve to the data obtained over the 300 mm length. The standard deviation is calculated using the deviations of the Texture Profile from the trend curve (Figure 3). These measurements are then averaged over lengths of 10 m or 100 m. The SMTD may be quite different from the MTD, as shown in Figure 4, for two types of theoretic surface textures.



$$SMTD = \sqrt{\frac{\sum_{i=1}^{n}(y_i - y_e)^2}{n}}$$

Legend:
SMTD = Sensor Measured Texture Depth
yi = laser height measurement at laser measurement i
n = number of laser measurements (odd)
y_e = curve obtained by quadratic least square regression
x = distance between measurements
a, b, c = curve parameters

Figure 3: Illustration of concepts related to the procedure calculation of the SMTD

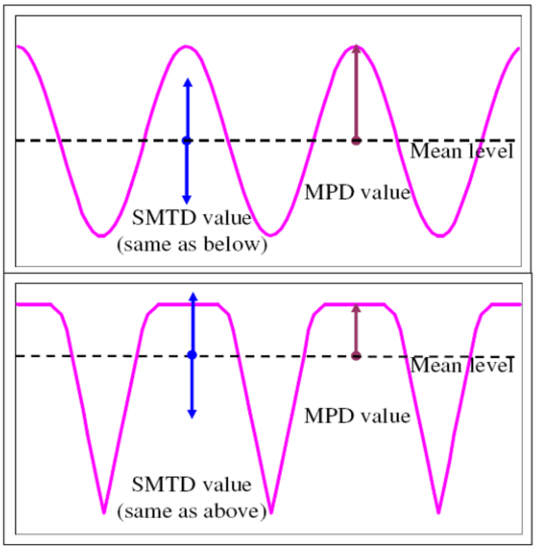


Figure 4: Comparison of SMTD and MPD for two types of surface texture

2.4. Volumetric methods versus high speed methods

Despite the actual preference for high speed measurements, the MTD is usually taken as reference by road administrations. Nonetheless, neither the volumetric patch nor the profiling method can measure the relevant characteristics covering all cases. Sometimes the volumetric patch method may give a more relevant result, while in other cases the profiling method may be preferred.

According to ISO 13473-1, experience has shown that the volumetric patch method may be not reliable if used in porous surfaces because some material may pour down into the pores. At the same time, the profiling method generally "underestimates" the texture depth on those surfaces when compared to the values obtained with the volumetric patch method. This is true provided that the profilometer works "correctly" on porous surfaces, i.e. without unacceptable high drop-out proportions and without any erroneous transients, what is not the case for all devices. On porous surfaces which have become clogged, experience has also indicated that the profiling method gives values which correlate well with the volumetric patch method.

Newly laid surfaces, namely asphalt surfaces, generally have a glossy and extremely dark appearance. Profilometers relying on optical beams usually have problems with such surfaces because too little light is diffused in the direction of the receiving element. Drop-out rates become high and there may be transients at extreme transitions to/from dark/bright surfaces. The same applies to surfaces which are dark due to wetness or humidity.

ISO 13473-1 also alerts that values given by different contactless techniques are not always comparable, although, individually, they generally offer good correlation coefficients with the texture depth measured with the volumetric patch method.

2.5. Data variability

Several sources may influence data variability, such as:

1. equipment instability;
2. software imperfections;
3. operator influence;
4. surface longitudinal inhomogeneity;
5. surface lateral inhomogeneity (difficulty of measuring in the same lateral track each time).

In the case of texture measurements, sources number 4 and 5 generally dominate the repeatability of results, while the other sources may also have an important contribution to their reproducibility. Both are generally characterized by the standard deviation of the measurements.

Specifically for profiling devices, repeatability is understood as the ability of a device to reproduce the same result in multiple runs. It is generally expressed as the average and the standard deviation for data from repeated runs. On the other hand, reproducibility refers to the closeness of the results reported by different devices under the same measurement conditions. It is characterized by the standard deviations for the values reported by different teams for a given index. It includes the standard deviations for the repeatability as well as the standard deviation for interdevice variability.

For controlled tests conducted on laboratory specimens having a range of macrotexture depth between 0.5 mm and 1.2 mm, the EN 13036-1 indicates that the standard deviation of repeated measurements performed by the same operator on the same surface can be as low as 1 % of the average texture depth and that the standard deviation of repeated measurements by different operators on the surface can be as low as 2 % of the average texture depth. It also indicates, in short sections (150 m), an uncertainty for MTD measurements of ± 0,227 mm for a confidence interval of 95%.

The PIARC International Experiment (Wambold et al., 1995) shows that ETD can be determined for a 150 m test section with a standard uncertainty of approximately 20 % of the average value. The reproducibility, which also includes the effect of the repeatability, using two different systems and test crews, was found to be 0.15 mm in the same experiment, corresponding to 10 % of the average texture depth in the experiment (residual error in regression between two devices). If more or longer runs are made over the same test section, the uncertainty decreases according to conventional statistical procedures when averaging random data.

3. EXPERIMENTAL PROCEDURE

The following test methods for macrotexture depth evaluation were analyzed in the experiment:

- The volumetric patch technique, as described in EN 13036-1 (MTD) and the sand patch method (ASTM E965);
- The test method based on surface profiles, as described in ISO 13473-1 (MPD);
- Other non standardized methods based on profile measurement, which provide the SMTD, used in Portugal.

The study methodology and the profilometers used are described below.

3.1. Test methodology

In order to carry out the analysis of the test methods, three surface layers with low, medium and high texture depth were chosen among the most widely ones used in Portugal, placed along a motorway and along a national road. They are made of dense asphalt (DA), gap graded asphalt known as “open texture asphalt” (OTA) and porous asphalt (PA). For each type of surface two sections, one for each road direction, were tested:

- PA – sections 1 and 3 with a length of 7 km;
- OTA – sections 2 and 4 with a length of 18 km;
- DA – sections 5 and 6 with a length of 1.5 km.

For the analysis of the test method based on surface profiles, five runs at traffic speeds were made by five profilometers over the six test sections.

The data registered every 10 m were position, speed, MTD or SMTD on the right wheel path and profile singularities.

For the analysis of the test method based on the volumetric patch technique, a road segment of 120 m was selected in section 3 (“open texture asphalt”) and another road segment of 150 m was selected in section 5 (dense asphalt). The tests were performed every 10 m on the right wheel path. For the reasons exposed before, the procedure was not used on the porous asphalt.

The test method applied involved two operators, two spreading materials (glass spheres and sand) and two spreading material volumes (25000 mm^3 and 56400 mm^3).

In test section 5 each testing spot was tested according to the following combinations:

- Operator 1 (OP1) – used the small container with glass spheres and then the same container with graduated sand;
- Operator two (OP2) – used the large container with glass spheres.

For operational reasons, each testing spot was tested in test section 4 by OP2 using glass spheres in the small container and again glass spheres in the large container.

3.2. Profilometers

The profilometers used belong to universities, research laboratories and consultancy companies (Figure 5). They all reach class 1 requirements for the measurement of the longitudinal profile according to ASTM E950. Three of them have 60 kHz lasers and provide the MPD (referred as PER1, PER2 and PER3 and the other two have 16 kHz lasers and provide the SMTD (PER 4 and PER 5).

Figure 5: Testing profilometers

4. ANALYSIS OF THE RESULTS OF HIGH SPEED PROFILOMETERS

This experiment was carried out under normal operation conditions, on dry weather. The data recorded was used as provided by each operator and possible outlier values were included. Therefore, all possible sources of error are included and will be reflected in the repeatability and the reproducibility of the methods under analysis.

4.1. Mean Profile Depth

The average (Aver.) and the standard deviation (St.D.) of the MPD calculated for each run of the three profilometers that provide this indicator in the six test sections are presented from Table 1 to Table 6. Sections 5 and 6 were not surveyed by PER3, for operational reasons.

Table 1: Statistics of MPD on section 1 (porous asphalt)

	PER1					PER2					PER3				
Run	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Aver.	1.58	1.61	1.60	1.60	1.57	1.77	1.79	1.81	1.80	1.79	1.55	1.58	1.56	1.55	1.56
St.D.	0.157	0.167	0.162	0.165	0.160	0.189	0.190	0.200	0.213	0.200	0.152	0.158	0.153	0.149	0.163

Table 2: Statistics of MPD on section 2 ("open texture asphalt")

	PER1					PER2					PER3				
Run	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Aver.	1.20	1.18	1.17	1.18	1.14	1.27	1.28	1.27	1.27	1.27	1.22	1.22	1.21	1.19	1.18
St.D.	0.121	0.123	0.126	0.132	0.128	0.138	0.143	0.136	0.143	0.140	0.125	0.124	0.128	0.123	0.122

Table 3: Statistics of MPD on section 3 ("open texture asphalt")

	PER1					PER2					PER3				
Run	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Aver.	1.25	1.21	1.21	1.20	1.20	1.29	1.30	1.30	1.30	1.29	1.26	1.25	1.25	1.23	1.23
St.D.	0.163	0.153	0.153	0.152	0.151	0.175	0.179	0.179	0.173	0.185	0.158	0.164	0.155	0.158	0.156

Table 4: Statistics of MPD on section 4 (porous asphalt)

	PER1					PER2					PER3				
Run	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Aver.	1.62	1.61	1.62	1.64	1.60	1.78	1.75	1.76	1.74	1.74	-	1.61	1.61	1.58	1.56
St.D.	0.152	0.138	0.154	0.160	0.172	0.174	0.171	0.174	0.173	0.168	-	0.150	0.152	0.153	0.141

Table 5: Statistics of MPD on section 5 (dense asphalt)

	PER1					PER2				
Run	1	2	3	4	5	1	2	3	4	5
Aver.	0.72	0.73	0.72	0.73	0.73	0.72	0.69	0.68	0.72	0.70
St.D.	0.120	0.106	0.113	0.109	0.109	0.101	0.118	0.126	0.112	0.125

Table 6: Statistics of MPD on section 6 (dense asphalt)

	PER1						PER2				
Run	1	2	3	4	5	6	1	2	3	4	5
Aver.	0.74	0.74	0.74	0.74	0.75	0.74	0.71	0.71	0.71	0.72	0.72
St.D.	0.089	0.094	0.094	0.092	0.096	0.093	0.099	0.099	0.100	0.098	0.101

The results presented in Tables 1 to 3 show that the three equipments that evaluated MPD provide results of the same order of magnitude, both in terms of average over the whole section and in terms of standard deviation. Furthermore, the following observations can be made:

- For each equipment, and for the three types of surfaces, the average MPD has negligible variations among different runs.
- The equipment PER 2 tends to provide higher values of MPD for the higher texture surfaces. For the dense asphalt the difference between devices is smaller.
- For higher texture depths (porous asphalt and "open texture asphalt"), the standard deviations obtained with any equipment on any run is less that 10% the average value. For dense asphalt, the ratio between the standard deviation and the average is slightly higher than 10%.

4.2. Sensor Measured Texture Depth

The same analysis procedure was used for the SMTD. Profilometer number 5 ran 4 times instead of 5 in sections 1 to 4. The results are presented in Tables 7 to 12.

In general, the average SMTD and the standard deviation are fairly similar either for the same profilometer or between profilometers. However, the following statements can be made:

- The average SMTD and the standard deviation for PER4 are slightly higher than for PER5. In practical terms those differences can be neglected;
- For each profilometer, the similarity of the average SMTD among runs is better for dense asphalt which has low texture depth;
- The ratio between standard deviation and average values increases with the increase of SMTD average. It means that higher texture depths are accompanied by considerable higher variability of the results.

Table 7: Statistics of SMTD on section 1 (porous asphalt)

	PER4					PER5			
Run	1	2	3	4	5	1	2	3	4
Aver.	1.09	1.10	1.09	1.06	1.05	1.10	1.08	1.05	1.03
St.D.	0.164	0.174	0.165	0.159	0.166	0.160	0.152	0.165	0.145

Table 8: Statistics of SMTD on section 2 ("open texture asphalt")

	PER4					PER5			
Run	1	2	3	4	5	1	2	3	4
Aver.	0.79	0.77	0.77	0.75	0.74	0.77	0.69	0.77	0.75
St.D.	0.105	0.104	0.106	0.104	0.097	0.093	0.093	0.107	0.099

Table 9: Statistics of SMTD on section 3 ("open texture asphalt")

	PER4					PER5			
Run	1	2	3	4	5	1	2	3	4
Aver.	0.81	0.78	0.78	0.75	0.76	0.77	0.77	0.76	0.76
St.D.	0.113	0.112	0.115	0.114	0.125	0.107	0.111	0.114	0.105

Table 10: Statistics of SMTD on section 4 (porous asphalt)

	PER4					PER5			
Run	1	2	3	4	5	1	2	3	4
Aver.	1.08	1.11	1.09	1.05	1.02	1.05	1.05	1.02	1.02
St.D.	0.145	0.171	0.164	0.157	0.154	0.152	0.145	0.146	0.140

Table 11: Statistics of SMTD on section 5 (dense asphalt)

	PER4					PER5			
Run	1	2	3	4	5	1	2	3	4
Aver.	0.50	0.51	0.51	0.51	0.51	0.51	0.52	0.51	0.51
St.D.	0.073	0.064	0.064	0.075	0.064	0.068	0.064	0.103	0.061

Table 12: Statistics of SMTD on section 6 (dense asphalt)

	PER4					PER5				
Run	1	2	3	4	5	1	2	3	4	5
Aver.	0.49	0.50	0.50	0.51	0.50	0.50	0.49	0.51	0.51	0.50
St.D.	0.050	0.051	0.051	0.061	0.047	0.055	0.046	0.047	0.045	0.048

5. ANALYSIS OF THE VOLUMETRIC METHOD

The mean texture depth measured on segments selected from dense asphalt and “open texture asphalt” sections by the procedure explained before and the corresponding average and standard deviation are presented in Table 13.

The results obtained indicate that the use of the large container leads to lower values of MTD, both for dense and open graded asphalt. For dense asphalt and for Operator 1 it may be concluded that using glass spheres instead of sand leads to a small difference in the average MTD (0.03) mm.

It can also be stated that the standard deviation is similar for both operators. The variability is higher for the “open texture asphalt” than for the dense asphalt.

Table 13: MTD measured on dense asphalt and on “open texture asphalt”

	MTD (mm) - dense asphalt			MTD (mm) - “open texture asphalt”	
Position	OP1 (small cont., glass)	OP1 (small cont.,sand)	OP2 (big cont., glass)	OP2 (small cont., glass)	OP2 (big cont., glass)
1	0.88	0.85	0.77	1.35	1.34
2	0.84	0.83	0.81	1.41	1.29
3	0.94	0.89	0.85	1.35	1.17
4	0.82	0.80	0.78	1.65	1.59
5	0.81	0.78	0.71	1.57	1.40
6	0.82	0.82	0.73	1.46	1.30
7	0.91	0.84	0.75	1.26	1.22
8	0.92	0.85	0.71	1.62	1.42
9	0.89	0.84	0.79	1.54	1.36
10	0.91	0.83	0.77	1.17	1.03
11	0.92	0.85	0.80	1.46	1.33
12	0.83	0.81	0.67	1.44	1.27
13	0.80	0.83	0.67	1.60	1.27
14	0.79	0.75	0.67	-	-
15	0.82	0.80	0.69	-	-
16	0.89	0.87	0.79	-	-
Aver.	0.86	0.83	0.75	1.45	1.31
St.D.	0.052	0.035	0.056	0.145	0.132

6. JOINT ANALYSIS OF THE TEXTURE INDICATORS

The development of correlations between the indicators that result from different test methods is very important since they provide values which are not directly comparable. Figures 6 and 7 show all the texture data acquired in the two road segments, where the volumetric method was used along with the high speed profilometers.

The best relation between MPD or SMTD and MTD were obtained using a higher volume of glass, what seems reasonable because a wider area is covered on each test point. These correlations are presented in Figure 9. For the "open texture asphalt" no acceptable correlation was found.

When the results obtained for MPD are compared with the results obtained for SMTD, on both types of surfaces, equipments PER1 and PER4 seem to provide the best correlation, as shown in Figure 9.

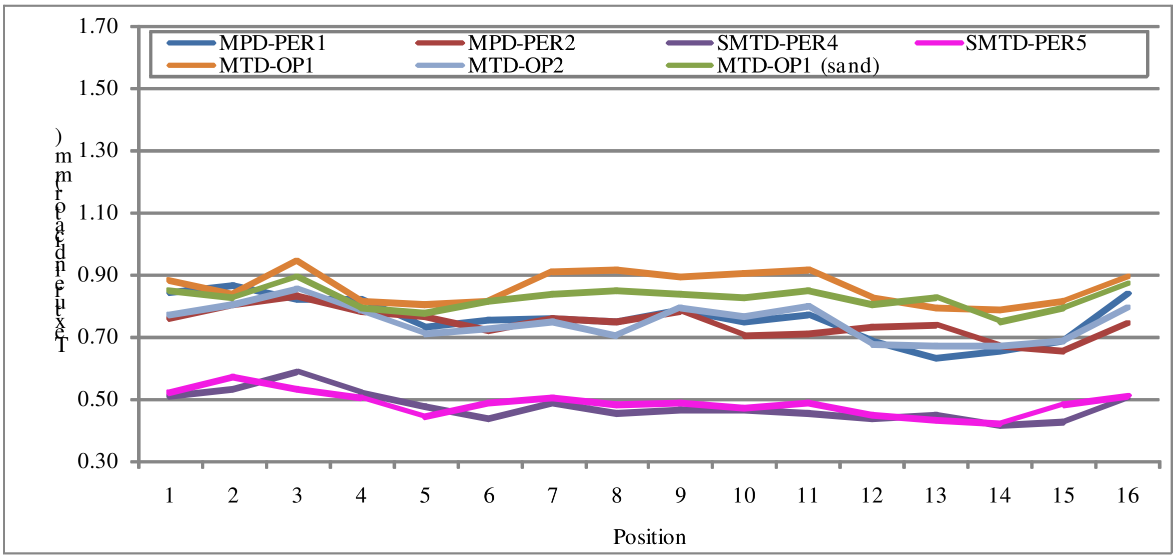


Figure 6: Texture indicators on 150 m segment of section 5 (dense asphalt)

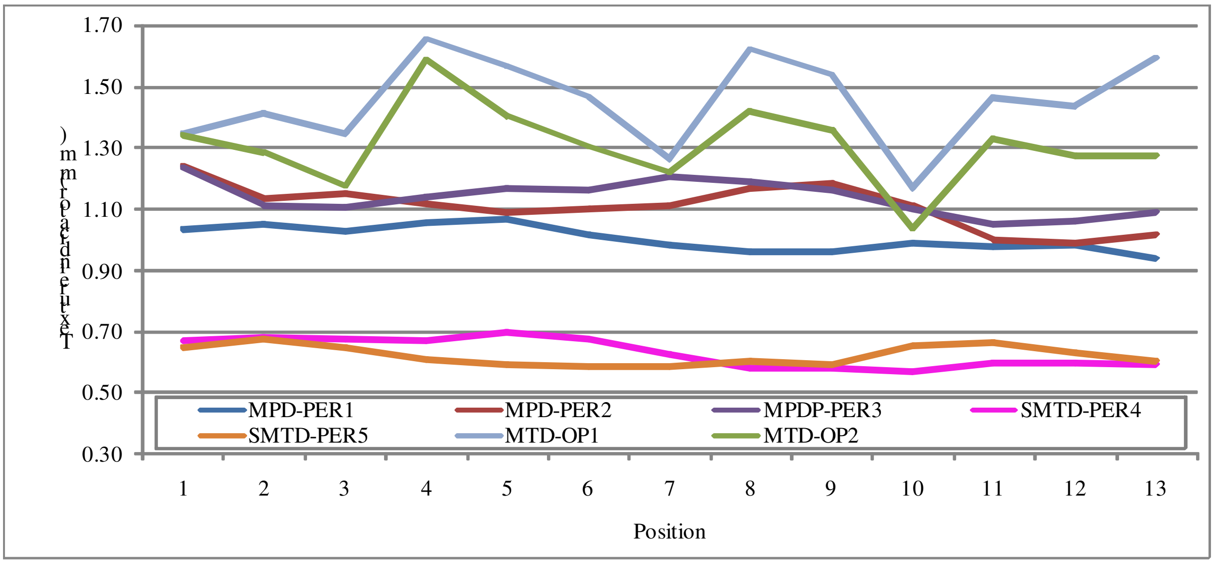


Figure 7: Texture indicators on 120 m segment of section 3 ("open texture asphalt")

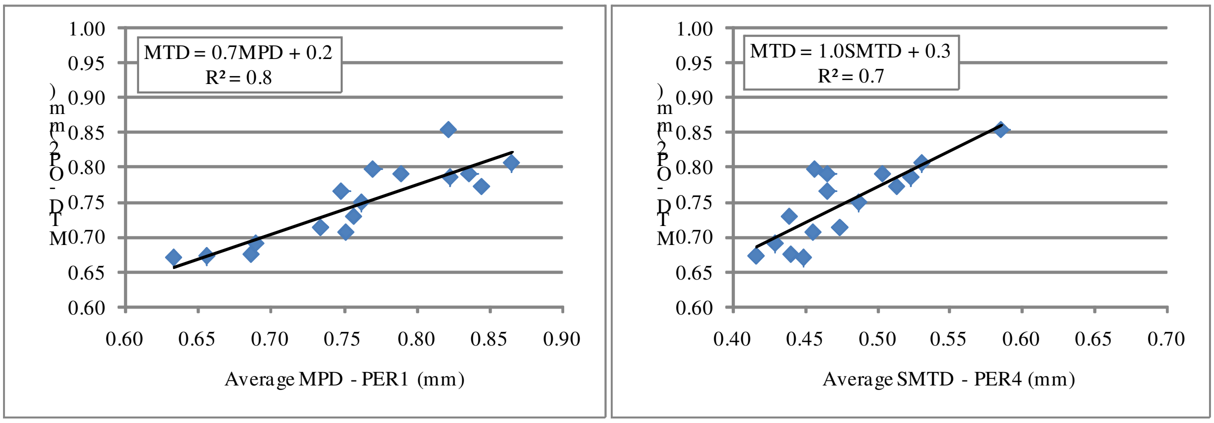


Figure 8: Best MTD-MPD and MTD-SMT correlations obtained for dense asphalt

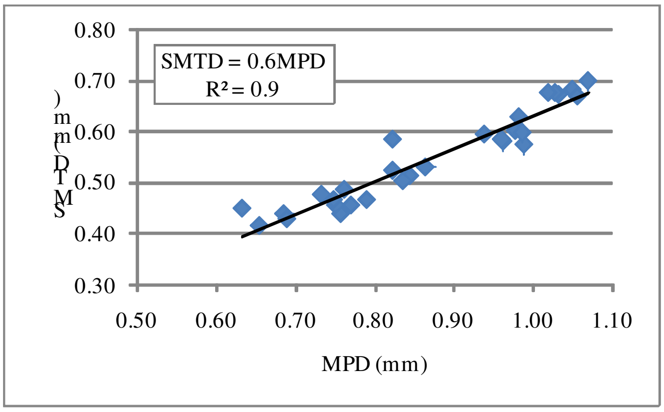


Figure 9: SMTD-MTD correlation obtained for dense asphalt and "open texture asphalt"

7. CONCLUSIONS

Texture has an irrefutable influence on the functional quality of pavements, what has made that several test methods for its assessment were developed over the last years. Since these test methods provide different results, it is important to perform comparative tests and to develop relations between indicators derived from the use of different methods. For this purpose, a comparative study on the different test methods used in Portugal for macrotexture depth evaluation was performed. Having the European standards as reference, the tests were carried out under ordinary testing conditions on three types of surfaces: porous asphalt, "open texture asphalt" and dense asphalt.

The following main conclusions may be reported:

- MTD results obtained with a volume of glass spheres that is larger than the minimum recommended in EN 13036-1 seem to better correlate with MPD results.
- For each equipment, and for the three types of surfaces, the average MPD has negligible variations among the different runs.
- The comparison between different high speed equipments that provide the same type of indicator (either MPD or SMTD) indicates that they provide similar results, both in terms of average and in terms of standard deviation, although there are slight differences between them.
- It was not possible to establish an acceptable correlation between MPD or SMTD and MTD.

- A good correlation between SMTD and MPD was established in the range of 0.6 to 1.1 mm for texture depths.

Finally, it is recommended that this type of experiment is repeated in order to broaden the experience to other types of surfaces, with different ages and under different conditions.

ACKNOWLEDGMENTS

The authors acknowledge the participation of the consultancy companies CONSULPAV, CONSULSTRADA and NORVIA in this study.

REFERENCES

Abe, H., Tamai, A., Henry, J. and Wambold. J., 2001. *Measurement of Pavement Macrotexture With Circular Texture Meter*. Transportation Research Record 1764, pp 201-209, Transportation Research Board, Washington DC.

ASTM E965-96. *Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique.*

Delanne, Y. and Daburon, P., 1999. *Unevenness and Vibrational Comfort of light Cars.* International Symposium of the Environmental Impact of Road Unevenness, Oporto, Portugal.

Domenichini, L. and Martinelli, F., 2004. *Influence of the Road Characteristics on Tyre Wear.* 5th Symposium on Pavement Surface Characteristics-Roads and Airports, World Road Association, Toronto, Canada.

Do, M.-T., Marsac, P., Delanne, Y.,2004. *Prediction of Tyre/wet Road Friction from Road Surface Microtexture and Tyre Rubber Properties.* 5th Symposium on Pavement Surface Characteristics-Roads and Airports, World Road Association, Toronto, Canada.

EN 13036-1. *Road and airfield surface characteristics — Test methods — Part 1: Measurement of pavement surface macrotexture depth using a volumetric patch technique*.

ISO 13473-1:1997. *Characterization of Pavement Texture by Use of Surface Profiles – Part 1: Determination of Mean Profile Depth.*

NCHRP 291, 2000. *Evaluation of Pavement Friction Characteristics*. NCHRP Synthesis 291, Transportation Research Board, Washington DC.

SILVIA, 2006. *Guidance Manual for the Implementation of Low-Noise Road Surfaces*. FEHRL Report 2006/02, Forum of European National Highway Research Laboratories, Brussels, Belgium.

Wambold, J., Antle, C., Henry, J., Rado, Z., Descornet, G., Sandberg, U., Gothié, M. and Huschek, S., 1995. *International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurement*. Final report, No. 01.04.T, to the Technical Committee on Surface Characteristics, World Road Association (PIARC), Paris.