DEFINITION AND VALIDATION OF A NEW METHODOLOGICAL APPROACH FOR FRICTION EVALUATIONS OF DROPPED-ON PRODUCTS FOR ROAD MARKINGS

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ABSTRACT

Road safety is well known to rely on a combination of the components man, vehicle and environment. The latter plays an important role through the geometric design of the infrastructure, but the road markings and signs are also highly strategic in reducing accidents, especially in the more unfavourable driving conditions, i.e. night time or when it is raining or foggy. As part of a study on the contribution to road safety of high-visibility road markings with dropped-on materials, a new test protocol has been defined in order to verify the surface friction requirements, at the same time studying which parameter might be most effective and representative of the in situ performances of the products, depending on the maintenance state of the pavement. This has led to the identification of more effective criteria of judgement than those reported in the current European standards (EN 1436:2008).

INTRODUCTION

To ensure driving safety it is essential a good adhesion between tire and pavement, which is related to the interaction between tire contact patch and road surfacing. For this reason, a real time analysis of the wearing course should be carried out, to inform drivers with respect to the state and condition of the pavement and, subsequently, the performance that may occur while driving. In this way, driver's behavior can be programmed, and the driver can handle the reaction of the vehicle as a result of a choice between the possible maneuvers. The information that must be transmitted to the driver are two and regard weather aspects and skid resistance; these information must be received by the driver in a synthetic and clear way, avoiding any form of ambiguity. Crucial is the timely communication of the meaningful variations in the driving (rainfall, fog banks, stormy weather, etc.), when sudden or unexpected. When heavy rains occur, it is essential to know the thickness of the water film interposed between the tread and the road, in order to determine the aquaplaning risk. Concerning the interaction between tire and road, the risks related to the presence of ice or other factors that can compromise gripping must be considered.

During the last few years, numerous research projects have been developed in order to describe the phenomena that determine the skid resistance with respect of pavement condition (ISAP 2001, FDOT 2003, PIARC 1988-2004, NCHRP 2005). More recently, the research has been based on a new point of view, due to the fact that safety does not only depend on physical interaction between vehicle and wearing course, but also on the visual perception of the road. The visibility of the road markings, during the day and in nighttime conditions, and the durability of the relative materials is considered a priority for all the agencies that manage the roads.

The conduct of guide is a choice, the trajectory is its result. This depends on the geometry and the composition of the platform, but today it is particularly tied to the road markings. The vertical signs communicate administrative constraints (prohibition, obligation, prescription) and other indication useful for the driver. The horizontal markings highlight other administrative ties, but also suggest the driving behaviors, indicating which part of the carriageway can be occupied by the vehicle and in which one the trajectory can be developed. At the end, the horizontal markings become the base on which the perspective vision of the road is constructed. This is also the reason why attention is usually focused on the performance characteristics of retroreflection of marking materials and on their duration and visibility.

In order to guarantee driving safety, technical standards have been prepared in order to ensure that the performances of the horizontal markings are certified by rigorous methods of measure and evaluation. The same attention to these topics has found specific evidence in specifications, technical guides and operating manuals.

As mentioned above, it should not be attributed all to an exclusive problem of visibility, based on the optical characteristics of markings. The road markings must stand the test of time, but also must not be an element of discontinuity for the adhesion between wheel and road, in special way for two wheels vehicles. Otherwise vehicle's stability could be compromised and the agency road manager would be responsible for incidental events that occur.

The aspect of gripping between tire and horizontal marking is considered in marginal way. Differently from the phenomenon of visibility, the skid resistance in markings often does not represent a priority goal but a subordinate condition. From the standardization point of view too, it can be observed the deficiency of tests and protocols defined with the aim of its characterization. The reasons of this empty of normative are various. The root cause is the fact that the economy tied to the traffic of two wheel vehicles is still negligible in comparison with the other ways of transport. Consequently also the relevance of the accidents turns out neglected. Actually the problem is more wide, because it concerns the process of production and application of paint materials (Migletz 1994, 2000).

The products are various and mainly covered by the industrial secret. The rules of checking and measuring the performances are fixed through the preliminary phase of the project. At last, times of maintenance are quite short (3 to 6 months in highways and 1 to 2 years in motorways) and render quite difficult planning evaluation tests in a reliable way.

In the U.S.A. the methodologies used to evaluate the performance of markings are reported in the Manual on Uniform Traffic Control Devices (MUTCD, 2009 Part 3). Therefore, in order to assure high performance markings, uniform standards were introduced in all the states. However, for road marking, the aspect of skid resistance is still rather neglected and subordinated to the visibility and perceptive conditions.

In the international field, the Federal Highway Administration (FHWA 1980) and the ASTM (Anderson 1980, ASTM IC 1980) gave a regulation to the question during the 80’s. The main object of the researches was the relationship between paving texture and skid resistance, also in presence of paints. Most recent studies have highlighted the importance of the optical performances of markings to be associated with their surface roughness (Carnaby 2001, Harlow 2005). Transverse variations in the skid resistance can determine variations of friction in the transmission of sideway forces which contribute to reduce the stability of vehicles during breaking or acceleration, also due to vehicle, tire, speed type, etc.

In Europe, the most interesting studies were carried out during 70’s (OECD 1975). A research project proved that differential friction for two wheels vehicles can be very dangerous, because it determines a loss of control, also during the simplest maneuvers. In general terms, later studies also demonstrated, by means of laboratory simulations, that the phenomenon is strongly influenced by speed variations (Richard 1976).

Moreover, for all the combinations of road paint and pavement texture, skid resistance values (i.e. SFC, friction coefficient, etc.) are lower in the markings than in the nearest pavement, especially when the marking has been applied on a surfacing not preliminarily treated. The difference usually grows at increasing speeds. Only at low speeds marking and pavement skid resistance values can be comparable, but it strictly depends on the properties of the two materials.

The effects of road marking on dynamics of accidents are difficult to define. This is mainly due to the bad cataloguing of the crashes, that does not always offer useful information in order to describe the real contribution of the good (or bad) marking to the accident.

In 2007, the Transportation Research Board cited the relation between retroreflection and skid-resistance on wet surfaces, as one of the most important research topics (“Pavement Marking Friction Requirements”, TRB 2007 Needs Statements - AHD55, Signing and Marking Materials). With the objective to reconstruct the functional ties between the variables descriptive of the phenomenon and the measurable properties, some Authors proposed a predictive model of the decay of the optical performances on markings due to variations of the humidity and texture (Lundkvist, 2007).

Today the topic is still controversial and the cues supplied from the international literature are very scarce (New Zealand and Unites States are, among few others, in the forefront, in this regard); this is another sign of a limited consideration against the problem (Pike 2008); surely, the topic of retroreflection has been investigated more widely than the problem of marking skid resistance. Among other things, the researches developed during the last few years have demonstrated that, on the road markings field, skid resistance and optical performances are inversely proportional, so much that TRB suggests the importance to establish a balance between those properties, evidencing the deficiencies of the research.

The Authors carried out some studies during the last years in this field, and evidenced how much nonskid quality and retroreflection optical performances are important for the horizontal markings. Both can be measured with portable instruments, which are also easy and simple to be used. However, the equipments are also distant from representing the real conditions of the pavement, in particular under the aspects of vehicle dynamics and tire-pavement interaction. Nevertheless, simulative systems in real scale do not properly exist.

This is the main reason why, within a new research project based on a new commercial product, the Authors have developed a test procedure alternative to that standardized. In this paper the results of the characterization of the protocol are described. As a consequence of the laboratory study, the road paint has been applied to some rural roads, characterized by a high level of traffic.

After the spreading of the road paints, a periodic monitoring was enforced in compliance with standard specifications (UNI EN 1436-2008). The traditional tests were adapted to the site and a new monitoring protocol was defined and then performed. The aim of the study was to put the attention on the parameters which affect the quality of marking; high relevance was attributed to the redundancy statistics of the controls. It was possible to verify the sensibility of the traditional indices that characterize the road markings.

The perspective of this work concerns the possibility of applying a monitoring procedure in any moment during the service life of markings. Moreover, the protocol that has been introduced can be integrated in the usual maintenance plans.

METHODOLOGY

In order to define a new test methodology it was necessary to make a comparison among the different laboratory equipments. The objective was to check the significance and representativity of the results related to the use of each equipment. In particular, the standard methods used to represent the indices of micro/macro- texture and grip were analyzed.

The measure of macro-texture by means of the Mean Profile Depth (MPD) is performed according to the procedure described in the European Standard EN 13036-1:2010, using the volumetric patch technique. The value of the MPD is the arithmetic mean of the distances measured between the peaks (highest and lowest) of the surface profile. The standard formulation of the MPD's value is shown in Figure 1.

The tests on materials for road markings, the application of road paints on test fields, the parameters to be measured and the frequency of measurement, are all described in the regulation EN 1824:2000. In particular, the index of skid resistance (SRT) was evaluated in accordance with EN 1436:2008.

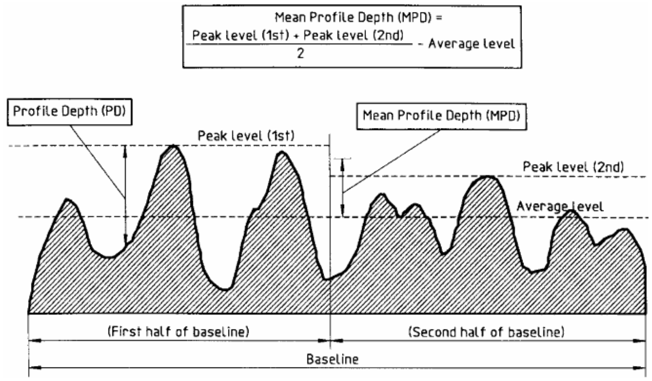


Figure 1: Illustration of the significance of Profile Depth (PD) and Mean Profile Depth (MPD) (EN ISO 13473-1:2004).

The test equipment consists of a pendulum (British Pendulum Tester, RRL no. 27, 1969, Oliver 1980) that has a rubber pad at the free end. The energy loss caused by the interaction between the pad and the road surface is measured. The result is expressed in SRT units. The equipment simulates the performance of a vehicle equipped with tire tread, wheels locked, at a speed of 50 km/h on a wet road surface.

At the beginning, high efficiency instruments were excluded from the comparison, mainly because they relate results to local calibrations, extending the results to conventional parameters. Moreover, a protocol to be applied to current maintenance plans was needed. There are other tools and methodologies, more technologically advanced and accurate (Henry 2000). The choice of simple tests in this case also corresponds to a higher diffusion of the requested equipments in the laboratories.

The methods listed derive from international standards; however, they have been studied for other purposes and considerations. Can not be said that the tests are simulative. However it has been demonstrated that the combination of different indices provides for a comprehensive description of the state of road surfaces (Hassan Khan 1999, Noyce 2007, Lundkvist 2007).

The International Friction Index (IFI) is the index here used to describe the tire-pavement adhesion phenomenon. Reference is made to a model prepared on the basis of the results developed by PIARC in the period 1992-1995 (Yeaman 2005, Ergun 2005, Noyce, 2007). The model considers a reference speed of 60 km/h. It calculates the value of the resulting friction forces F (S), at any speed (S), considering the texture (Sp).

$$F(S) = F_{60} \cdot e^{(\frac{60-S}{S_p})} \qquad \text{Eq. 01}$$

Sp value is calculated using the linear model represented in equation Eq.02, with reference to texture values (MTD).

$$S_p = -11.6 + 113.6 \cdot MTD \qquad \text{Eq. 02}$$

Friction coefficient value (Fv) is calculated using the F60 model presented by the equation Eq. 03, referring to skid resistance (SRT).

$$F_{60} = 0.0436 + 0.0095 \cdot SRT \cdot e^{-\frac{50}{S_p}} \qquad \text{Eq. 03}$$

The available values permit to estimate a value of the Skid Number (SN):

$$SN(V) = (-31 + 1.38 \cdot SRT) \cdot e^{[-0.00456 \cdot S \cdot (MTD)^{-0.47}]} \qquad \text{Eq. 04}$$

DATA COLLECTION

The test protocol here illustrated represents an extension of the European Standards EN 1436 and EN 1824. Figure 2 shows how tests were performed. 8 m long alignments were traced. For every line, nine points were drawn, placed to the distance of 1 meter. In every point the measure was executed, and therefore texture and skid resistance were calculated. The measurement was performed on the paint alignment as well as on the adjacent pavement, at 20 cm from the marking. The mean values were successively calculated.

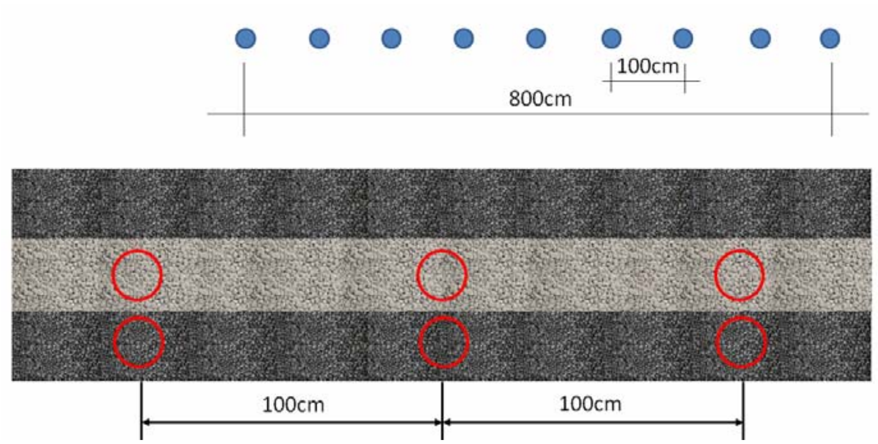


Figure 2: Scheme of test layout and survey application

After the first test, the product was applied along some roads of the road network in a Province of the North-eastern Italy. For this application 16 rural roads were selected, below indicated with letters “A” to “P”. Pavements “B” and “O” had a SMA (Stone Mastic asphalt) surfacing. Pavements “D”, “E”, “F”, “G”, “H”, “K” had a bituminous close graded wearing course, with selected aggregate (basalt, porphyry). The other surfacings were traditional bituminous close graded ones.

In each pavement the same type of paint was applied in both directions. Horizontal markings were applied in stretches for a global 40 km distance; the weather conditions were good. The road layout was characterized by the absence of curves, with the purpose to avoid tangential stresses on the material applied. The alignments were distant from intersections, passages, parking and maneuvering areas.

The surface was preliminarily cleaned with mechanical brushes and prepared for the painting. For this application, the Authors refer to a high visibility paint for road marking. The composition of the painting is covered by trade secret. The liquid matrix is of solvent-based type, solid structure is made of two inert elements: 80% of the weight is a mixture of glass beads with controlled size range; 20% of the weight of solid material is represented by quartz aggregates, normally used for anti-skid surface treatments. The average thickness of paint spread is equal to 300 μm. The spread speed of the paint and the dosage of glass beads and aggregate were defined in a separate test field. This activity permitted to optimize the application. The results described in this paper represent the monitoring of the marking, from its laying and for the duration of 1 year.

DISCUSSION

The mean value of the measurements is reported in Table 1.

In all cases, the paint produces a reduction of skid resistance and of pavement roughness (Figure 3 and 4). This result well matches with data from literature. The presence of solid antiskid material (20% in weight) improves the characteristics of painting gripping, but is not sufficient to increase the values till those of the pavement. The roughness indices present variations between 2 and 30% for macro-texture and 8% and 25% for micro-texture.

Table 1: Mean texture depth (MTD) and skid resistance (SRT) values for road pavement and markings.

Road code	MTD (mm)				SRT			
	Pavement	Marking	Δ	Δ (%)	Pavement	Marking	Δ	Δ (%)
A	0.66	0.58	+0.08	+12.36%	46	42	+4	+8.70%
B	1.28	0.91	+0.38	+29.44%	71	55	+16	+22.54%
C	0.93	0.76	+0.17	+18.56%	47	42	+5	+10.64%
D	0.98	0.72	+0.26	+26.53%	57	49	+8	+14.04%
E	0.82	0.72	+0.09	+11.55%	58	46	+12	+20.69%
F	0.74	0.67	+0.07	+8.98%	58	46	+12	+20.69%
G	0.84	0.72	+0.12	+14.07%	59	48	+11	+18.64%
H	0.74	0.72	+0.02	+2.37%	56	47	+9	+16.07%
I	0.66	0.60	+0.06	+8.51%	47	43	+4	+8.51%
J	0.80	0.74	+0.06	+7.10%	49	41	+8	+16.33%
K	0.60	0.51	+0.09	+15.00%	62	47	+15	+24.19%
L	0.63	0.58	+0.05	+7.94%	50	46	4	+8.00%
M	0.58	0.51	+0.07	+12.07%	49	41	8	+16.33%
N	0.66	0.58	+0.08	+12.12%	46	42	4	+8.70%
O	1.15	0.88	+0.27	+23.48%	71	57	14	+19.72%
P	0.80	0.74	+0.06	+7.50%	49	41	8	+16.33%

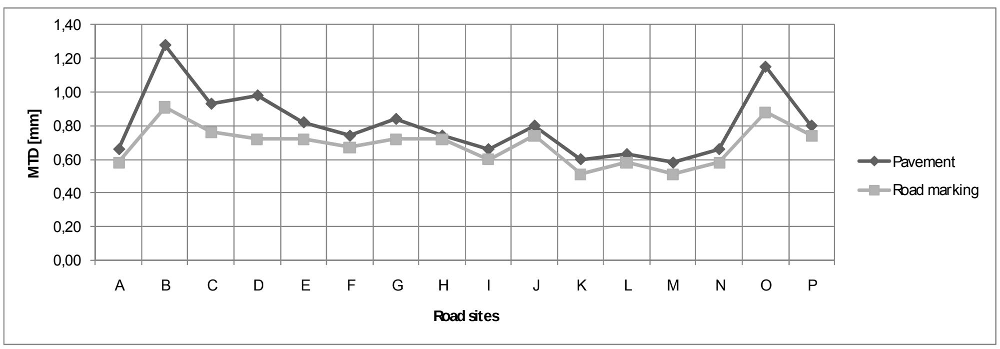


Figure 3: Comparison of MTD values between pavement and road marking.

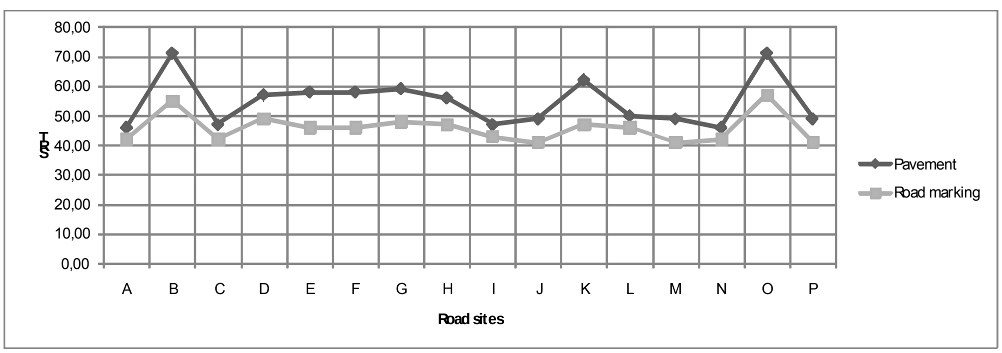


Figure 4: Comparison of SRT values between pavement and road marking.

The relationship between texture and skid resistance values for pavement and marking is similar. Figure 5 shows the standardized values of MTDn and SRTn measured on the road marking and the adjacent pavement. The normalization of values is calculated with reference to the average value μ(MTD) and μ(SRT), in order to bring out a not-dimensional representation. Both surfaces (pavement and marking) show similar tendencies.

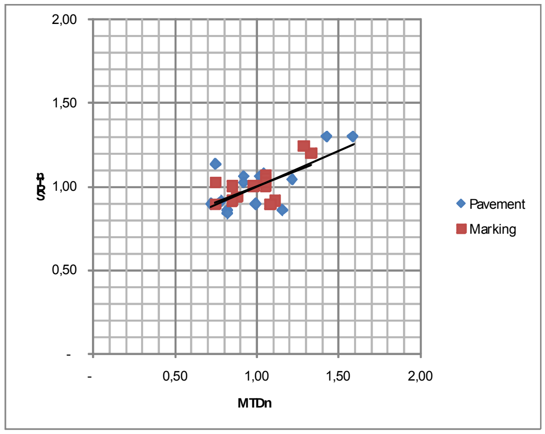


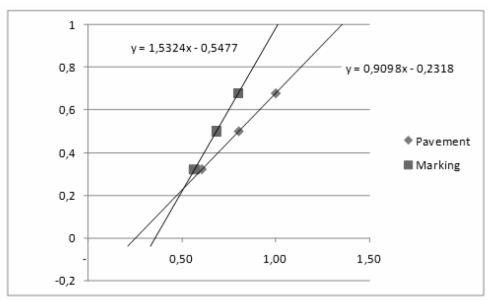
Figure 5: Texture and skid resistance indices (MTD and SRT), normalized to the average value.

There is also a statistical affinity; the Criterion of Chauvenet doesn't highlight outliner data inside the population of values. With regard to texture indices (MTD), the distribution of measurements shows an average value of 0.80 mm (SD = 0.02) for the wearing course, and 0.68 mm (SD = 0.01) for the road marking. The two ways F-test shows a value of 2.83 for F(p = 0.026) while Fcrit is 2.40. STR values are more variable than MTD ones. The SRT mean value is equal to 54.7 (SD = 8.25) for the pavement, while is equal to 45.8 (SD = 4.82) for the marking. The statistical analysis produces F(p = 0.022) value of 2.93, while Fcrit is still 2.40.

The Gaussian distribution was associated to mean μ and variance σ values. Values corresponding to the percentiles of the central portion of the (μ-σ:0.68, μ:0.50, μ+σ:0.32) were determined. The ratio R=MTDp/MTDm was also calculated (Figure 6).

MTD

	Pavement	Marking	F	R
μ+3σ	1.40	1.04		0,74
μ+σ	1.00	0.80	0.68	0.80
μ	**0.80**	**0.68**	**0.50**	**0.85**
μ−σ	0.61	0.57	0.32	0.93
μ−3σ	0.21	0.33		1.57



SRT

	Pavement	Marking	F	R
μ+3σ	79.4	60.3		0.76
μ+σ	62.9	50.6	0.68	0.80
μ	**54.7**	**45.8**	**0.50**	**0.84**
μ−σ	46.4	41.0	0.32	0.88
μ−3σ	29.9	31.4		1.05

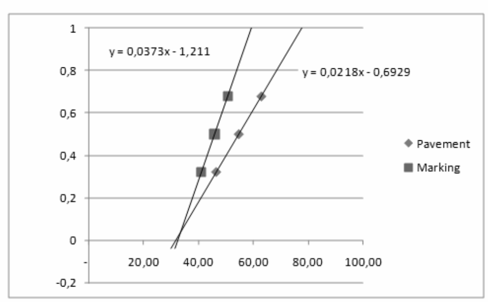


Figure 6: Comparison between texture and skid-resistance indices (MTD and SRT) and R ratio values.

In consequence of this analysis, 25% (i.e. 0.25) was considered as the normal R threshold. In fact, at the same operative and technical conditions, referring to (□+3□), road marking parameters (MTD and SRT) showed low probability to have values lower than 75% of the same parameters' values in the adjacent unpainted surfacing. With reference to (□), the threshold can be set at 15% (0.15). In this case, the minor skid resistance in the road marking can be accepted (the R ratio is higher than 0.85).

Starting from this point, the selection protocol was applied to the different pavement values, with the aim to observe which had to be rejected (Figure 7). Only 4 cases (roads “B”, “C”, “D” and “O”) showed values registered on the marking below the 15% threshold. With regards to the measurements of skid resistance (Figure 8), results rejected are 6 (“B”, “E”, “F”, “G”, “K”, “O”), while 3 of them are borderline (“H”, “J”, “P”), but still compatible with the threshold.

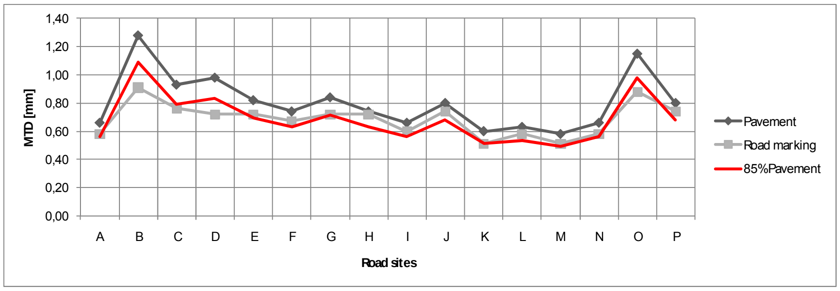


Figure 7: Mean texture depth for markings and road pavement and relationship with pavement 85% MTD value

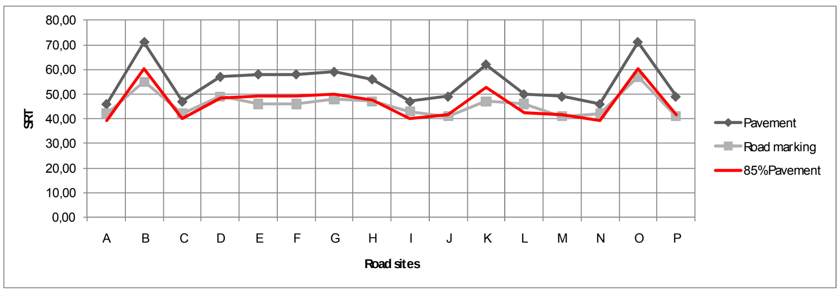


Figure 8: Skid resistance for markings and road pavement and relationship with pavement 85% SRT value.

IFI and SN values were calculated according to the standards. The operating speed was equal to 50 km/h (Table 2).

Table 2: Friction coefficients for road pavement and markings at 50 km/h.

Road Code	Side Friction Coefficient (reference speed: 50 km/h)			
	Skid Number		International Friction Index	
	Pavement	Marking	Pavement	Marking
A	0.22	0.18	0.28	0.24
B	0.45	0.30	0.55	0.39
C	0.21	0.16	0.34	0.28
D	0.32	0.25	0.41	0.31
E	0.34	0.21	0.39	0.30
F	0.35	0.22	0.37	0.29
G	0.35	0.23	0.40	0.31
H	0.32	0.22	0.36	0.30
I	0.23	0.19	0.29	0.25
J	0.24	0.15	0.33	0.27
K	0.41	0.24	0.34	0.24
L	0.26	0.22	0.30	0.26
M	0.26	0.17	0.28	0.22
N	0.22	0.18	0.28	0.24
O	0.46	0.32	0.53	0.39
P	0.24	0.15	0.33	0.27

With regards to the statistic analysis, the Skid Number (SN50) distribution shows an average value of 0.305 (SD = 0.083) for the paving and of 0.212 (SD = 0.05) for the road markings. The F-test gives a value of F (p = 0.027) of 2.80 (Fcrit= 2.40). International Friction Index (IFI) has an average value equal to 0.361 (SD = 0,082), while the marking has 0.285 (SD = 0.049). The 85% threshold of acceptance must be compared with the thresholds established in literature (Kuttesch 2004). This value is fixed and is 0.20, for both the IFI and SN values. 0.20 is the minimuml level of acceptance and it is equivalent to SRT= 45 and MTD= 0.4. With reference to a speed of 50 km/h, the threshold value should have been equal to 0.21

Figures 9 show the relationship between the indexes of pavement and horizontal markings. This representation confirms the previous evaluations: the two populations are well correlated and maintain a high degree of affinity for both indices.

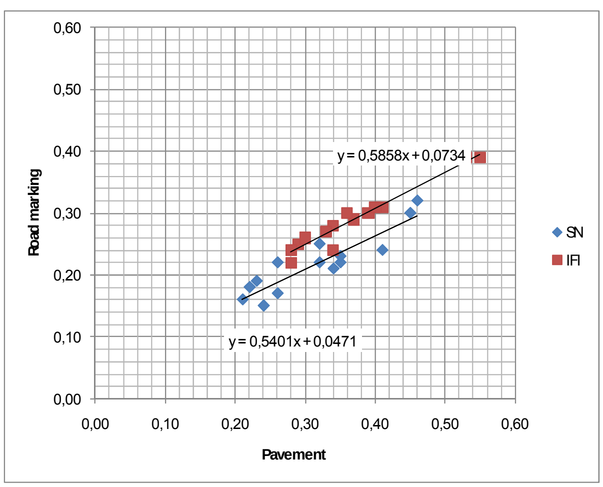


Figure 9: Skid Number and IFIr. Comparison between pavement and painting values.

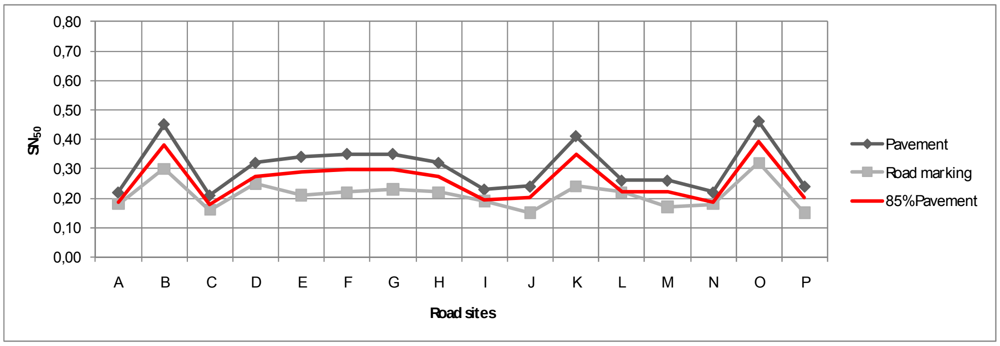


Figure 10: Skid Number. Comparison between pavement and painting values.

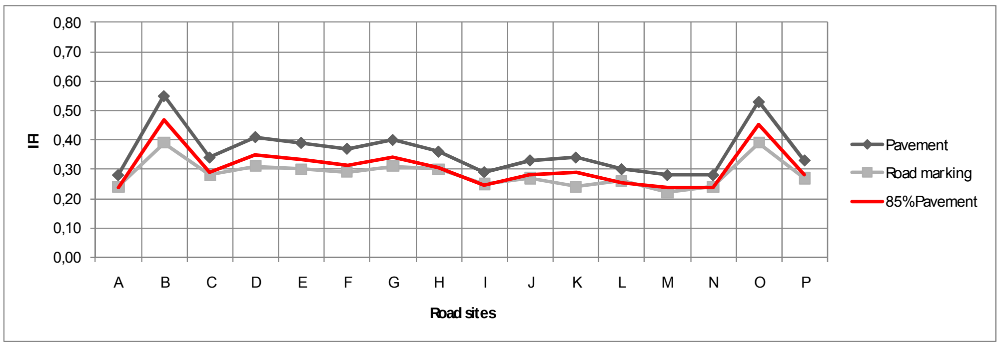


Figure 11: International friction Index. Comparison between pavement and painting values.

The indices can be calculated for any speed. In particular, it is interesting to check the methodology for the maximum speed value. The speed, in Italy, on rural roads is limited to 70 km/h. The result of this calculation, both for IFI and SN values, is evidenced in Table 3. In this case the threshold derives from SRT value equal to 45 and MTD value equal to 0.40. The threshold for a speed of 70 km/h determines a value of 0.19.

Table 3: Friction coefficients for road pavement and markings at 70 km/h.

Side Friction Coefficient (reference speed: 70 km/h)				
Road Code	Skid Number		International Friction Index	
	Pavement	Marking	Pavement	Marking
A	0.18	0.14	0.21	0.17
B	0.37	0.25	0.47	0.31
C	0.17	0.13	0.28	0.22
D	0.26	0.20	0.34	0.24
E	0.29	0.17	0.30	0.22
F	0.30	0.18	0.28	0.21
G	0.30	0.19	0.31	0.23
H	0.28	0.18	0.27	0.23
I	0.19	0.15	0.21	0.18
J	0.20	0.12	0.26	0.21
K	0.36	0.20	0.24	0.16
L	0.22	0.19	0.21	0.18
M	0.22	0.14	0.19	0.14
N	0.18	0.14	0.21	0.17
O	0.39	0.27	0.45	0.31
P	0.20	0.12	0.26	0.21

It can be observed that the distribution of characteristic values of the pavement in the roads “C”, “I”, “J”, “N” and “P” is out of range, lower than the value threshold. Roads “L” and “M” are instead near the acceptance limit (SN = 0.20). This result confirms that, in the current context, the traditional criterion is affected from a partial incongruity (PIARC 1992-1995).

CONCLUSION

In this paper a methodology for the evaluation of in situ performances of road marking has been introduced. First of all, the inadequacy of single measurements according with the European standards has been stressed. In fact, this procedure has been abandoned and tests were performed on an alignment, with the purpose to reduce the fluctuations of results related to the selection of the site and casual events.

The road paints appear to get worse the condition of the pavement from a texture and a skid resistance point of view, in spite of the presence of non skid aggregate. It is mainly depending on pavement condition (Pasetto 2008). The aim of the study was, therefore, the formulation of paintings suitable for satisfying both requirements (skid resistance and retroreflection), without compromise the durability.

By means an experimental activity concerning a new high visibility painting for road markings, a test protocol was defined, based on two common indices: MTD and SRT. The choice was based on the purpose of applying indices that can determined with diffuse equipments. Statistical analysis was used to support the study.

Macro-texture of road paints was compared with the same parameter measured on the pavements. The latter influences the morphology of the paint film, because of its roughness. The saturation effect depends on the characteristics of the support, as well as the thickness of paint. Thresholds of potential saturation must be established, which represent the conditions (depending on statistical analysis) beyond pavement’s texture has to be taken into account. In fact, when a gripping problem depends on a saturation defect, it is related with the original texture of the wearing course and not with the painting formulation.

In conclusion, the research puts also in evidence the relevance of the wearing course’s quality in relation to road marking performances, highlighting the importance of macrotexture and microtexture of the surfacing, not only for safety, but also for a correct functional role of markings applied.

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