EXPERIMENTAL TESTING FOR PHYSICAL AND FUNCTIONAL CHARACTERIZATION OF WEARING COURSES

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ABSTRACT

A methodological-experimental approach is here given, aiming to foresee, during the phase of mix design in laboratory, the physical and functional properties of bituminous layers once in place, by means of characterization tests and by taking into account the most common raw materials, techniques for mixtures production, and laying process used in maintenance works.

In detail, it has been validated a testing protocol for in situ tests for determining the functional and physical characteristics that is possible to obtain for wearing courses, as a function of the final thickness of the layer, once in place.
Keywords: bituminous mixtures physical and mechanical characterization, laboratory and in situ tests

1. INTRODUCTION

In the last few years, laboratory tests on mix design of bituminous mixtures have already identified the main composition factors that, in different way, are able to affect in situ performances of flexible layers. Several field studies, in turn, have shown that the compaction temperature, as well as the thickness of the layer to be compacted, are amongst the main factors able to affect compactability and, therefore, final performances, too.

As it is well know, the design of a mixture aims to define components and mutual proportion of the different mixtures, in order to guarantee the desired properties to be reached and maintained for the whole design life.

Nevertheless, the adopted compaction conditions, both in situ and in the laboratory, may affect the physical, mechanical and volumetric properties of the product to be laid on field (Button et al. 1994, Khosla et al. 2004, Delorme et al. 1990).

Therefore, aim of this paper was to calibrate a testing protocol for in situ characterization of bituminous layer for wearing courses, in order to be able to evaluate the most common technique for construction and/or maintenance works, as well as the effectiveness of the equipments used in the construction site.

2. IN SITU TESTING

Considering the high costs and disadvantages related to full scale testing on field, as well as the need for a preliminary calibration of the experimental protocol, this study was focused on a bituminous mixture for wearing course used for maintenance work, as available thanks to the Local Road Authority. Therefore, the physical characteristics of this mixture have been determined, for two different final thicknesses (commonly used for this kind of mixture) of the wearing course, with equipments and compaction procedures currently used by the contractors. The main attempt of this study, in fact, is to define a methodology that, based on simple and reliable tests carried out both in situ and in the laboratory, allows to predict, during the mix design, the physical and functional characteristics of the mixture as laid on site.

Table 1 Composition of the studied mixture

Riddles or sieves size	*Nominal aggregate size [mm]*	*Percent Passing [%]*
ϕ 15	12	100.00
ϕ 10	8	91.02
ϕ 5	4	41.34
# 2	2	19.64
# 0,4	0.4	7.75
# 0,18	0.18	5.91
# 0,075	0.075	4.73
Bitumen content (on the weight of the mix) *b* (%)		5.00

Table 1 gives the aggregate grading and the bitumen content of the studied mixture: it can be noticed that this mixture is quite poor of sand and fines content and is characterized by a Nominal Maximum Aggregate Size of the equal to NMAS = 8 mm.

In situ activities did imply to prepare two experimental road sections, both located on the slower lane of an highway, with different final thickness of the wearing course, being the first equal to t = 3 cm and the second equal to t = 4 cm.

Each testing section was compacted with a smooth steel roller in a static mode, with a weight per unit of width of 21,50 kg/cm. When compacting each section, 4 different zones were made, each compacted with a different number of roller passes, as given in Table 2.

Table 2 Number of roller passes , Nr, for each testing zone

Nominal thickness (cm)	Experimental section	Nr
3	0-1	3
	1-2	5
	2-3	7
	3-4	9
4	0-1	3
	1-2	5
	2-3	7
	3-4	9

2.1 Experimental plan

After about 3 months from the opening of the highway to the traffic, after the above mentioned maintenance work, for each different testing zone the data related to the surface characteristics of the pavement as calculated by Sand patch tests, Skid tests with a British Pendulum (BP) and laser profile analysis were obtained.

In order to carry out the volumetric characterization of the mixture as laid in the different final thicknesses, several cores were also taken from the testing sites. At each homogeneous zone (in terms of layer thickness and applied number of roller passes), measurements were duplicated along two alignments located in the wheel paths (right one and left one), as shown in Figures 1 and 2.

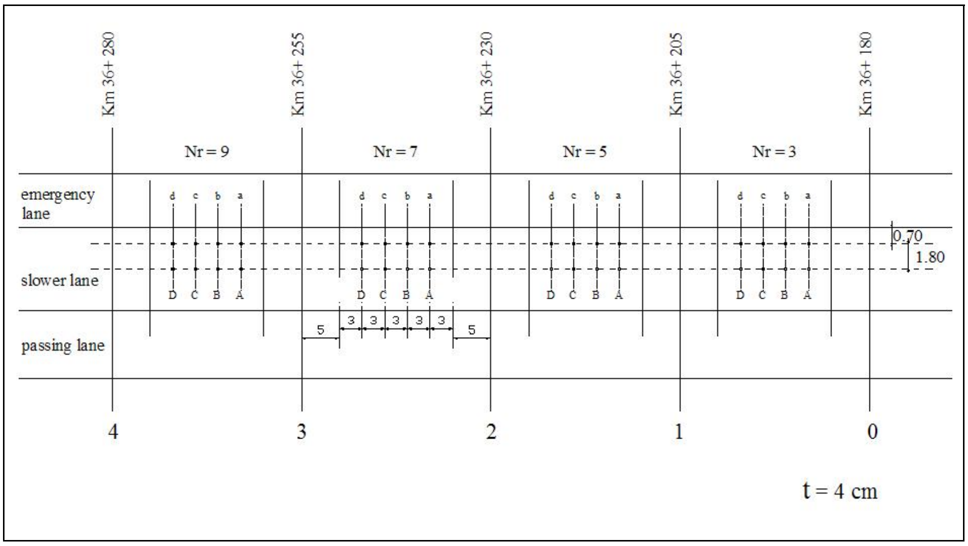

Figure 1 Representation of the testing site. Layer thickness t = 4 cm

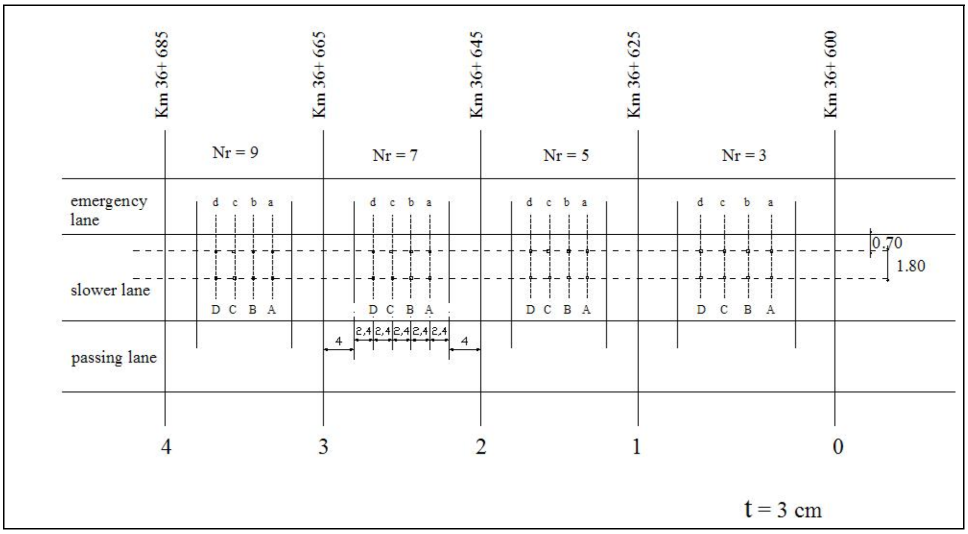

Figure 2 Representation of the testing site. Layer thickness t = 3 cm

In detail, the experimental plan did concern:

- preparation of 2 experimental sites with different final thicknesses (t = 3 and 4 cm);
- preparation, for each site with constant thickness, of 4 zones compacted with a different number of roller passes (Nr= 3 – 5 – 7 – 9);

- selection, for each site with constant thickness, of two alignments in both the wheel paths of the slower lane;
- location, for each zone and each alignment, of 4 measuring points spaced about 2,50 m one from each other, for the repetition of the tests in homogeneous conditions (A – B – C – D);
- determination of the surface characteristics in each measuring point of each zone, via Sand patch tests, Skid tests with the British Pendulum and laser acquisitions of pavement profiles. For each thickness and each level of compaction (i.e. applied number of passes of the roller), 4 repetitions for the sand patch and the skid tests out at each alignment were carried out, with a total of 64 measurements for each test. As far as the surface profile acquisition is concerned, since each profile was repeated two times on each measuring point, a total of 128 measurements were taken;
- determination of the physical properties at each measuring point of each zone: the control of the residual air voids in the mixture as well as the one on the final thickness was carried out. The data on the degree of compaction were compared with those calculated in the laboratory for the same mix, during compaction at the gyratory press.

2.2 Test results

2.2.1 Testing with the Sand Patch Method and the British Pendulum

From in situ testing with the British Pendulum, according to the Italian Standard (CNR 105/1985) , the results for the British Pendulum Number (BPN) given in following Table 3 were obtained, as a function of the layer thickness and the number of roller passes.

Table 3 Results for the BPN as function of the layer thickness and the number of passes of the roller, Nr

Roller passes Nr	Layer thickness t = 3 cm					
	A	**B**	**C**	**D**	**Average**	**General Average**
3	51.13	51.67	51.83	52.33	*51.74*	*51.47*
5	52.17	51.00	52.33	51.17	*51.67*	
7	52.00	52.17	50.83	52.00	*51.75*	
9	50.67	50.17	50.50	51.50	*50.71*	
Roller passes Nr	**Layer thickness t = 4 cm**					
	A	**B**	**C**	**D**	**Average**	**General Average**
3	54.00	53.17	53.83	53.50	*53,63*	*54.30*
5	54.00	56.00	54.83	53.83	*54,67*	
7	55.50	53.83	52.67	54.50	*54,13*	
9	56.17	54.67	55.00	53.33	*54,79*	

In the same Table, a general average for the BPN results is given for each layer thickness, since the results were found to be independent on the number of roller passes used for compacting the testing zone. As it can be noticed, with the exception of the normal variability of results obtained from in situ testing, the average values calculated for the BPN for each layer thickness seem to be quite constant, independently on the number of roller passes Nr. It is therefore reasonable to believe that the different number of roller passes is not able to affect the results in terms of BPN and that this kind of results can be considered as dependent on the chosen formula of the mixture and not jeopardized by laying processes. On the contrary, it seems that the layer thickness is slightly able to affect the results in terms of BPN, presumably due to a different settlement of the mineral aggregates on the pavement surface. It is interesting to notice that the average BPN increases with the layer thickness.

The measured values for the Sand Patch Height (HS) as measured with the sand patch method (CNR 94/1983) and given in Table 4 are consistent with the BPN results.

Table 4 Measured values for HS as a function of the layer thickness and the number of passes of the roller, Nr

Roller passes Nr	**Layer thickness t = 3 cm**					
	A	**B**	**C**	**D**	**Average**	**General Average**
3	1.07	1.07	1.06	1.07	*1.07*	*1.09*
5	1.06	1.09	1.10	1.07	*1.08*	
7	1.14	1.07	1.06	1.19	*1.11*	
9	1.09	1.14	1.12	1.12	*1.12*	
Roller passes Nr	**Layer thickness t = 4 cm**					
	A	**B**	**C**	**D**	**Average**	**General Average**
3	0.78	0.80	0.74	0.73	*0.76*	*0.72*
5	0.70	0.67	0.68	0.64	*0.67*	
7	0.70	0.68	0.73	0.74	*0.71*	
9	0.75	0.75	0.71	0.74	*0.74*	

It can be seen that the measure values of HS for each layer thickness are, also in this case, quite constant with the applied number of roller passes, when considering the normal scattering of the measurements during in situ testing.

The same values are indeed quite different for the different layer thicknesses of this study. As said for the BPN values, it is possible to suppose that the differences between the measured values for the 2 layers, at the same number of passes of the roller, may be due to the different settlement of the mineral aggregates on the pavement surface, as better explained from the results of the profile analysis via laser equipment, detailed in the next paragraph.

Furthermore, the joint analysis of the measured values for BPN and HS provides us with a consistent result: for thicker layer there is a better indentation of the aggregates into the surface with the consequent reduction of the pavement macrotexture (lower HS values) together with a wider contact area between the rubber slider of the pendulum and the pavement surface (higher BPN values).

3. LABORATORY TESTING

3.1.1 Testing with a laser profiler

During this study, also characterisation of pavement texture by use of surface profiles was carried put, as determined from duplication of profile acquisition at the measuring point depicted in Figures 2 and 3. For obtaining the surface profile, a conoscopic laser profiler was used (Vaiana, 2002).

In this study, the following texture indicators have been determined (Boscaino and Praticò 1999) :

- Estimated Texture Depth, ETD_{iso};
- Mean Profile Depth MPD (ISO, 1997);
- Average Asperity Density, AAD.

Since several researches (AIPCR, 2000) have already shown the good correlation between the ETD and MPD values with those measured with the sand patch method as well as the good correlation between the AAD values with those measured with the British pendulum, for the aims of this study, it has been chosen to analyze the data acquired via laser profile and to chart the HS values with both the MPD_{iso} and ETD_{iso} values as a function of the number of passes of the roller and for each layer thickness (see Figures 3 and 4). The same was done for the BPN and the AAD values (see Figures 5 and 6).

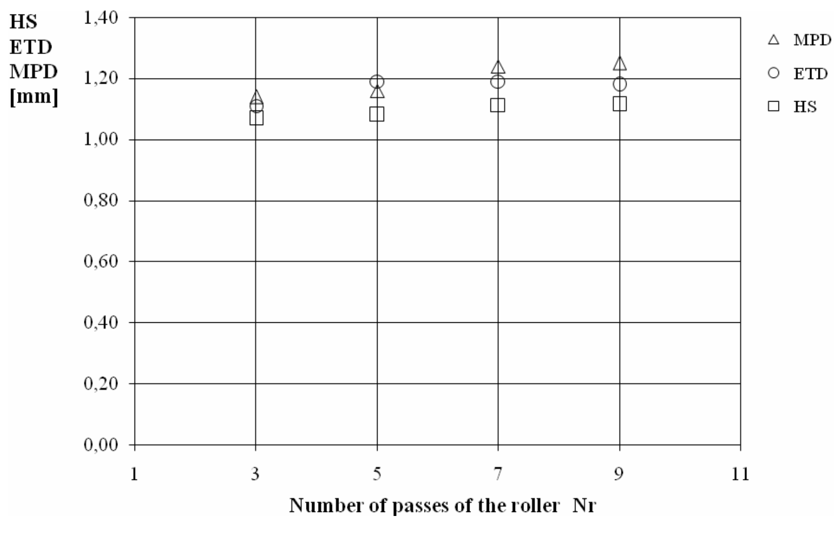

Figure 3 HS, MPD and ETD_{iso} as function of the number of passes of the roller, Nr
Layer thickness t = 3 cm

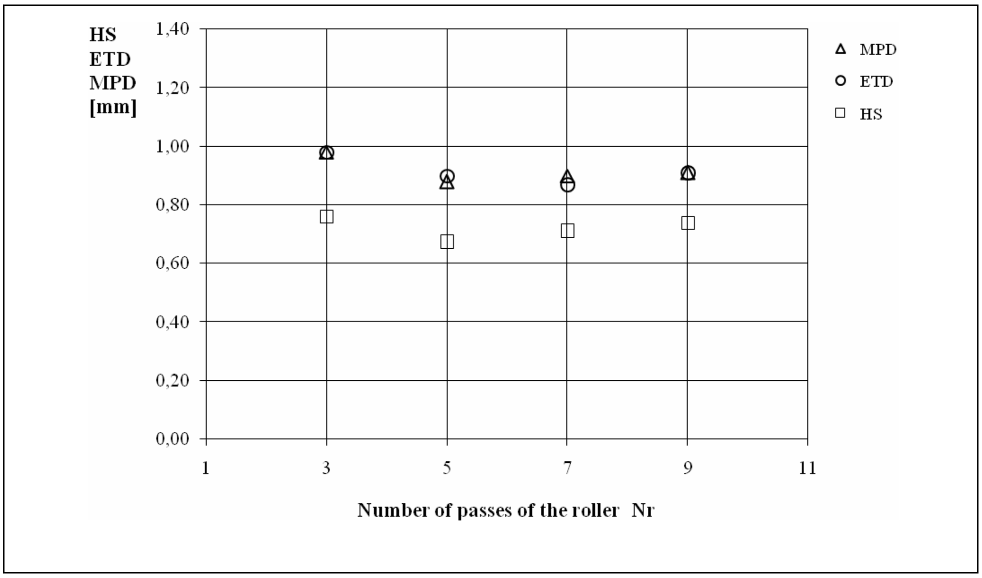

Figure 4 HS, MPD and ETD_{iso} as function of the number of passes of the roller, Nr Layer thickness t = 4 cm

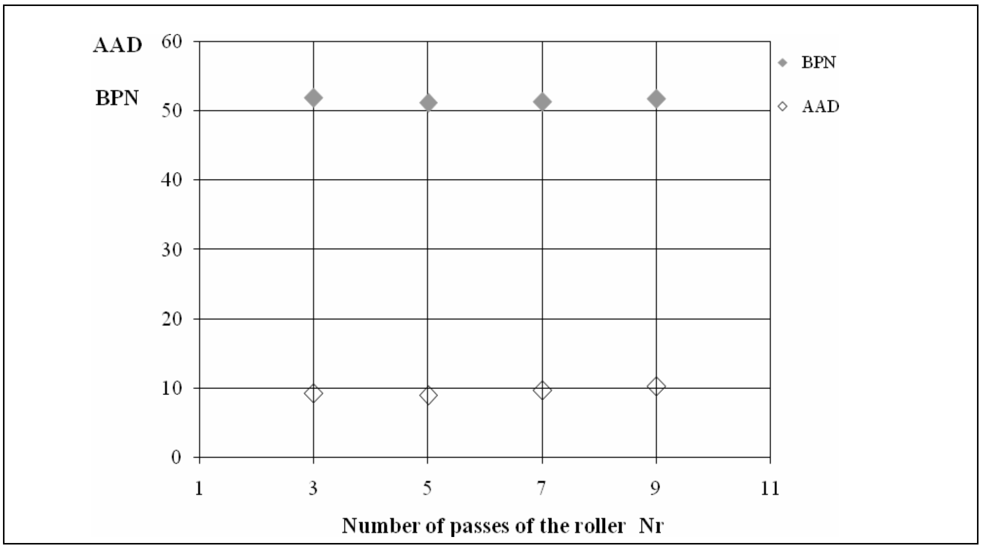

Figure 5 AAD e BPN as function of the number of passes of the roller, Nr Layer thickness t = 3 cm

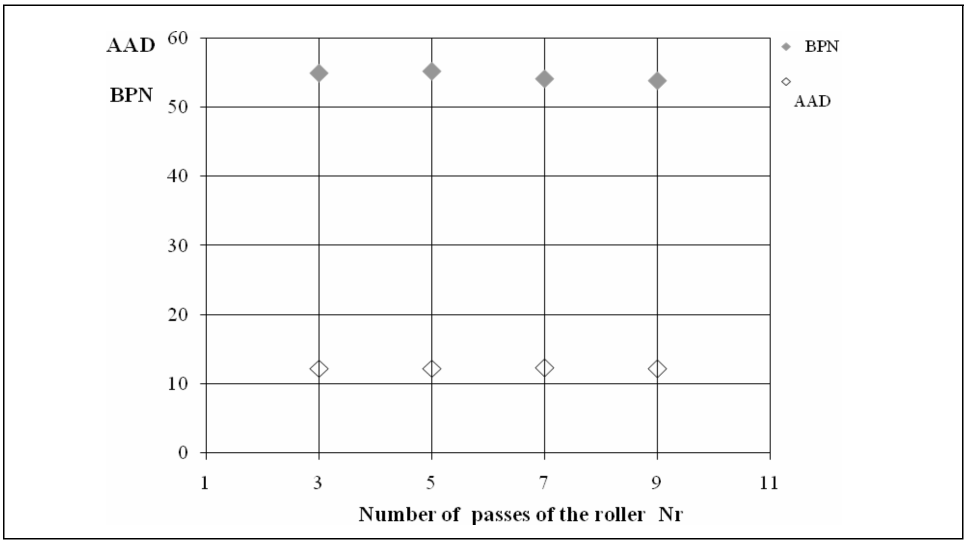

Figure 6 AAD e BPN as function of the number of passes of the roller, Nr
Layer thickness t =4 cm

It is interesting to point out that, for the same layer thickness, the values for the ETD and the MPD are very close to those measured with the patch method and also that the AAD indicator (that is the one that is based on the density of crests in the surface profile, when related to the BPN, provides the same qualitative trend, though with a noticeable and constant numerical difference. This constant difference is easily understandable when thinking of the testing procedure used for measuring the BPN, the asperity density in the contact area between the rubber slide of the pendulum and the pavement surface brings to a BPN value higher than the corresponding AAD value even though calculated along a section of the same length of the contact area.

From the analysis of the profiles it was also possible to deduce useful information about the functional dependence of the profile itself from its own wavelengths or, that is the same, frequencies (Boscaino and Praticò 2001).

Thanks to the spectral analysis applied to the profile data, it is possible to define a texture level , *Lt*, as a function of wavelength λ_k This can be done by applying the discrete Fourier transform according to the relation give in Equation 1:

$$L_t(\lambda_k) = 10\mathrm{Log}\frac{c_k^2}{\tilde{h}_0^{\,2}} \qquad \text{Eq. 1}$$

being:

- *Lt* = texture level ,
- c_k = complex Fourier coefficient;
- $\tilde{h}_0$ = 10^{-6} m, for this study.

As it is possible to see in Figures 7 and 8, the texture levels, at a constant layer thickness, are about the same for each zone compacted at a different number of passes of the roller, Nr; this is particularly evident in the short- wavelength range.

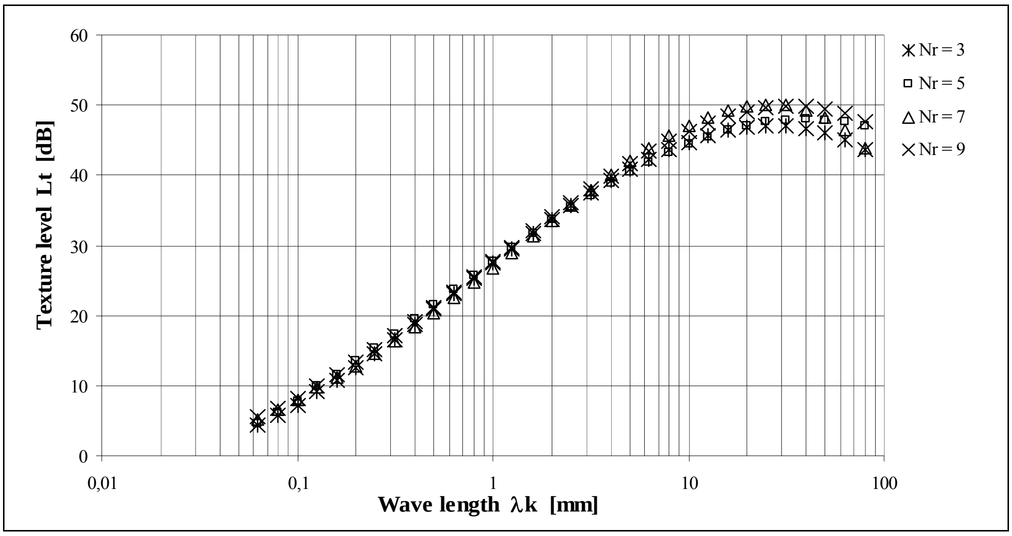

Figure 7 Texture level - Layer thickness t = 3 cm

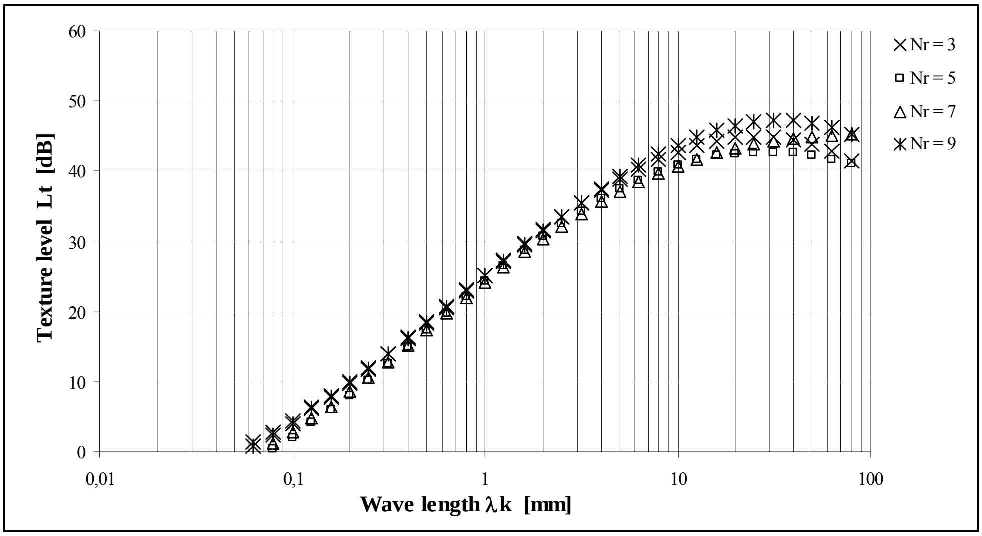

Figure 8 Texture level - Layer thickness t =4 cm

This result is consistent with what was found for the HS and BPN testing, i.e. that the only variable that is able to significantly affect the surface characteristics of the studied mixture is the layer thickness, as shown by the comparison of the texture level as determined for the layer with thickness t = 3 cm with the one for the layer with thickness t = 4 cm.

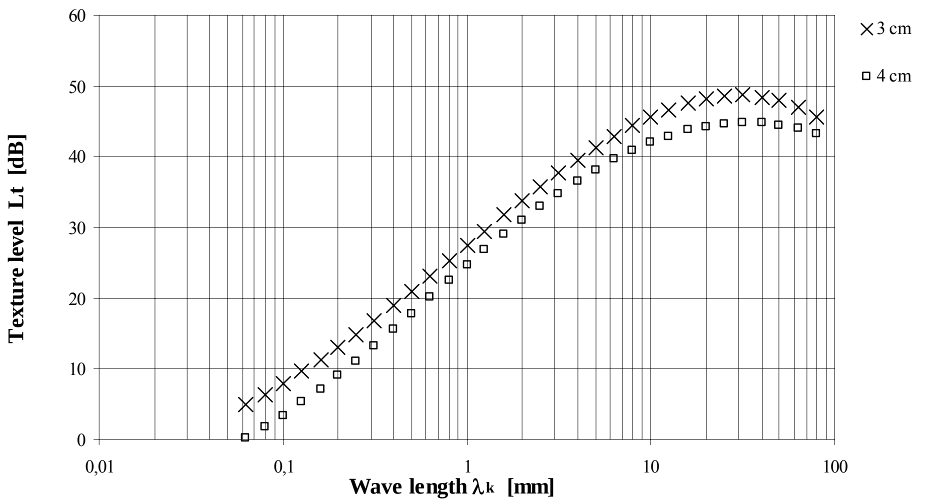

Figure 9 Comparison of the texture levels for the 2 different layer thickness

3.1.2 Determination of the residual air voids contents

The residual air voids content of the compacted mixture was determined on the cores extracted from each measuring point given in Figures 1 and 2, according to the AASHTO Standard TP4 (AASHTO, 1998). For each layer thickness, the measured average values are given in Figure 10 as a function of the number of the passes of the roller, Nr.

It can be seen that for the same mixture when laid in two different final thicknesses, it is possible to achieve different compaction degree, far form each other of about 3 percentage points. An higher value of compaction in situ is achieved by the mixture when laid in a thicker layer (4 cm). Such a result was predictable, considering that the ratio between the layer thickness and the nominal maximum aggregate size (NMAS) of the mixture is, for the layer 3 cm thick, equal to a value of t/NMAS = 3.75, lower than the minimum value as suggested for bituminous mixtures, mainly for those poor in sand and filler such as the one studied in this paper.

A layer thickness that is adequate reference to the maximum size of the aggregate in the mix, besides allowing a slower cooling of the mixture during the laying process, does bring to an appropriate settlement and interlocking of the mineral aggregates during the compaction phase, to advantage of the compaction degree, of the surface characteristics as well as the reduction of permeability of the mixture in place (Brown et al, 2004; AA.V., 2005; Flintsch et al., 2002; Mallick et al, 2003). This is well corroborated by the results that have been found for the mixture of this study, simply considering the differences in terms of surface characteristics as evaluated by testing with the British Pendulum, or with the sand patch method or, again, by analyzing the surface profile with a laser profiler, for the different layer thicknesses.

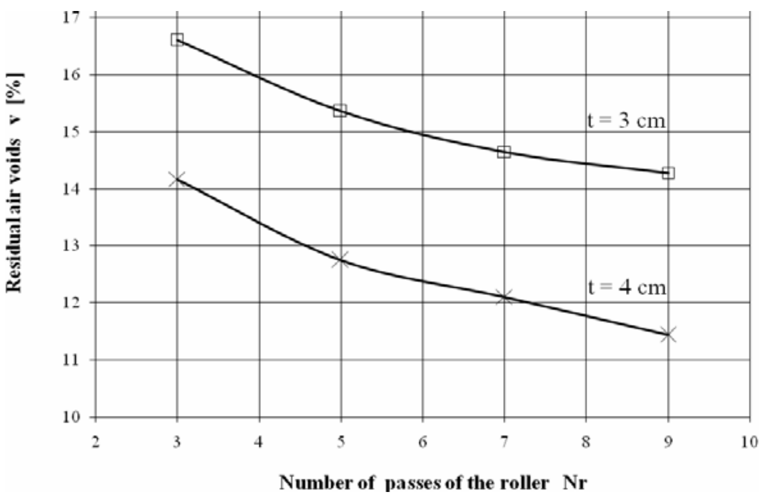

Figure 10 Residual air voids as a function of the number of passes of the roller, for each layer thickness

In order to compare the in situ compaction degree with the one that is predictable in the laboratory, several samples with different final height have been compacted at the Superpave Gyratory Compactor (SGC), by introducing into the mould with D = 150 mm different quantities of mixture, ranging from 2200 g to 6000 g, with a final height of the specimen, when compacted at a constant number of gyration (Ng = 300), ranging from 55 mm to approximately 150 mm.

Also in this study, as in previous ones (Boscaino et al., 2006) , the experimental results do highlight that there is a noticeable difference, in terms of compactability, of the same mixture when compacted at the gyratory in specimens with different height. In detail, the densification curves for the smaller specimens show higher values for the residual air voids content, up to more than 3 percentage points with respect to those calculated for higher specimens.

A comparison between the results of the densification curves obtained in the laboratory with the gyratory press and those measured on site when compacting with a smooth roller in static mode was also carried out. Before doing this, it has been necessary to define the existing correlation, for the specific compaction equipment used on site in this study , between the number of passes of the roller, Nr, applied at the construction site and the number of gyration, Ng, that is necessary in order to achieve the same compaction degree.

According to the Moutier (Moutier, 1982; Moutier et al. 1990), the correlation between the number of passes of the roller, Nr, and the corresponding number of gyrations, Ng, depends on the type of roller as well as on the thickness, t, of the compacted layer, as follows:

$$Ng = K \cdot t \cdot Nr \qquad \text{Eq. 2}$$

Therefore, the coefficient “K” depends on the roller, i.e. on its ability of compacting, that the relation between in situ compaction and gyratory compaction can be set by defining the compaction energy for each layer, with an horizontal affinity between Ng and Nr.

For each layer thickness and each final height of the gyratory samples, it is possible to determine from the densification curves at the gyratory the number of gyrations Ng that allow to gain the same compaction degree obtained by Nr passes of the roller, on site.

For this study, by using the data as collected n situ and those obtained in the laboratory with the gyratory for the studied mixture, a constant value for K was determined, equal to K = 10. Thanks to the Moutier’s correlation given in Equation 2 and the K value determined for the used smooth roller, it is possible to compare the in situ densification curves with those obtained in the lab, as depicted in Figure 11.

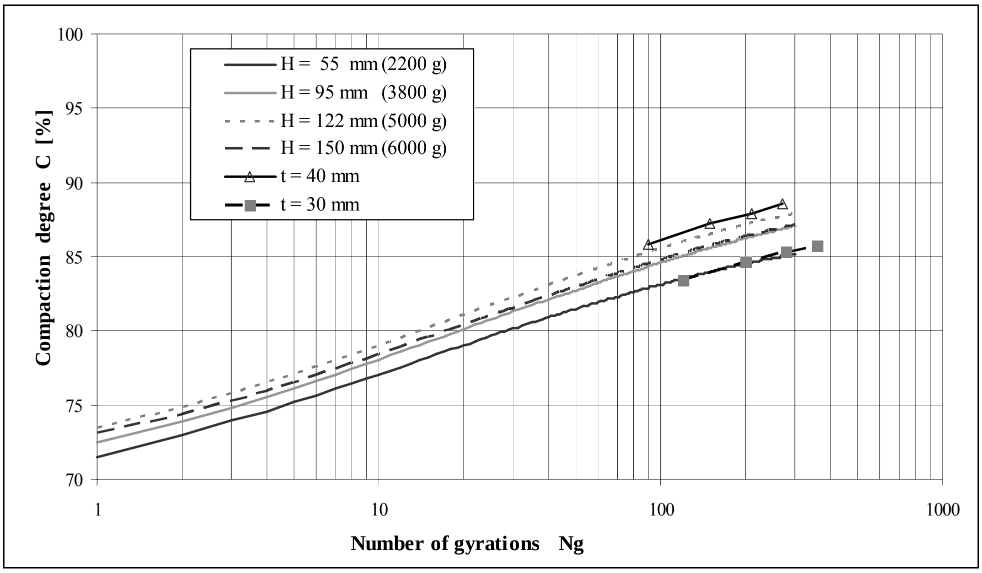

Figure 11 Comparison between the in situ densification curves and those obtained at the gyratory with specimens of different final height

It seems from the previous figure that a gyratory sample of at least 115 mm is necessary for adequately estimate the in situ compaction degree when the mixture is compacted in layers having an appropriate thickness (t/NMAS > 4). For smaller layers, that means for t/NMAS < 4, the better estimation seems to be the one made with gyratory samples compacted at a reduced height (H = 55 mm).

4. CONCLUSIONS

This study aimed to define a methodology that, based on simple and reliable tests carried out both in situ and in the laboratory, allows to predict, during the mix design, the physical and functional characteristics of the mixture as laid on site.

The experimental plan was focused on a bituminous mixture for wearing course used for maintenance work, as available thanks to the Local Road Authority. Therefore, the physical characteristics of this mixture have been determined, for two different final thicknesses (commonly used for this kind of mixture) of the wearing course, with equipments and compaction procedures currently used by the contractors (smooth steel roller in static mode).

The joint analysis of the measured values for BPN and HS provides consistent results:

- the average values calculated for the BPN and the HS for each layer thickness are quite constant, independently on the number of roller passes Nr. It is reasonable to believe that the different number of roller passes is not able to affect the results in terms of BPN and HS and that this kind of results can be considered as dependent on the chosen formula of the mixture and not jeopardized by laying processes. On the contrary, it seems that the layer thickness is slightly able to affect the results in terms of BPN and HS, due to a different settlement of the mineral aggregates on the pavement surface;
- for thicker layers (t/NMAS > 4), there is a better indentation of the aggregates into the surface with the consequent reduction of the pavement macrotexture (lower HS values) together with a wider contact area between the rubber slider of the pendulum and the pavement surface (higher BPN values), when compared to smaller layers (t/NMAS < 4);

The results do also show that there is a noticeable difference, in terms of compactability, of the same mixture when compacted both in situ and at the gyratory in different thicknesses (height). In detail, the densification curves for the smaller specimens show higher values for the residual air voids content, up to more than 3 percentage points with respect to those calculated for higher specimens. The same result is obtained when comparing the degree of compaction of the two layers in situ, being the thicker more compacted that the other one: also in this case the difference was found to be about 3 percentage points.

Such a result was predictable, considering that the low ratio between the layer thickness and the nominal maximum aggregate size of the mixture for the layer with a thickness of 3 cm, lower than the minimum value as suggested for bituminous mixtures, mainly for those poor in sand and filler such as the one studied in this paper.

In addition, by using a correlation as the one suggested by Moutier between the number of passes of roller and the number of gyrations, and determining the coefficient of such a correlation for the case of the smooth roller, it is possible to compare the in situ densification curves with those obtained in the laboratory.

From the data, it seems that a gyratory sample of at least 115 mm is necessary for a correct estimation of the in situ compaction degree, when the mixture is compacted in layers having an appropriate thickness (t/NMAS > 4). For smaller layers, that means for t/NMAS < 4, the better estimation seems to be the one made with gyratory samples compacted at a reduced height (H = 55 mm).

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