SPECTRAL TEXTURE INDICATORS SIGNIFICANCE IN RELATION TO FLEXIBLE PAVEMENTS SURFACE PERFORMANCE

G. BOSCAINO
Dipartimento di Ingegneria Infrastrutture Viarie, Università di Palermo, Italia
boscaino@ing.unipa.it

F. G. PRATICÒ
D.I.M.E.T. Department, Mediterranean University of Reggio Calabria, Italy
fpratico@ing.unirc.it

R. VAIANA
Dipartimento di Ingegneria Infrastrutture Viarie, Università di Palermo, Italia
r_vaiana@inwind.it

ABSTRACT

As well known, pavement texture intrinsic indicators may be divided into two different classes: aggregate and spectral ones.
In the first set there are MPD, ATD, RMS, etc, while in the second one there are, for example, texture amplitude Power Spectral Density and texture amplitude levels.
On the other hand, many experiences remark that extrinsic texture indicators (such as, for example, friction and outflow time), though measured in different manners, are not equally dependent on the various wave-lengths classes of texture amplitudes.
So, when an Agency has measured service quality indicators based on aggregate texture parameters (for example Sand Height), it is not possible to be sure on friction or drenability requirements.
So, it is not possible to say if safety essential conditions have been satisfied.
According to these problems, in this paper, Authors have planned a set of experiments to study in deep the correlation among texture levels on different wavelenghs and friction or outflow measures.
Spectral levels have been obtained by amplitude profiles measured by a laser device, based on conoscopic olography, and a signal post-processing by a specific dedicated software.
Friction measures have been effected by the British Pendulum while outflow times have been measured by a typical belgian outflow meter.
The obtained results have remarked the specific influence of some particular wave-lengths on the above mentioned extrinsic parameters.

KEY WORDS

PAVEMENT SURFACE TEXTURE / FRICTION COURSE / PERFORMANCE / NON-CONTACT PROFILOMETER

1. INTRODUCTION

As well known, texture may be considered a very strategic parameter both in assessing and in analysing surface performance of road pavements, especially by referring to safety topics (G.Bosurgi, S.Cafiso, 2002).
In particular it is possible to remark that, by analysing texture indicators, it is possible to get information about outflow characteristics and so about friction properties in wet conditions at high speed.

Nowadays, owing to the recent technical and scientific progress in detecting bituminous surface mix asperity by non-contact devices (R.Vaiana, 2002), pavement texture surveying results more and more precise and reliable.
On these bases, the Authors designed and effected experiments on different typologies of bituminous mixes, in order to study more in deep the correlation among texture amplitudes, for different spatial frequencies, drenability and friction parameters.
In particular, main objectives were the followings:

- establishing the different importance of the wavelengths in analysing and forecasting both friction and outflow parameters;
- researching for multivariate correlation among BPN and different texture levels;
- researching for multivariate correlation among drenability and different texture levels;
- exploring the relation among mean texture level spectra and mean BPN values, for different friction courses;
- prospecting the relation among mean texture level spectra and mean drenability values, for different friction courses.

2. INTRINSIC AND EXTRINSIC TEXTURE DESCRIPTORS

In characterising pavement texture one can identifies two different logical sets (G.Boscaino, F.G. Praticò, 1999, 2001):

1. extrinsic criteria, that is to say criteria for analysing pavement texture by strictly correlated parameters, such as outflow (M.Bocci, 1990) or friction parameters;
2. intrinsic criteria, that is to say based on surveying and analysing surface geometry and interpreting it by appropriate algorithms and hypotheses (G.Boscaino, F.G. Praticò, R. Vaiana, 2000, 2001).

Intrinsic criteria may be divided into two other sets:

a. space-frequency or spectral or dis-aggregate descriptors; these are obtained by imaging pavement profile as the superposition of "many" elementary components (harmonics), which are properly connected to a single wavelength, by Fourier analysis math instruments (see table 1);
b. aggregate descriptors, which are referred to all the surveyed wavelengths (see table 2).

Table 1- Aggregate intrinsic descriptors

01	n/L	$[L^{-1}]$	Average asperity density
02	R_{max}	[L]	Maximum peak-to-valley height
03	R_t	[L]	Peak-to-valley height
04	R_z	[L]	Average peak-to-valley height
05	MAA,(Σh/n)	[L]	Mean Apparent Amplitude
06	(Σh/n)	[L]	Average Asperity height
07	(Σh/n)/(L/n)	$[L^o]$	Average shape factor
08	$\bar{z}$	[L]	$z_{media}=\Sigma_i z_i p(z_i)$. Mean line, arithmetic mean
09	R_a	[L]	$R_a=\Sigma_i \lvert z_i - z_{media} \rvert \cdot p(z_i)$. Average Roughness or Centre-line average
10	R_u	[L]	$z_{max}-z_{media}$. Levelling Depth,
11	R_m	[L]	Mean Depth. The RMD Rut Mean Depth as defined in E1703-E1703M-95 ASTM can be related to this parameter.
12	R_p	[L]	$R_p=\Sigma_i(z_{max}-z_i)\cdot p(z_i)$. Depth of surface roughness
13 14	PD; MPD (MPD Short)	[L]	Profile Depth; Mean Profile Depth measured for wavelengths of between 2.5 and 100 mm). The parameter MPD Short (measured, for example, with a Texture Meter mounted on a SCRIM) is however measured for wavelengths of between 2.5 and 10 mm.
15	z_4	$[L^0]$	$z_4=[\Sigma(\Delta x_i)_+ - \Sigma(\Delta x_i)_-]/L$. Parameter involving the number of profile segments with a positive difference in elevation

16 17 18 19 20	R_q, σ; z_1; SD; SMTD; CSMTD	[L]	$R_q \approx \sigma \approx z_1 \approx [\Sigma(z-z_{media})^2 p(z)]^{0.5}$. Root-mean-square roughness; Standard Root-mean-square Standard Deviation; Sensor Measured Texture Depth Corrected SMTD;
21	TDMA	[L]	$\rightarrow\sigma$. Texture depth of macrotexture
22	S_k	$[L^0]$	$S_k=\sigma^{-3}\cdot\Sigma(z-z_{media})^3\cdot p(z)$. Skewness
23	K	[L]	$S_k=\sigma^{-4}\cdot\Sigma(z-z_{media})^4\cdot p(z)$. Kurtosis
24	z_2	$[L^0]$	$z_2=[\Sigma z'^2 p(z)]^{0.5}$. RMS difference in elevation
25	z_3	$[L^{-1}]$	$z_3=[\Sigma z''^2\cdot p(z)]^{0.5}$. RMS value of second derivative
26	r_e	[L]	$r_e=r^*N_k$. Effective radius
27	27. D_f	$[L_0]$	$\rightarrow l=k^*u^{1-Df}$. Fractal dimension D_f
28	28. W	[L]	Mean groove width
29	29. D	[L]	Mean groove depth
30	S	[L]	Span (pitch)
31	VarW	$[L^2]$	Variance in width W
32	VarD	$[L^2]$	Variance in depth D
33	VarS	$[L^2]$	Variance in span
34	NumGRV	$[L^0]$	Number of grooves
35 - 36	NumGRVD≤(x_i)	$[L^0]$	Number of grooves with depth D less than or equal to x_i''; x_i is generally expressed in inches
37	NumGRV W≤(1/8)	$[L^0]$	Number of grooves in the section of profile with width W less than or equal to 1/8'' (3.175 mm)
38	NumGRV G≤(1/8)	$[L^0]$	Number of grooves with width W or Depth D less than or equal to 1/8''
39	TAWRG	$[L^0]$	Total area within the 10 foot segments with recognizable grooves
40 41	MPDwG MPDnoG	[L]	Mean profile depth (MPD) with grooves; Mean profile depth (MPD) with no grooves
42	A_r	[L]	$A_r=n^{-1}\cdot(\Sigma a_{ri})$. Roughness width (Mean distance between the peaks n in the profile)
43	A_w	[L]	$A_w=n^{-1}\cdot(\Sigma a_{wi})$. Mean waviness width (Mean distance between the peaks n in the profile)
44	l_t (c)	[L]	$l_t(c)=\Sigma l_i(c)$. Bearing length at height c from mean line
45	λ_a	[L]	$\lambda=2\pi R_a$/(mean slope). Average wavelength
46 47 48	MTD HS NASA G.S.P.	[L]	Mean Texture Depth; Hauteur de sable; NASA Grease Smear Parameter. These are two-variable intrinsic indicators experimental analysis of which can provide an estimate of the ratio between $\int_S z(x,y)\,dx\,dy$ and $\int_S dx\,dy$, a first order moment I. For maintenance, the MTD can be calculated by the formula MTD=0,2 mm+MPD. Many other acronyms designate indicators measured with different devices (often high-speed) which are similar to the parameter HS.
49 - 54	A, B, C, D, E, F		Qualitative and quantitative parameters, essentially concerning macrotexture and microtexture defined in ASTM E770; initially, they can be considered to relate to all the intrinsic two-variable aggregate indicators.

Table 2 - Aggregate intrinsic damage descriptors			
55 56 57 58	ACA; NTP; ARV; MAS;	$[L^0]$	Intrinsic descriptors essentially relating to individual typologies of damage and defects: 55. Area of cracking ACA (the ratio between the area affected by cracking and the total area of the surfacing; the zone of cracking is defined as the sum of the areas of the rectangles containing cracks); 56. Number of standard potholing NTP (defined as the number of holes with a radius of more than 150 mm and a depth of more 25 mm on 1 km of road); 57. Ravelled area ARV (describes ravelling of the surface layers; equal to the percentage of the surface affected by stripping); 58. The descriptor MAS (Mean Absolute Slope), measured using ARAN devices for example, relates to the regularity of the pavement surface, particularly in the case of concrete pavements where the upper limit for a new surfacing is 3 mm/m.

59 60 61	PSI; PCI; DS (Amm)	$[L^0]$	Intrinsic descriptors (i.e. descriptors that depend only on geometric characteristics), expressing surface deterioration in a summarized manner. 59. The PSI (Present Serviceability Index), used by AASHTO for the design of surfacings, represents the deterioration of the surfacing. It is determined with reference to the mean differences in level along the longitudinal profile, the length of visible damage, the surface of holes and patches and rut depth. 60. The PCI (Pavement Condition Index), used in FAA (Federal Aviation Administration) standards, is an adimensional indicator with values of between 0 and 100 (optimum) that represents deterioration of the surfacing (generally used for airport pavements). 61. The Deterioration index DS (Distress), often referred to as Amm equal to $\Sigma D_{ik,}$, where D_{ik} is the degree of severity (equal to 0, 1, …, 3) for the type of deterioration (=1, …, 7), for the k-th subsection of pavement. DS refers to a zone with a length of 1 kilometre, which is broken down into n subsections with the index k.

Table 3 - Disaggregate intrinsic indicators			
62 63 64 65 66 67	PSD; PS; c_k, L_T a_5, $a_{mega;}$ $H_{APL;}$ $I_{NBO;}$	$[L^3]$ $[L^2]$ $[L^0]$ [L] [L] $[L^0]$	Spectral descriptors: 62. Power Spectral Density (PSD); 63. Power Spectrum (PS); 64. Texture amplitudes (c_k), Texture Level (L_T); 65. Texture amplitude for the wavelength of 5mm (a_5, established with reference to the band centres of 4mm, 5mm and 6.3mm) or 25mm (a_{mega}, based on the amplitudes for 20mm, 25mm and 31mm); 66. Amplitude of the irregularities for a zone with a specified wavelength (H_{APL}); 67. Class of indicators that are determined by associated a scalar quantity of between 0 and 10 to short, medium and long waves (I_{NBO}, Notation par Bandes d'Onde - NBO –Wave Band Rating [14, 15]). By extension, with reference to the transverse profile of the pavement surface the RMD (Rut Mean Depth) also be linked to the parameter H_{APL} according to E1703-E1703M-95 ASTM.

Table 4 - Extrinsic descriptors			
68 69 70 71 72 73 74 75	a, $a_{0;}$ BPN; SFC [CAT]; GN; Drainability; IRI; RCI; IFI;	$[L^0]$ $[L^0]$ $[L^0]$ $[L^0]$ $[L^3/T]$ $[L^0]$ $[L^0]$	Extrinsic descriptors (related to texture but not geometry): 68. a: sound absorption coefficient ($\rightarrow$ noise nuisance); $a_{0:}$ sound absorption coefficient in normal incidence ($\rightarrow$ noise nuisance); 69. British Portable Tester Number (BPN, $\rightarrow$ pendulum friction measurement); 70. Sideway force coefficient - SFC (measured, for example, by SCRIM); 71. Grip number GN (device: Grip Tester) 72. Drainability; 73. International Roughness Index ($\rightarrow$ Comfort); 74. Riding Comfort Index ($\rightarrow$ Comfort); 75. International Friction Index.

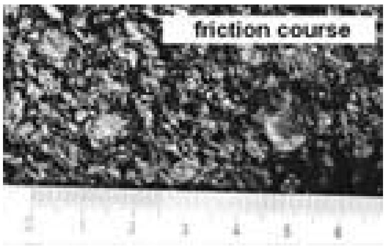
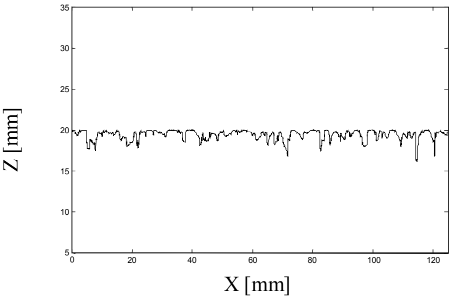
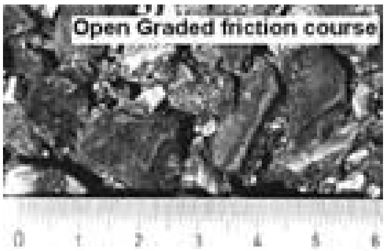
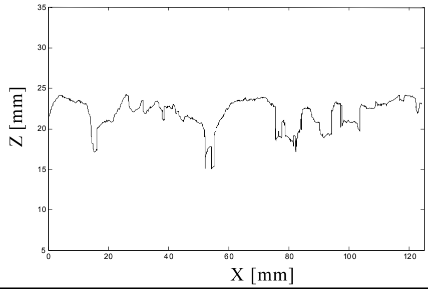
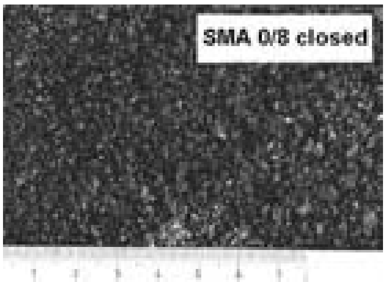
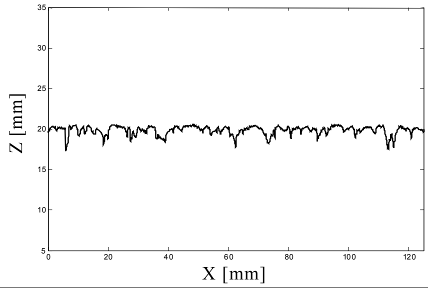
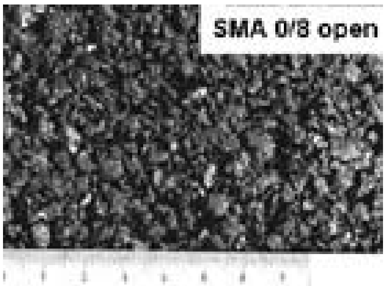
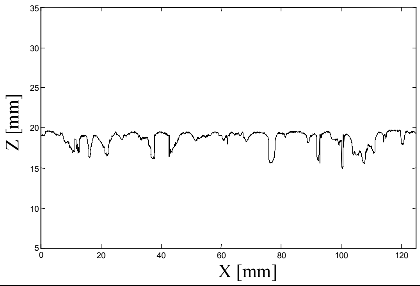
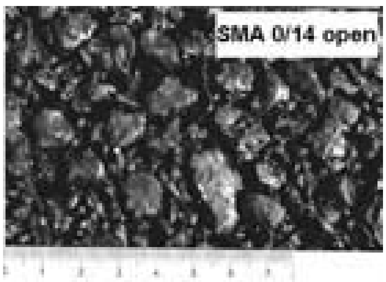
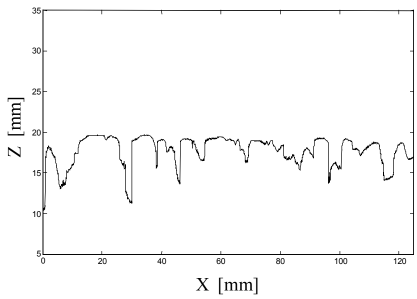
3. EXPERIMENTAL PLAN

3.1 Analysed surfaces

The road surfaces examined in this paper are described in the following table 5.
Two different survey methodologies were applied:

a. indoor surveys on slabs (in-lab compacted or from-situ extracted);
b. outdoor measurements on site.

Table 5 – Observed surfaces				
N°	**Typology**	**age**	**Origin**	**Number of measurements and/or slabs**
1	Friction course	new	In-lab compacted slabs by Roller Compactor (in-situ compaction simulation)	Number of slabs = 4
2	Open graded friction course (≈10 years old)	old	Extracted slabs from highway site	Number of slabs = 10
3	SMA 0/8 closed	new	On-site (Noise test track)	Number of measurements = 12
4	SMA 0/8 open	new	On-site (Noise test track)	Number of measurements = 12
5	SMA 0/14 open	new	On-site (Noise test track)	Number of measurements = 12

Table 6 - Observed surfaces - visual aspect and profiles			
1	Friction course		
2	Open graded friction course (≈10 years old)		
3	SMA 0/8 closed		
4	SMA 0/8 open		
5	SMA 0/14 open		

3.2 Measure devices and techniques

The analysis of the different surfaces were conducted by the followings devices:

a. British Pendulum (skid-resistance measurements, see table 7);
b. Belgian outflow meter for measuring drenability values (see table 7);
c. Laser profilometer, based on conoscopic olography, for the characterization of pavement texture on the basis of surface profiles z(x) (see table 7).
   Post-processing to profile-signal was realised and developed by a specific dedicated software.

In figure 1 some typical Texture Level spectra are reported for all the considered wearing courses, while in the following table 7 are summarised the obtained statistics for the tested extrinsic descriptors.

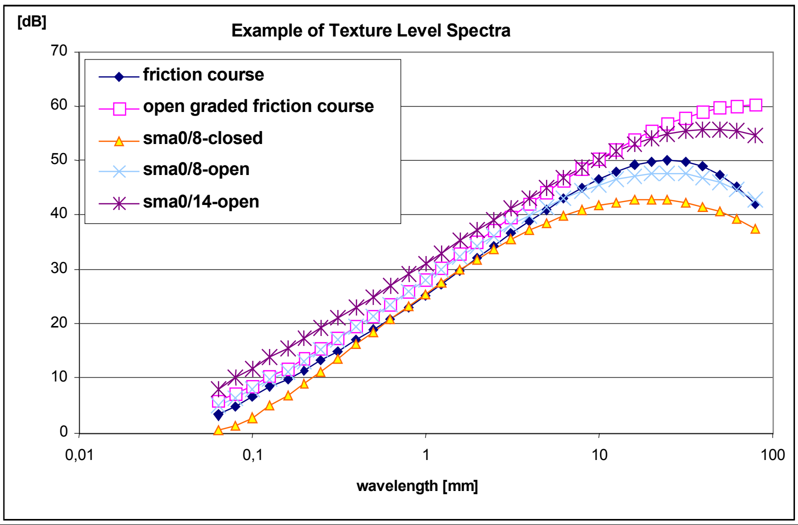


Figure 1 – Texture Level Spectra. On the right, the employed laser profilometer during a survey (Noise Test Track)

Table 7 – Mean texture levels in macro and micro domain

wavelength [mm]	Friction course	Open graded friction course	SMA 0/8 closed	SMA 0/8 open	SMA 0/14 open	Texture Domain
40	*48.95*	*58.96*	*41.55*	*46.93*	*55.78*	***MACRO***
4	*38.85*	*41.88*	*37.14*	*39.96*	*43.17*	
0.20	*11.42*	*13.44*	*8.89*	*13.05*	*17.18*	***MICRO***
0.08	*4.70*	*6.96*	*1.42*	*6.27*	*9.84*	

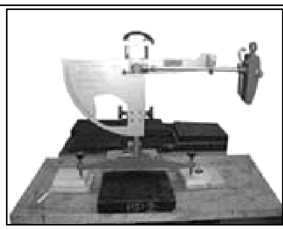
Table 8 – Tested surface performance (extrinsic descriptors)

N°	**Typology**	**BPN**			**OutFlow [sec]**		
		Min	**Max**	**Average**	**Min**	**Max**	**Average**
1	Friction Course, FC	*56*	*62*	***58***	*335*	*801*	***501***
2	Open Graded Friction Course, OGFC	*52*	*63*	***57***	*23*	*77*	***44***
3	SMA 0/8 closed	*68*	*77*	***74***	*65*	*177*	***98***
4	SMA 0/8 open	*66*	*71*	***69***	*25*	*54*	***37***
5	SMA 0/14 open	*65*	*71*	***68***	*25*	*39*	***31***

Figure 2 – Test Devices for pavement surface survey
a) Roller Compactor; b) Slabs extraction from-site; c), Indoor and outdoor skid-resistance measurement; d) outflow measurements

a

a



c

d

3.3 Data interpretation

Here is reported a particular analysis of the obtained results for BPN (see figures from 1 to 10 and tables 7 and 8). SMA stands for Splittmasticasphalts (F.G.Pratico, R.Vaiana, 2002) (rhombic indicators, 0/8 open=mix4, 0/8 closed=mix3, 0/14=mix5), while FC for Friction Courses (triangular indicators, mix1), and OGFC (circular indicators, mix2) for Open Graded Friction Courses.

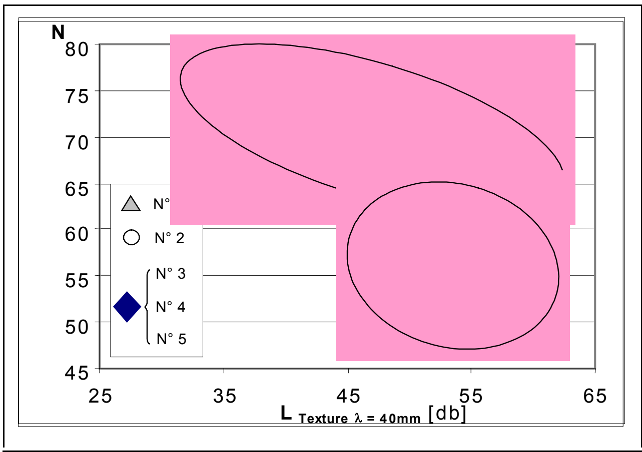


Figure 3

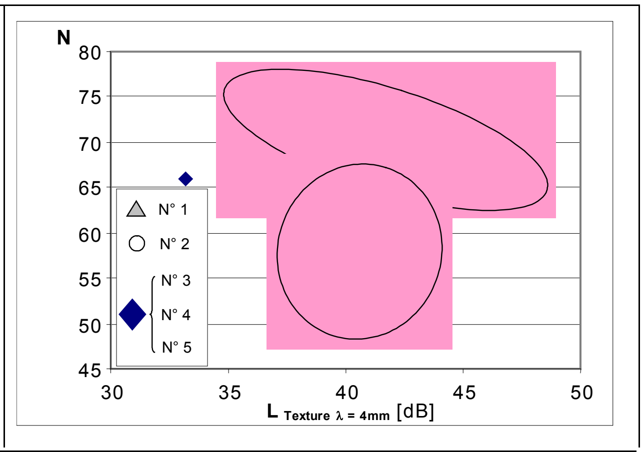


Figure 4

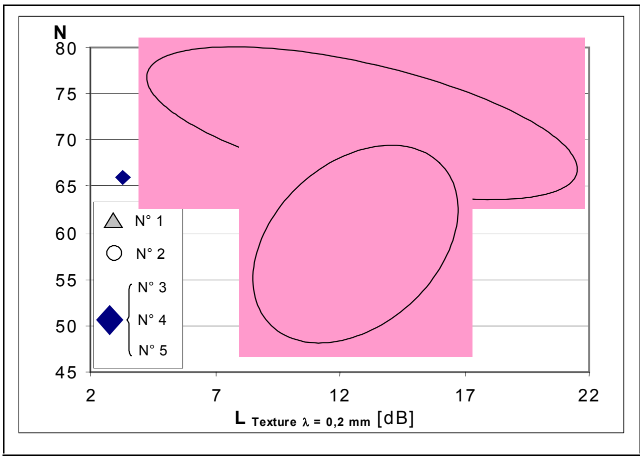


Figure 5

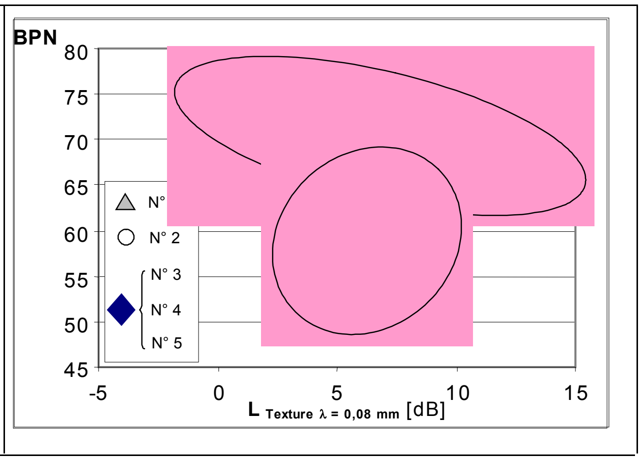


Figure 6

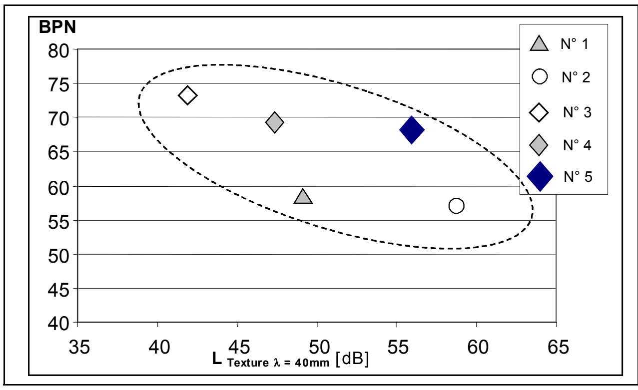


Figure 7

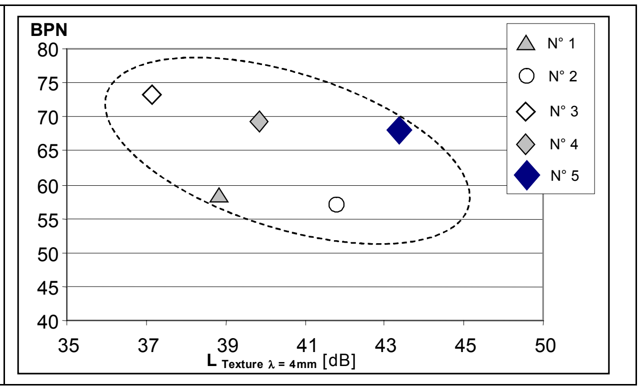


Figure 8

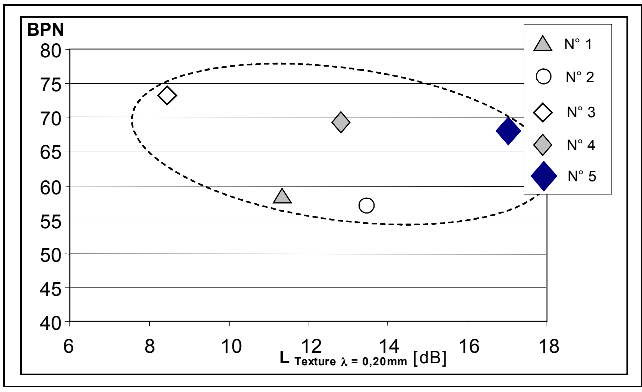


Figure 9

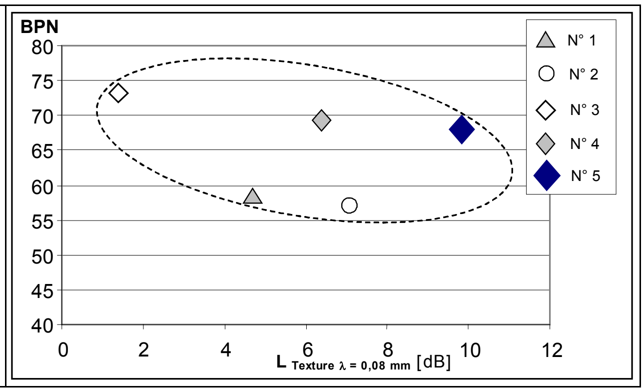


Figure 10

By observing the obtained results for BPN (see figures from 1 to 10 and tables 7 and 8) one can put in evidence that:

a. Other studies are needed in order to obtain a more reliable correlation background;
b. It is possible to define two main groups of BPN values: "high values" (mixes 3, 4 and 5 of table 8) and "middle" ones (mixes 1 and 2 of table 8);
c. According to texture spectra (see figure 1), bituminous mixes may be divided into three sets: "middle-high" values (OGFC, SMA 0/14), "middle" ones (FC, SMA 0/8 open), "low" ones (SMA 0/8 closed);
d. BPN is decreasing as texture level increases, for given wavelength; this behaviour is more and more effective as texture spatial frequency is going to become lower (see figures 3 and 4 for macro and 5, 6 for microtexture domain); this could be explained by referring to the fact that as heights increase wavelengths increase too, then contact surface decreases;
e. This behaviour could be also examined by substituting to clusters the referred mean values (Cfr. figures from 7 to 10); in these plots, especially in macrotexture domain (Cfr. figures 7 and 8), BPN decreasing trend is manifest and it can be interpreted by thinking to a decreasing contact area the more texture levels are increasing;
f. It is evident (by analysing all the figures from 3 to 10) that the behaviour of the old Friction Course is quite different from the others, may be owing to a very different friction mechanism;

Having analysed BPN data, now it is possible to examine some other results concerning outflow meter measures.
Here is reported a particular analysis of the obtained results for Outflow times (see figures from 11 to 18 and tables 7 and 8).

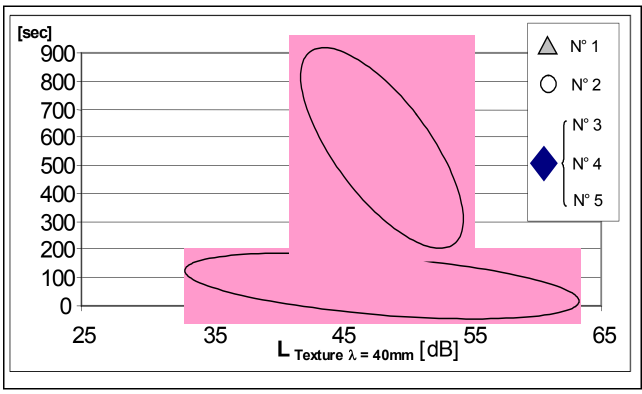


Figure 11

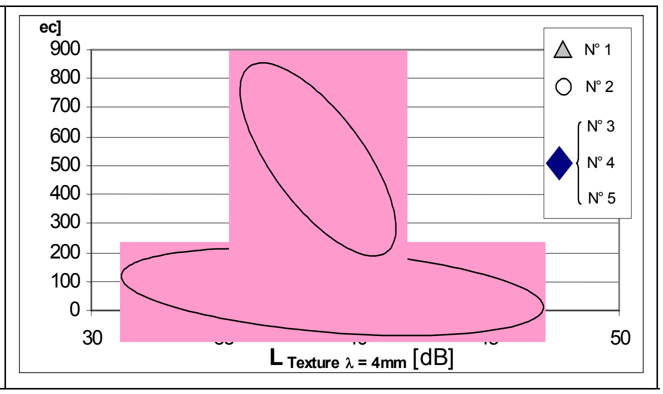


Figure 12

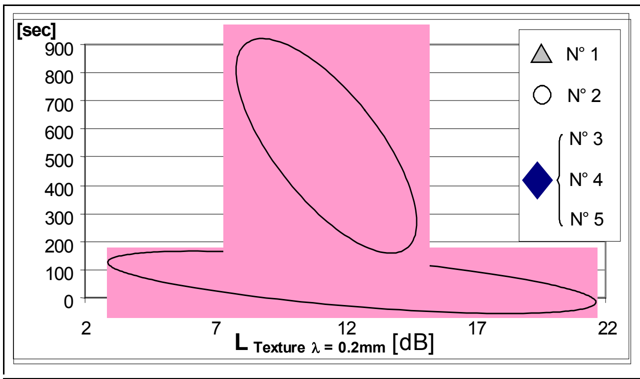


Figure 13

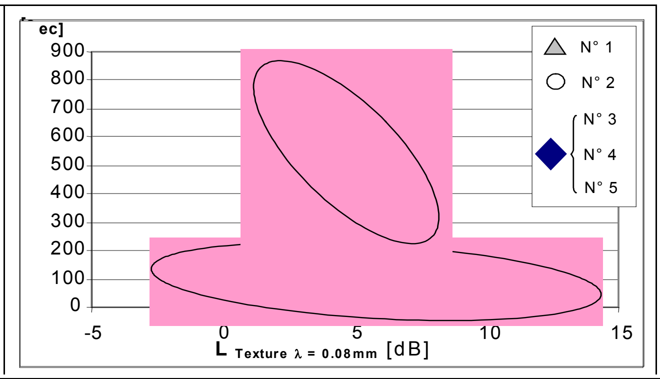


Figure 14

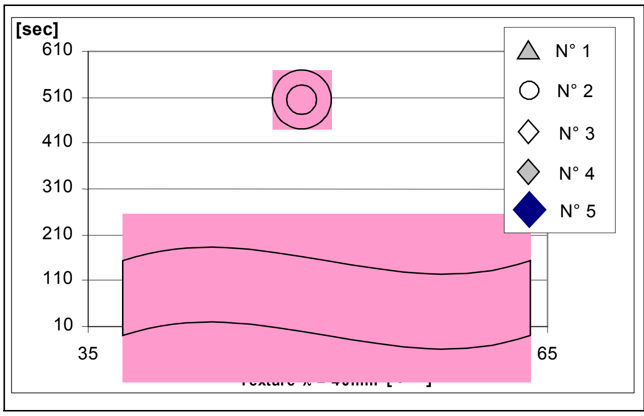


Figure 15

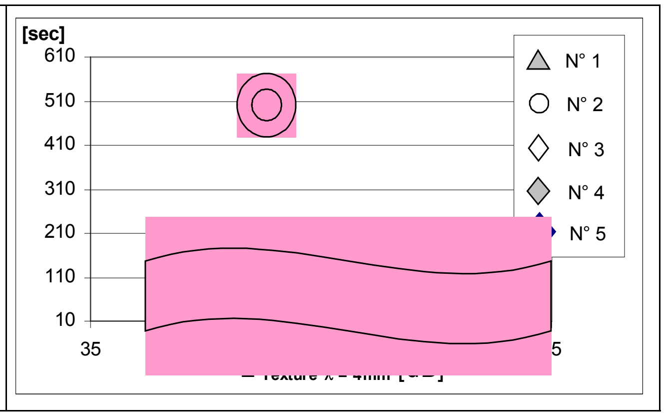


Figure 16

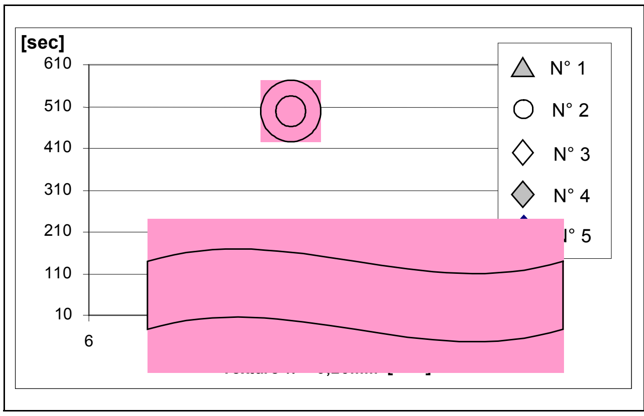


Figure 17

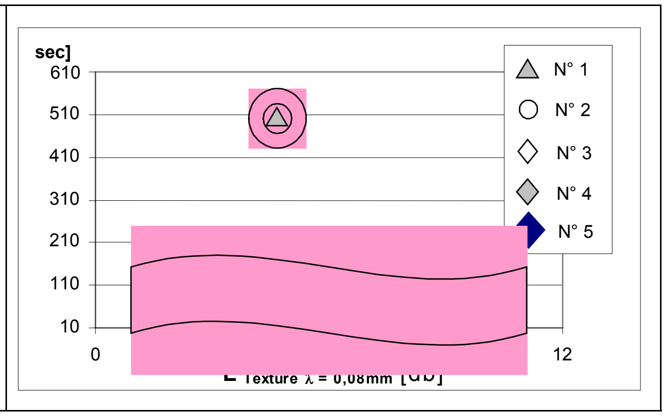


Figure 18

If one considers L(λ) - outflow plots, for each given wavelength, it is possible to observe that outflow values could be considered as decreasing when texture levels increase (see figures from 11 to 18).
This experimental behaviour must be referred to a singular degree to each of the tested mix typologies.
In general, it could be explained by thinking to a “tank” or porosity effect, that is to say by referring to the fact that when texture levels increase than also valley volumes increase.
In particular, the extreme importance of mix typology and conditions (especially for the old friction course FC) is quite plain both for micro and macro domain and it can be better detected by the effected “mean values” analysis (see figures from 15 to 18).

4. CONCLUSIONS

Owing to the complexity of the effected studies and experiments, the following considerations may be looked upon as an “intermediate” step.

Anyhow, it is possible to put in evidence some interesting points:

1. other experiments and data will be useful in order to get a reliable statistic context and in order to better single out physical interpretations and models;
2. simple $L(\lambda_j)$ spectra values seem not to completely express the complexity of the involved phenomena both for friction and for outflow values;
3. it could be considered somewhat clear the anti-correlation between BPN and $L(\lambda_j)$ values, especially in macrotexture domain; this represents an indirect new confirmation of microtexture main influence on friction properties;
4. it may regarded as not negligible the outflow values tendency to decrease the more spectra levels are going to increase; this experimental result, which seems significantly reliable for certain wavelengths, could be explained as a “tank” or porosity or permeability effect;
5. Typology and condition "imprint" and distinctive influence seem not to be exhaustively represented by texture spectra levels.

REFERENCES

Bosurgi G., Cafiso S. - *Quaderni AIPCR: Aderenza dei manti bituminosi - Legami tra aderenza e sicurezza* – XXIV Convegno Nazionale Stradale AIPCR, St. Vincent (AO), giugno 2002;

Bocci M. – *La permeabilità nei conglomerati bituminosi drenanti. Osservazioni su un tronco sperimentale* – XXI Convegno Nazionale Stradale AIPCR, Trieste, Giugno 1990;

Boscaino G., Praticò F. G. - *Classification et inventaire des indicateurs de la texture superficielle des revêtements des chaussées* – Bullettin des Laboratorie des Ponts et Chaussées n° 234, sept-octo 2001;

Boscaino G., Praticò F.G. – *La tessitura superficiale delle pavimentazioni stradali* – Documento PRIN ’98, Palermo 1999;

Boscaino G., Minnella I., Praticò F.G., Vaiana R. - *L’analisi della tessitura stradale attraverso il sistema S.I.R.A.T.* – X Convegno Nazionale SIIV, Acireale, Catania, 2000;

Boscaino. G, Praticò F.G., Vaiana R. - *Sversamenti inquinanti su pavimentazioni stradali e rischi conseguenti al decadimento delle proprietà superficiali: indagine sperimentale* - XI Convegno Nazionale SIIV, Verona 2001;

Boscaino G., Giunta M.S., Vaiana R. – *Tessitura superficiale di manti stradali: indicatori derivanti da acquisizione profilometrica con metodo non-contact* – XXIV Convegno Nazionale Stradale AIPCR, St Vincent (AO), 26/29 Giugno 2002;

Norma ISO 13473-1 – *Characterization of pavement texture by use of surface profiles. Part 1: Determination of Mean Profile Depth* – 1° edition 01/09/1997;

ISO 13473-3 (Draft) – *Characterization of pavement texture by use of surface profiles. Part 3: Specifications and classification of profilometers* – 2001;

Norma ISO 13473-4 (Draft) - *Characterization of pavement texture by use of surface profiles. Part 4: Spectral analysis of texture profiles* – Edition 17/10/2000;

Praticò F.G., Vaiana R. – Stone Mastic Asphalt: performance e caratteristiche superficiali – XII Convegno Internazionale SIIV, Parma 2002;

Vaiana R. – *La tecnologia laser nella caratterizzazione della micro e macro tessitura superficiale dei rivestimenti stradali* – Strade&Autostrade n° sett.-ott. 2002.