Study on the effect of surface texture saturation of road pavements with drop on road markings

Marco Pasetto
Andrea Manganaro

University of Padova
Construction and Transport Dept.
Via Marzolo, 9 - 35131 Padova (Italy)
Phone +39 049 8275569
Fax +39 049 8275577
E-mail: marco.pasetto@unipd.it
E-mail: andrea.manganaro@dic.unipd.it

ABSTRACT

Road markings contribute greatly towards improving road safety standards. For some time now, manufacturers, researchers and road management authorities have been interested in the development of high-performance products in terms of durability, night-time retroreflection, visibility in wet conditions and more recently, skid resistance.
To meet these functional requisites, the latest generation of products for road markings often contain mixtures of glass beads and aggregates, of varying quantities and types, which in many cases involves an appreciable alteration of the skid resistance parameters of road pavements (MTD, PTV), due to the partial saturation of the road surface micro- and macro-texture.
This paper reports the results of intensive road monitoring of products with drop on materials for road marking, during which the characteristic road texture parameters were measured and compared, of both asphalt pavement and markings, using the most common international indexes (SFC, SN, IFI) to obtain the specific skid resistance coefficients for each of them. Crossed comparison of the different parameters determined the effect of saturation of the road pavement surface texture caused by the presence of road markings with drop on materials, and also evaluated the decline of performance in terms of skid resistance.

1. INTRODUCTION

Road markings play an extremely important role in road safety. Their main contribution to safety is the reaching of assigned performance standards in terms of visibility (night-time retroflection in particular) and surface adhesion. In order to meet these requirements, different types of paint-based products (solvent-based, water-based or heat-hardened) are currently available on the market, to which mixtures of beads are added that are dropped on or pre-mixed (to improve visibility), often with the addition of quartz or ceramic antiskid granules (to improve the surface skid resistance characteristics).

In recent years, the University of Padova has been supervising the development, both in the laboratory and on the road, of a new product for road markings - a solvent-based paint with drop on beads. This has provided important information on the performance characteristics in situ and the methods of verification. In particular, the study of the performance requisites of the product in situ has allowed not only innovative test protocols to be developed compared to those in European Standard EN 1436:2003, but also to verify if and how the application of the products for road markings can modify the surface texture characteristics of the road pavements. More specifically, starting from the skid resistance requisites certified for the product applied within the ambits of the laboratory tests, the performance in situ of the product was tested not only from the point of view of friction, but also to evaluate any alterations it might cause to the natural texture of the road surface. These deliberations were extended to the macro-texture by the acquisition of the Mean Texture Depth (MTD) with the sand patch method. Once the parameters of micro-texture/Skid Resistance (SRT) and macro-texture (MTD) had been acquired, it was possible to calculate the more common coefficients of transverse adhesion (SFC, IFI) using some well-established formulas reported in the literature. The experiments conducted and subsequent data analyses allowed a numerical evaluation of the impact of the studied product for drop on road markings on the surface texture of road pavements.

2. METHODS

In recent years, the University of Padova has been supervising the design and development stages of a new product for road markings composed of solvent-based paint with dropped-on beads and antiskid granules - in proportions of 80% and 20% in weight respectively – on a depth of wet paint of 300 μm. After a first experimental phase in the laboratory, based on tests of skid resistance, retroreflection and repeated cycles of accelerated abrasion, the optimised product was applied along the road network of an important Province in north-east Italy. Following these applications, the University of Padova conducted tests to verify the performances in situ, in terms of both retroreflection and skid resistance, according to the European Standard EN 1436:2003. The surveys were also extended to the determination of the surface macro-texture according to European Standard EN 1824:1998. A specific experimental protocol was defined for this, developing on the European regulations, which is represented in the geometric configuration in figure 1: in each study context a test alignment was identified 8 m in length in a longitudinal direction along the line. The values of skid resistance were determined using a portable pendulum tester every 1 m along the alignment, for a total of 9 point values. At each measuring point, the SRT (Skid Resistance Test) value was acquired of the line and of the asphalt road pavement on which the product was applied. The reference skid resistance value (of the line and pavement) derives from the arithmetical average of the 9 point values. The macro-texture was determined using the Sand Patch Method in correspondence to points 1, 5 and 9 of the alignment, both on the markings and on the pavement. Also in this case, the reference value of MTD corresponds to the arithmetical average of the values acquired singly. The decision to conduct the tests along an alignment instead of in a single point – as implicitly provided for in the European Standards – derives from repeated observations of the extreme variability of parameters along the line, which – depending on the cases – may differ by up to 20% between two successive measurement points. In order to reduce these uncertainties statistically it was decided to adopt a test alignment of a significant length (8 m), with enough measurement points to give a sufficiently reliable representation of the effective functional state of the markings in the survey point.

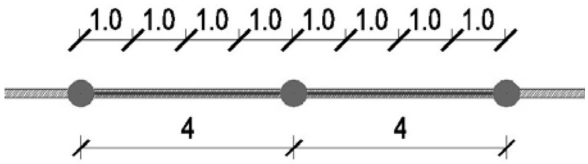

Figure 1. Test geometry

The data were gathered at different points along 16 extra-urban roads, on exclusively straight stretches in order to ensure the best application conditions and maximum homogeneity of the product along the entire length of the alignment. The stretches considered for the tests were identified in a remote position with respect to intersections, access roads and manoeuvring areas (or car parks) in order to also eliminate any disturbance effect caused by the transit of vehicles in a transverse direction to the line at concentrated points.

3. DATA COLLECTION

The experimental campaign was conducted during spring-summer 2007, in sunny weather and with air temperatures of between 20 and 30 °C. The surveys were done on the product for road markings 12 months after its application. The values of skid resistance (SRT) determined in correspondence to each point of the alignments were firstly corrected as a function of the temperature, as provided for in European Standard EN 1436:2003, and then aggregated by reduction to the arithmetical average in order to describe the functional state of the alignment with a single parameter. The same procedure was used for the measurements of skid resistance of the road pavement.

The macro-texture measurements were conducted on just three points of the single alignment, using the Sand Patch Method. These three values were then averaged to give a single representative value for the alignment. The same criterion was adopted for both the line and the pavement. When surveys were done on more than one alignment on the same road, the average value of the parameters of the single alignments was considered representative if the difference between them was no higher than 10% in absolute value. If the differences between the values determined in different alignments were higher than 10%, a choice was made on the basis of other objective criteria linked to the functional state of the road surface: the existence of external factors influencing the result of the tests and state of the markings (e.g., abrasion of the road-edge lines by granular material from the verge) and the presence of elements (other than vehicle traffic, naturally) that could potentially alter the natural state of the markings, such as heavy farm or gritting machinery.

The results of the surveys conducted on the 16 roads are reported in table 1.

Road code	MTD [mm]				SRT [-]			
	Pavement	Marking	Δ	$\Delta_{p/m}$ (%)	Pavement	Marking	Δ	$\Delta_{p/m}$ (%)
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

Table 1. Parameters of micro-texture and macro-texture on the 16 surveyed roads.

The simple statistical calculations reported in the table demonstrate the following:

- the average abatement of the macro-texture (measured by the parameter MTD) is generally around 10% in absolute value with respect to that of the road surface. Higher percentage incidences (roads B, D and O) are associated to surface macro-texture values of the road pavement of more than one millimetre;
- the effect of the markings on the lowering of the skid resistance properties is on average between 15% and 20% in absolute value on the reference value of the road surface. Incidences of less than10% were observed on road surfaces with an SRT typically less than or equal to 50, on which the application of the markings evidently had minimal or insignificant effects.

Figure 2 highlights an interesting aspect, i.e. that even with a high reduction percentage (of between 25% and 30%), the value of MTD measured on the markings on rougher road surfaces (B, D and O) remains significantly high and generally above that measured on the other test surfaces. It can therefore be concluded that on road surfaces with high macro-texture the applied product causes a higher abatement in relative terms (percentage) with respect to the reference value, but the values of residual macro-texture remain entirely satisfactory and adequate for traffic safety. The reason for such a significant saturation effect is the natural tendency for the segregation of the paint in the surface hollows: consequently, with more accentuated roughness, there is a greater propensity of the paint to fall into the voids rather than evenly cover the surface of application.

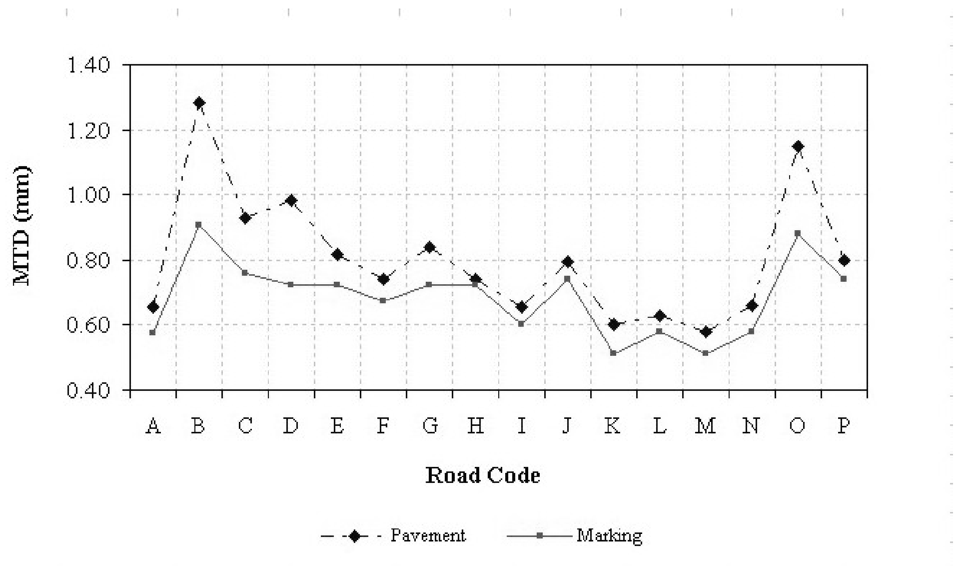

Figure 2. Comparison between the macro-texture values of the pavement and markings.

As the value of MTD of the road surface decreases, there is a reduction in the abatement percentage caused by the markings on the macro-texture, but one which contributes significantly to a worsening of the general conditions of surface texture of the pavement. This is because it is drawing closer to the lower limit of acceptability of the MTD for road safety (especially given the speed limit on the studied roads, set at 70 km/h by the Italian Highway Code). In other words, it is certainly less hazardous “to lose” 0.30 mm in macro-texture starting from an MTD of 1.20 mm (-25%) than 0.10 mm starting from 0.60 mm (-16%). The diagram reported in figure 2, compared with the data in table 1, clearly shows the absolute and relative magnitude of the reductions measured in the different cases.

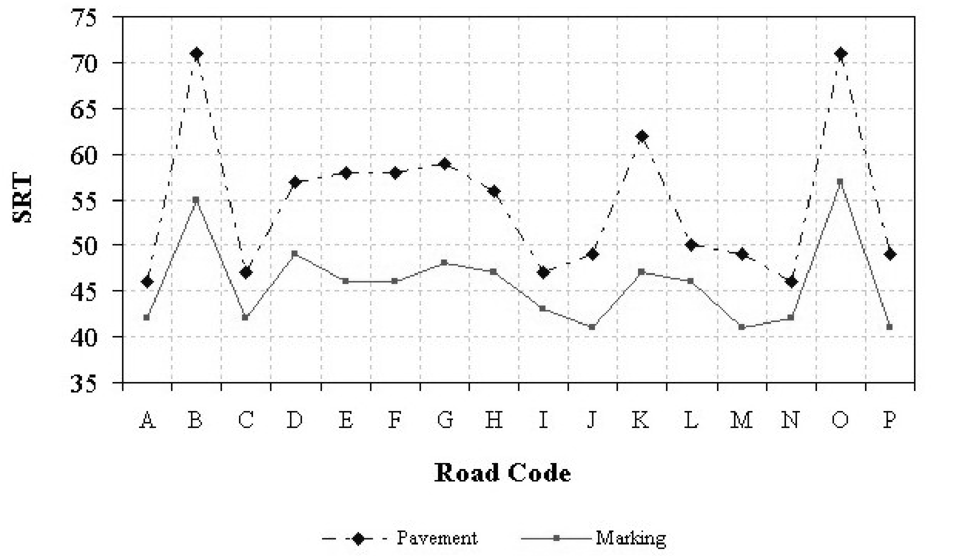

Figure 3. Comparison between the micro-texture values of the pavement and markings.

In terms of the skid resistance, there are two contrasting trends: the first is characteristic of the road surfaces with relatively low SRT in value absolute, typically below 50; the second is characteristic of the surfaces with higher SRT, with typical values of above 55 to more than 70. In the former case, the abatement caused by the application of the markings is modest, both in absolute (ΔSRT = 4-5) and percentage value (< 10%). Having excluded that the product might have properties that improve the natural micro-texture of the road surface (despite the presence of the antiskid aggregates in the drop-on mixture), it is evident that, on very smooth road pavements with poor adhesion characteristics, the impact of the markings is minimal, or at least does not worsen the functional characteristics of the road surface, on which it tends to align (if always on lower performance levels).

On the contrary, on road surfaces with good micro-texture levels, with SRT of above 55, there is an increase of the abatement in both absolute and percentage value. The reason is obviously the inevitable covering of the surface texture of the road by the paint and drop on beads. An inhibitory effect of the micro-surface texture of the pavement is to be expected and is not by chance partly compensated for, at least that is the intention, by the presence of the antiskid granules (quartz or ceramic) in the drop-on mixture applied on the surface of the markings. Starting from entirely adequate values of skid resistance, two very different circumstances can be observed: in the first case, with initial values above 70 (roads of code B and O) there is also an acceptable SRT on the line (SRT = 55-57), despite an abatement of more than 15 SRT units (-20%); in the second case (more frequent) there is a very different trend, in which, with initial values of above 55 (roads of code E, F, G, H, K), SRT < 50 are measured on the line, with reductions not only relevant in percentage value (-20%) but also in absolute value, with an obvious destabilising of the initial micro-texture conditions of the road surface.

The former situation (relevant percentage abatements but acceptable in absolute value) was limited to just two cases out of 16, characterised by road surfaces with high surface macro-texture. In the majority of cases, on the contrary, there was an opposite trend, i.e., that of a substantial abatement of the micro-texture that varied in absolute and percentage value with the varying of the surface of application, but with SRT values of the markings typically within the variability range 40 < SRT < 50. In other words, the studied product for markings appears to take almost all the road surfaces to a skid resistance level below 50 SRT units, with the exception of those with very high SRT and MTD values.

4. DISCUSSION

The above considerations suggested the possibility of interpreting the two parameters of texture determined experimentally in an integrated way instead of separately. This is justified not only by the experimental evidence but also by the most consolidated theories on road adhesion, which recognise that it is the combined action of the micro-texture and macro-texture that make the real contribution to road safety, especially at vehicle speeds above 50 km/h. This is why, starting from the values determined within the ambits of the experimental campaign, an attempt was made to construct empirical equations that could formulate the relationships between macro-texture and skid resistance of both the pavement and the markings. Lastly, starting from the indirect indexes of texture SRT and MTD, the most commonly-used indexes of adhesion (SFC, SN, IFI) were calculated with the help of empirical equations available in the literature (Pasetto, 1998 and 2006; De Luca, 2006).

A first consideration derives from the overlaying of the experimental diagrams relative to the SRT and MTD of the surfaces examined in the previous section. Indeed, figure 4 confirms the assumption made above referring to the two roads of code B and O: in these cases, a very accentuated macro-texture of the road surface corresponds to a net divarication between the SRT values of the pavement and the markings, even if the latter remain above the level usually assumed as the minimum of acceptability. However, it should be said that roads B and O are notable for their good texture characteristics in terms of both SRT (> 70) and MTD (> 1.10 mm). Instead, for the other roads with good surface macro-texture (C and D), these considerations are not valid because of the concurrent presence of not excellent values of SRT (47 and 57, respectively). With respect to the initial hypothesis, it can certainly be concluded that there is no direct dependence between macro-texture of the pavement and micro-texture of the markings, as the general trend of the two parameters is almost always coherent (as the MTD increases, so does the SRT of the markings, independently of the original micro-texture value). Moreover, the indications provided by cases B and O lead to the presumption that the presence of accentuated macro-texture – if associated with a good micro-texture of the road surface – may in some way be synonymous with a good performance of the markings in terms of residual skid resistance, even if in the presence of important impact differentials. In these cases, the abatement of macro-texture by the markings is not insignificant, even if it is acceptable because of the good initial values of the parameter. Case D partly confirms this, whereas case C does not comply. However, according to the general trend of the MTD and SRT of the markings represented in figure 4, it is clear that case C is a special case because of the low initial SRT value (with an MTD = 0.93 mm), with respect to which the contribution of the markings is not very significant in terms of a more general understanding of the phenomenon.

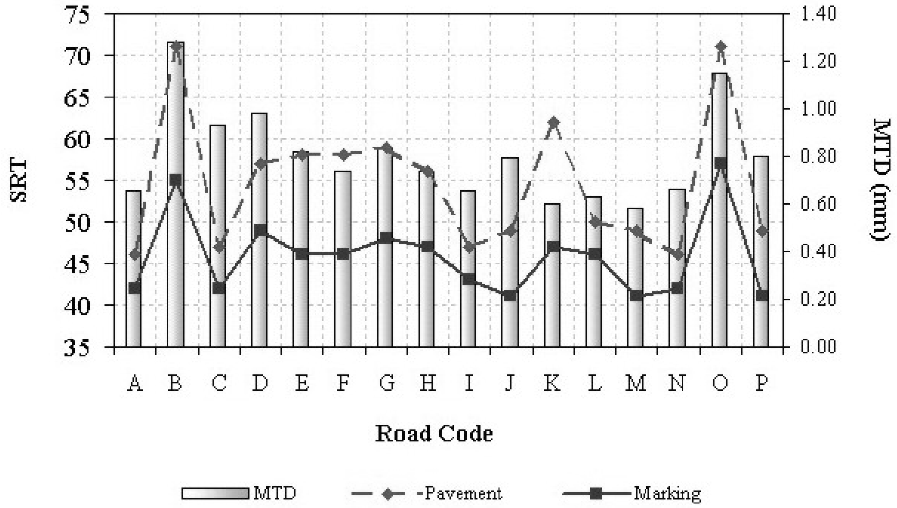

Figure 4. Comparison between SRT and MTD of the tested surfaces.

A second way of looking at the experimental data is represented in figure 5, in which the differences are compared between SRT of the road surface and of the markings depending on the macro-texture of the asphalt pavement on which the product was applied. Apart from a few cases – mentioned below – a substantial trend emerges towards an increase in the divarication between the two SRT values as the road surface macro-texture increases. In general lines, the phenomenon could be explained by the fact that typically a more accentuated macro-texture corresponds to bituminous mixes with larger aggregates and improved mechanical performances compared to traditional asphalts. Consequently, it is acceptable to associate increasing values of MTD with correspondingly high values of SRT, referring to the conditions already observed for the cases of the roads B and O. Indeed, if the markings stand out for having characteristic SRT values of skid resistance of between 40 and 50, it is obvious that as the SRT value of the pavement rises (likely associated to the increase of MTD) the divarication between the two will widen. The obvious exception is in the cases where there is a high MTD with inadequate SRT, usually descriptors of a state of imperfect maintenance of the pavement and therefore not reliable from the point of view of a general analysis of the question. In fact, when pavements are degraded, or are affected by imperfections and/or surface stripping, apparently adequate values of macro-texture can be measured, which corresponds to a non-representative judgement of the effective functional state of the surface. The cross-checking of this value with the SRT value of the same test context expresses the real textural quality of the products in situ very faithfully. The cases of the test surfaces with values of MTD of 0.63 mm, 0.66 mm and 0.93 mm should be read in this way.

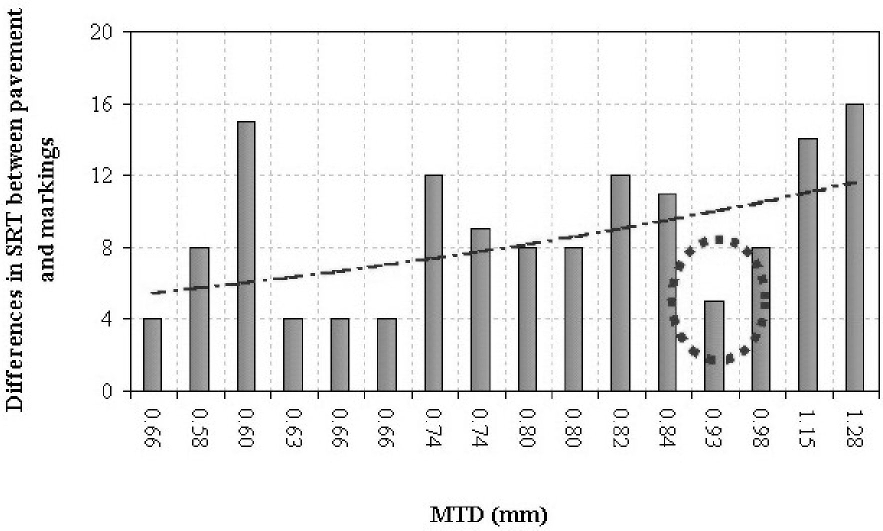

Figure 5. Differences of SRT as a function of the MTD of the test surfaces.

For an effective evaluation of the loss of adhesion on road surfaces caused by the road markings, it is not possible to exclude appropriate indexes (or coefficients) that take into account the synergic action of the micro-texture and macro-texture in the performance of the forces involved in the vehicle movement. A further step was therefore taken with respect to the European Standards for the functional verification of products for road markings by introducing the concept of "loss of adhesion" in global terms, weighting separately the contributions of the macro-texture - through the MTD index, according to Standard EN 1824:1998 – and micro-texture – through the SRT index, according to Standard EN 1436:2003 – using empirical-analytical formulas for the more common indexes of adhesion described in the literature. More specifically, determinations were made of the Sideway Force Coefficient (SFC) according to two different formulations (De Luca, 2006), the Skid Number (SN) (Pasetto, 1998) and the International Friction Index IFI updated to the measurements of micro-texture and macro-texture with the British Pendulum Test and the Sand Patch Method, respectively (Pasetto, 2006). An example of these elaborations is reported in table 2, referring to the case of the surface J, with

MTD = 0.80 mm and SRT = 49 on the road and 41 on the line. A calculation speed of 50 km/h was assumed to satisfy the hypotheses on which the equations utilised were constructed.

	FRICTION PARAMETERS @ 50 Km/h [-]			
	SFC (1)	SFC (2)	SN	IFI
Road Pavement	0.26	0.30	0.24	0.33
Road Marking	0.20	0.23	0.15	0.27
Differences [-]	0.06	0.07	0.09	0.06
Loss in friction [%]	24.55	24.44	35.93	17.00

Table 2. Example of calculation of the loss in friction for the road surface “J”.

For each of the test surfaces, the “loss in friction” caused by the road-marking product was therefore determined according to four different formulations of the coefficient of transverse friction of the road pavement, depending on the micro-texture (SRT) and macro-texture (MTD). The results of these elaborations are reported fully in table 3 and then represented graphically in the diagram in figure 6, for each of the road surfaces. The calculated values show, among other things, the different sensitivity of the formulas adopted as a function of the assigned parameters. In particular, SN is highly sensitive to small variations of SRT to which it is correlated linearly (the contribution of the MTD is exponential and weak), whereas the IFI is sensitive, but less so, to the two SFCs, even if generally aligned with them. The formulas for calculating the two SFC are linearly correlated with both the SRT and MTD, but with different weights.

Road Code	LOSS IN FRICTION [%]			
	SFC (1)	SFC (2)	SN	IFI
A	15.35	15.00	18.64	14.33
B	31.55	31.15	32.94	29.56
C	19.07	18.60	21.79	16.84
D	23.01	22.46	22.48	23.64
E	29.22	29.06	37.75	22.80
F	29.12	28.97	37.90	21.91
G	26.65	26.44	32.93	22.25
H	22.25	22.24	31.08	14.87
I	14.20	13.96	18.43	11.84
J	24.50	24.39	35.99	16.83
K	34.26	33.94	40.93%	29.20%
L	12.90	12.69	15.98	11.42
M	26.16	25.79	34.11	20.65
O	27.28	26.97	29.13	25.73
P	24.55	24.44	35.93	17.00
Average	24.00	23.74	29.73	19.93
Stand. Deviation	6.33	6.34	8.16	5.77

Table 3. Percentage loss in friction on the different test surfaces.

The greater potential of the last elaborations conducted consists of the ability to express a concise judgement on the loss of adhesion caused by the presence of the road markings on the road surface, according to the texture differentials determined with the British Pendulum Test and Sand Patch Method. In particular, a comparison between the diagram reported in figure 6 with those describing the impact on the micro-texture (figure 2) and macro-texture (figure 3) confirms the greater propensity of the aggregated indexes to describe the phenomenon, for at least two reasons:

1) the adhesion (and, therefore, loss of adhesion) depends on the combined action of the micro-texture (measured by the SRT) and macro-texture (measured by the MTD), so it is restrictive to express a judgement on just one of the parameters (as in European Standard EN 1436:2003), or anyway to express a separate judgement on the two contributions;
2) the independent analysis of the two texture indexes often leads to ambiguous situations in which the quality of one of the two is compromised or disqualified by negative judgements of the other without it being possible to establish to what extent this reflects on the real reduction in road safety.

Recourse to the evaluations of percentage impact on adhesion through the saturation of the texture has allowed the effective incidence of the markings on the pre-existing textural state of the road surfaces to be estimated in a varying proportion of between 15-20%, only occasionally above this and for specific reasons, as described in the previous sections.

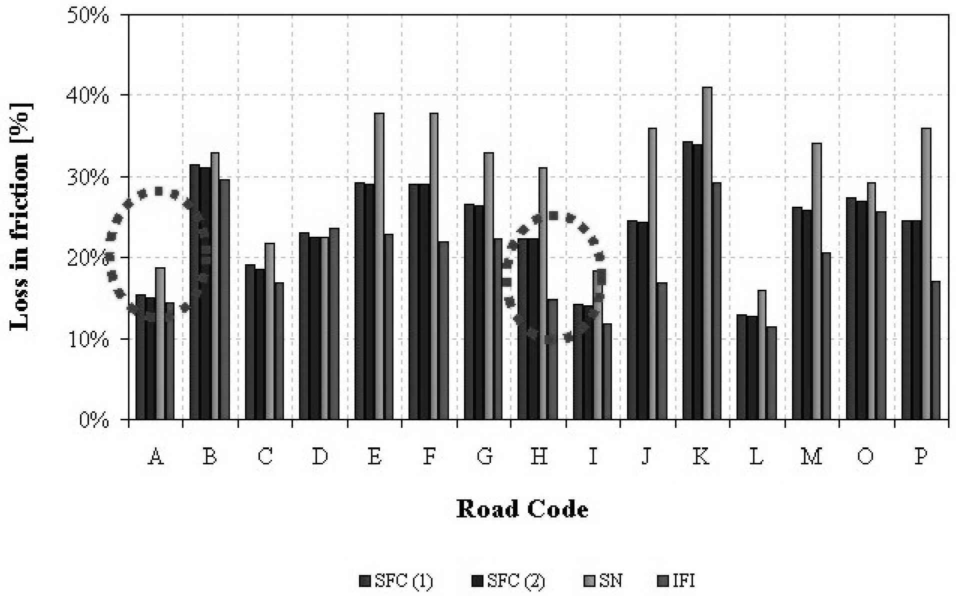

Figure 6. Comparison between losses in friction calculated for the different test surfaces.

5. CONCLUSIONS

The application of road markings on roads inevitably causes a saturation of the original texture, with the consequent alteration of the surface characteristics of the road in terms of adhesion and drainage. The European Standards on the subject of verifying the in situ performance of products for road markings (EN 1436:2003 and EN 1824:1998) provide for the measurement of the indexes of micro-texture and macro-texture of the products, ignoring the need for a direct comparison with the original characteristic parameters of the surface of application (indicating that, in some cases, the road markings should actually improve the pre-existing state of the pavement!), for which there is no evaluation of impact.

Within the ambits of the in situ monitoring of a product for road markings, consisting of a solvent-based paint with drop on glass beads and quartz antiskid granules, the research group of the University of Padova conducted texture measurements on the markings and on the road surfaces on which they were applied, following an experimental protocol based on the European Standards. The results obtained led to the following conclusions:

a. There is no direct correlation between macro-texture of the surface of application and micro-texture of the markings as there is a weak affinity between the two parameters. The relationship appears to be closer between the MTD of the pavement and the SRT of the markings, rather than between the SRT of the pavement and markings;
b. there is a weak linear correlation between the macro-texture of the road surface and the divarication of SRT between the road pavement and the markings, justified by the fact that a higher MTD usually tends to correspond to materials (aggregates) of higher quality that have an influence in raising the SRT value of the road surface, with a value of SRT of the markings generally comprised between 40 and 50 (weakly dependent on the MTD, as mentioned in the previous point);
c. on roads with an averagely-rough surface (MTD = 0.60-0.70 mm), the impact of the markings on the texture is on average in the order of 10-15% with respect to the initial value. The effect of abatement of the SRT is highly variable and depends, among other things, on the MTD;
d. the cross-checking of the separate indexes of texture is affected by strong limitations, so – despite the greater immediacy of determination and representation – is not retained sufficiently representative of the effective impact on the overall adhesion.

Recourse to the analytical determination of the indexes (or coefficients) of transverse friction, using well-established formulas available in the literature, corresponds better to the objective of a concise judgement of the real impact of the markings on the texture of the surface of application. Depending on the surfaces investigated, and according to the different relative weight attributed by the formulas to the two indirect indexes of micro-texture (SRT) and macro-texture (MTD), a percentage impact on the original adhesion varying between 15% and 20% was estimated, only occasionally higher than this in the presence of unusual circumstances (peaks of MTD, wide divarication of SRT between pavement and markings).

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