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A study on texture and acoustic properties of cold laid microsurfacings

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Abstract

Slurry microsurfacing is an economical maintenance intervention that provides effective skid resistance and surface evenness in a thin layer, thus improving the road safety. Researchers aimed to develop an innovative application of slurry seal, capable of gathering in a single material some technical solutions for various functional and environmental aspects. The purposes of this intervention are: restoring skid resistance, sealing surface cracking, reducing tire/pavement noise, adding crumb rubber from tires as a recycling material and reducing atmospheric emissions using the cold technique. A 3D laser scanner device has been used to evaluate the surface texture and analyze the roughness parameters.

Keywords: Bituminous microsurfacing, acoustic properties, 3D Laser scanner, texture.

1. Introduction

This study aim was to develop a slurry seal microsurfacings which, in addition to skid resistance and roughness characteristics, would provide acoustic features for reducing the effects of sound generation and sound enhancement mechanisms. At the same time, with the use of recycled crumb rubber and the cold laying technique, the mixtures have been given eco-compatibility characteristics: the reduction of direct and indirect emissions – traffic queues and delays - at production and laying. Although the amount of crumb rubber used in the mixture is relatively small, it provides a significant contribution to the volumes disposed in other way and, at the same time, the cold technique excludes externalities caused by the hot fumes.

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The use of porphyritic aggregates adds reddish colouring to the pavement, improving its aesthetic features and making it become particularly suitable for urban areas.
The experimentation has been divided into different steps:

- pre-qualification of the materials and the mix design in laboratory to find out the mixtures with the best mechanical performances;
- in situ tests to assess the skid resistance performances, the texture and the noise features of the existing pavements;
- laying of selected mixtures and the repetition of in situ tests, allowing to assess the effectiveness of these slurries by comparing the tests carried out before and after paving [1].

All these steps are explained in detail in the following sections, beginning with the mix design stage.

2. Mix Design

Various bituminous mixtures for cold microsurfacings have been tested in laboratory conditions: they contained porphyry and basalt aggregates and a fraction of crumb rubber equal to 1.5 % on the mixture weight. Then, they were mixed with Portland cement, water and 60% bitumen emulsion modified with latex.

The bituminous mixtures have been studied by varying the aggregates type and gradation, rubber and binder content. The gradation parameters have been varied by modifying the maximum size of the coarser fraction limited to 8 mm and the particle size distribution to have it as discontinuous as possible. The mixture stiffness has been varied by calibrating the volumetric content of rubber and the percentage of cement and residual bitumen.

To achieve the best mix design two aspects have been tested: the minimum content of basaltic sand fraction necessary for the development of the asphalt concrete consistency and the minimum bitumen amount to balance the lower affinity of crumb rubber with bitumen, compared to the porphyritic and basalt aggregates.

The mix design for multi-purpose microsurfacings has been started from the analysis of the characteristics of the traditional basaltic-made asphalt concrete. The slurry breaking time, the characteristics of consistency and the quality of the aggregate bituminous coating have been analyzed for each mixture.

After the definition of the gradation curves by determining the best dosage of the compounds, four mixtures have been selected for the in-situ application: one with only basaltic aggregates (KmodBB), one with basaltic sand and porphyritic aggregate (KmodBP) and the same two mixtures, where a part of the sand fraction has been replaced by crumb rubber (KmodBBp and KmodBPp).

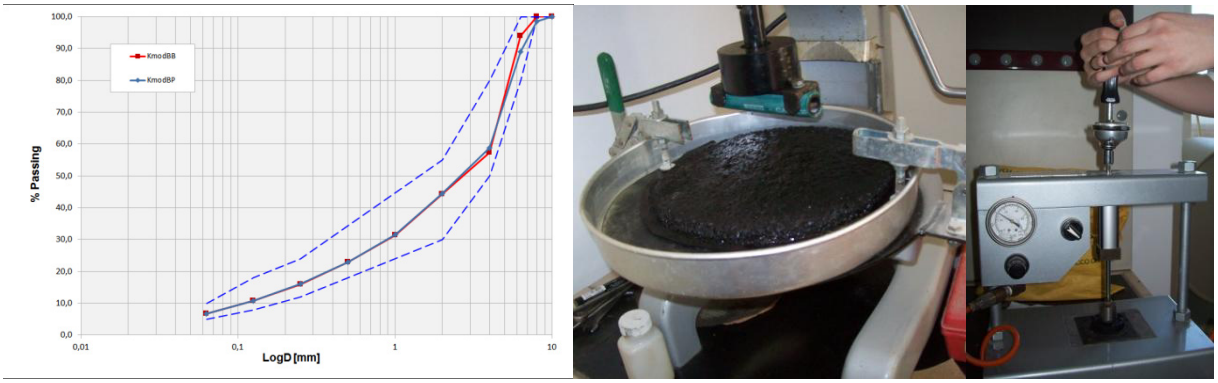

Fig. 1. (a) gradation curves for porphyritic (KmodBP) and basalt (KmodBB) mixtures; (b) wet track abrasion test; (c) cohesion test

In Figure 1 a discontinuity located between 3 and 6 mm can be observed in the KmodBB and KmodBP mixtures: in previous experimentations on micro-porous asphalt it has been noticed that a discontinuity in the aggregate distribution is related to acoustic features [2]. The dotted lines in the graph represent the reference gradation curves. Removing a coarse aggregate fraction creates a small discontinuity in the gradation curve, which may give a contribution to the acoustic performances, as it increases the surface roughness.

Porphyry has a lower affinity to bitumen than basalt: therefore, mixtures with coarse porphyritic aggregates have required 1% more emulsion, compared to the mixtures with only basaltic aggregates, in order to satisfy these first tests. The same happens with the mixtures with crumb rubber, where a 14% of emulsion is required, compared to the 12% in mixtures with only basalt and to the 13% in mixtures with basaltic and porphyritic aggregates.

The four selected mixtures, as defined in Table 1, provided the best performances to the preliminary laboratory tests: in particular, they provided the same initial setting time, equal to 5 minutes, a very good evaluation to the consistency test (International Slurry Surfacing Association – ISSA TB-102) and an aggregate covering which can be visually evaluated as a percentage of 100% in the mixtures of only basaltic aggregates and of 75% in the basaltic and porphyritic mixtures. Although the consistency test is highly depending on the manual ability of the executer, it provides in a quick and simple way a first indication about the strength of the mixture and about the affinity between the bitumen and the aggregate. Both values indicate a satisfactory mix design.

The verification of traffic opening time, measured according to the ISSA TB-102 standard, has been recorded after 40 minutes and it attests the possibility of using all the mixtures when a fast intervention is required, so that it does not cause excessive impacts on local traffic.

Table 1. Characteristics of the four selected mixtures with 1 % of cement and 7 % of water on aggregate weight. The nominal size range of the aggregate fractions is specified (e.g. 0/3 mm)

	% 0/3 mm basalt	% 4/8 mm basalt	% 4/8 mm porphyry	% crumb rubber on mix weight	% emulsion on aggregate weight	Breaking time [s]	Adhesion starting time [min]
KmodBB	50	50	0	0	12.0	195	5'
KmodBBp	47	50	0	1.5	14.0	215	5'
KmodBP	50	0	50	0	13.0	195	5'
KmodBPp	47	0	50	1.5	14.0	195	5'

For the physical and geometrical properties of the aggregates, some tests have been carried out to determine the Sand Equivalent Test (ES) (UNI EN 933-8), the Methylene Blue Test for fines (MB) (UNI EN 933-9) and the Los Angeles Test (LA) for the determination of the resistance to fragmentation (UNI EN 1097-2).

The VB test was performed only on fine basaltic aggregate, since it is the same for all mixtures, with a result equal to 3.3 g/kg. The ES test, performed on the fine basaltic aggregate as well, has returned an average percentage rate equal to 67.3%. The LA test, finally, gave a weight loss of 18% for basaltic aggregate and 20% for the porphyritic one.

Other tests have been carried out in order to characterize the bituminous slurry and to select the mixtures with the best physical-mechanical performances: these are the Cohesion Test (UNI EN 12274-4 and ISSA TB-139) and the Wet Track Abrasion Test (UNI EN 12274-5 and ISSA TB-100) (Figure 1). The results of the Cohesion Test on the mixture specimens show that all the tested specimen returned positive results, showing a strong cohesion to the surface torsion force. The Wet Track Abrasion Test results attest that for all the mixtures the values are below the maximum acceptable limit, which is established by the ISSA standard as 538 g/m^2. In particular, values of about 220 g/m^2 were recorded, with the exception of the sole mixture with porphyritic and basaltic aggregate, which provided a value of about 380 g/m^2. Bounding condition were not assessed [3].

3. Track field and in situ tests pre and post paving

In order to assess the durability and the effectiveness in time of the materials in service conditions, three stretches of roads around Bologna were used as experimental sites with different geometric and traffic characteristics:

- IV November street in Crespellano, about 180 m long: it is between 5.45 and 5.75 m wide, with two lanes, one for each direction. The pavement surface appears homogeneous, with some transverse cracking, crossing the entire pavement section;
- E. Nardi street in Ozzano dell'Emilia: it is about 245 m long and 9 m wide, with a single carriageway with one lane in each direction, with sidewalks on both sides. Patching can be observed along the stretch of road.
- N°4 "Galliera" Province Road (Province of Bologna) which crosses San Giorgio di Piano: it is about 500 m long and between 7.30 and 7.50 m wide. The road has two lanes, one for each direction and quite a high traffic flow, as it is a major transport link to Bologna.

The laying of the multi-purpose microsurfacings has been realized according to the conventional technique. A specific dispenser of the mixer-spreader machine has been used to include crumb rubber into the mixture. In each site a double layer has been laid, first a basaltic microsurfacing 0/4 mm to regularize the existing pavement surface, then a multi-purpose microsurfacing 0/8 mm selected with the aforementioned mix design.

In each site a single aggregate mixture has been prepared and crumb rubber was added in one of the two lanes. Thus the effect of crumb rubber was analyzed with equivalent external conditions: same laying and climate. In the road stretch of San Giorgio di Piano basaltic mixtures KmodBB and KmodBBp have been used, whereas in Crespellano and Ozzano dell'Emilia basalt and porphyry mixtures KmodBP/KmodBPp have been laid (Figure 2).

Before and after the placement of the multi-purpose microsurfacings, a series of in situ tests have been carried out to assess the characteristics of skid-resistance of the existing pavements and the road noise.

Fig. 2. (a) microsurfacing laid in Crespellano; (b) in San Giorgio di Piano; (c) in Ozzano dell'Emilia

Some standard tests have been carried out in order to characterize the pavement performances: the surface patch technique (HS, Sand Height) to measure the average surface macrotexture (CNR 94/83, UNI EN 13036-1), the British Pendulum Number Tests (BPN or PTV, Pendulum Test Value) (CNR 105/85, UNI EN 13036-4) to measure the surface slip/skid resistance and, finally, the measurement of the influence of road surfaces on traffic noise and their acoustic performances with the Statistical Pass-By Method (SPBI, UNI EN ISO 11819-1).

After the microsurfacings have been laid, a series of in situ surveys was carried out to characterize the road surface texture by means of a high-precision laser scanner device. The system used in this work is produced by the NextEngine and is based on the Multi-stripe Laser Triangulation (MLT) technology (Desktop 3D), capable of recording the three-dimensional representation of the surface texture of a portion of pavement.

The BPN and HS tests were performed in 10 longitudinally-equidistant road sections for both directions, in order to cover the whole road stretch, while two road areas per lane close to the Sound Level Meter have been laser scanned (Figure 3).

The Statistical Pass-By Method (UNI EN ISO 11819-1) was chosen, as it is one of the most reliable and representative of the actual perception of road noise by receptors located close to the transportation infrastructure [4]. It can be applied on a statistically significant sample of passing-by road vehicles, related to its category and to the number of passages. The method involves the noise measurement due to the transit of each vehicle registered by a sound level meter, placed at the road side, 7.5 m away from the lane axis and 1.2 m above the ground.

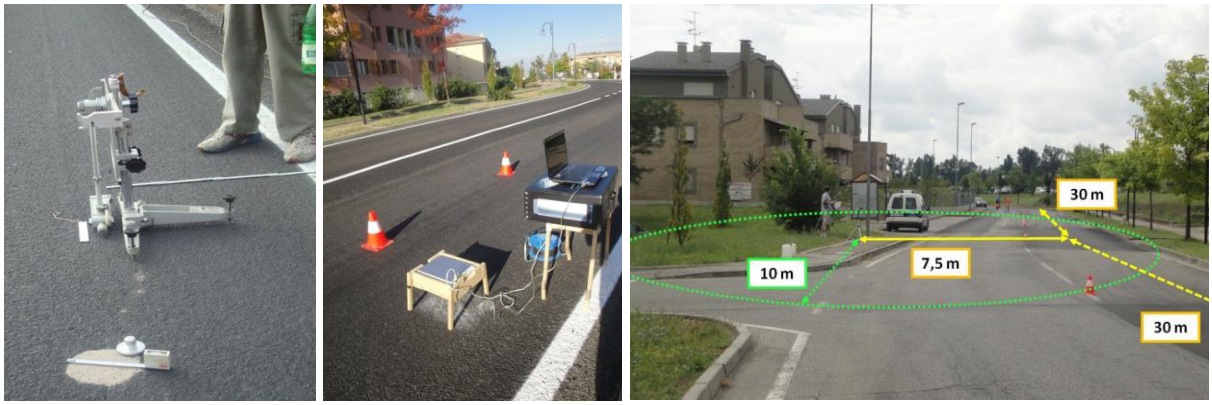

Fig. 3. (a) skid resistance; (b) laser Scanner; (c) acoustic tests

The Sound Level Meter records the noise peak when each vehicle passes by: the peak is measured as a A-weighted sound pressure level. Therefore, the sound level meter shall be placed in a straight, flat stretch of road and in an area without sound reflecting obstacles. Moreover, the background noise shall be negligible compared to the sound peak at the time of the vehicle passage. According to the UNI ISO 11819-1, in an urban area at least 100 cars and 80 trucks (30 dual axes and 30 multi-axes) are required, passing by with a speed ranging between 45 and 64 km/h. In order to comply with the standard requirements, a specific vehicular sequence has been set in addition to the existing road traffic. The same vehicular sequence, composed by both light and heavy vehicles, has been used in each site. Speeds were set by on-board cruise control devices and in San Giorgio di Piano their reliability has been confirmed by means of a speedometer, placed on the centreline of each lane. Each vehicle of the sequence passed by the Sound Level Meter with a speed included in the specified range, avoiding speedups and decelerations in the 30 meters before and after the device.

4. Skid resistance and texture analysis

One month after the opening to vehicular traffic, acoustic and surface tests have been carried out according to the methods previously described. The obtained results have been compared before and after the paving process, assuming the same operating and testing conditions.

Table 2. Pre and post laying: skid resistance tests

Index	Crespellano		Ozzano dell'Emilia		San Giorgio di Piano	
	KmodBP	KmodBPp	KmodBP	KmodBPp	KmodBB	KmodBBp
BPN pre	57.3	60.0	54.1	55.1	60.7	55.0
BPN post	72.5	71.5	70.7	61.9	67.1	68.4
HS pre	0.59	0.55	0.78	0.75	0.53	0.45
HS post	0.93	0.97	0.85	0.89	0.98	1.01

As for the skid-resistance results, by a simple comparison between the pre and post paving data for all the three sites, it is evident how the pavements have undergone an increase in values of BPN and HS with the application of the proposed microsurfacings (Table 2).

For what concerning the texture studies, for each of the 3 experimental sites, 4 sample areas have been identified. These are divided into 2 per lane on the zones having the highest probability to be part of the wheel trajectories (Figure 4). In literature 2 approaches for the acquisition through geomatics techniques can be found: the first is image based and the second one is range based (by distance measurements) [5]. The adopted method belongs to the second type and is based on the use of a triangulating laser scanner. This measures, in a suitable reference system, the coordinates of all the points in which, under the instrument specifications, it is possible to discretize the targeted surface. The results consist of a point cloud of three-dimensional points. Applying triangulation algorithms to the point cloud, it is possible to turn it into a continuous digital copy of the real surface, called mesh. The instrument is easily transportable and can be used both in laboratory and on site. The operational mode chosen for the survey, among the two available ones, is the one called "Macro". To the Macro mode corresponds an accuracy of 0.127 mm on the measured coordinates, a field of view of 13x10 cm on the object and an operating distance from the pavement of about 20 cm.

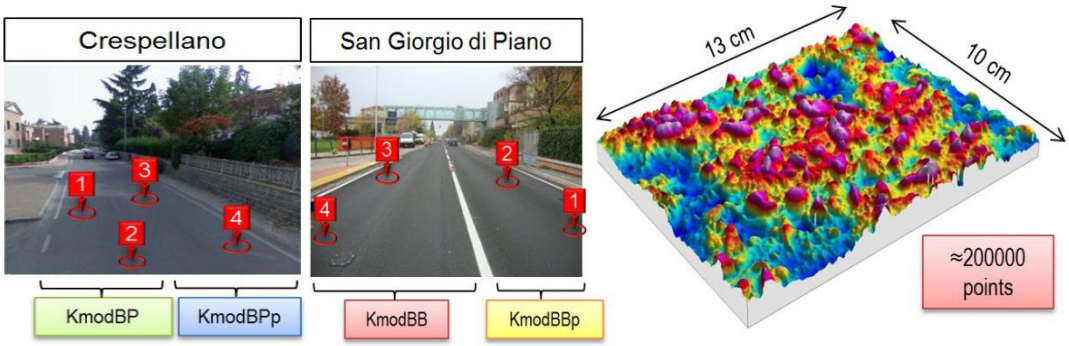

Fig. 4. (a) scan positions along the site of Crespellano; (b) in San Giorgio di Piano; (c) an example of the acquired 3D representation

Previous works have shown the possibility to calculate indicators on profiles through the laser technique [6]. Punctual indicators, such as the highest "peak" or the deepest "valley", either calculated on the entire scanned portion or on different profiles in which the area can be divided, should be considered with low representativeness because they are affected from the singularities of the road surface. The representativeness of these indicators may increase only if calculated over a large number of profiles.

The results of the texture study are presented below and are related to two of the three sites on the basis of the different aggregates included in the mixtures: San Giorgio di Piano and Crespellano.

For the two analyzed sites, Table 3 accounts some indicators with the classical 2D approach (ISO 13473-2), calculated with this type of laser scanner, and their respective 3D counterparts. The Mean Profile Depth (MPD) index is the result of an average of two points on a single profile; R_a (roughness) is given by the ratio between the area and the length of each profile, calculated on 9 profiles. Other indexes are the Skewness (R_{sk}) and the Kurtosis (R_{ku}) calculated on profiles as required by the same standard. The values reported on the table are averaged between the two scans of the same lane in order to represent a single reference parameter for each material used. By means of laser scanner it is possible to extend the 2D approach to an upper level, by calculating the indexes not just on profiles, but considering the entire 3D scan data too. In Table 3 these indexes are characterized by the prefix "S", which means "surface".

The values of the indexes calculated as the average among 9 profiles, and those calculated on the entire scan, practically coincide; moreover, the 3D parameters have the advantage of being calculated faster than the ones retrieved from profiles. MPD is the average value of profile depth by considering two points and averaged on 9 sections. Given a sufficient number of sections, the obtained MPD value should be less affected from errors due to singularities in the scans. As these first data have proved to be reliable, an experimentation is being carried out in order to make a comparison between data measured both by a profilometer and the adopted laser scanner.

Comparing two lanes of the same site, the values do not differ significantly in Crespellano and San Giorgio di Piano. This aspect is an evidence of the homogeneity of the maximum peak heights in the pavement surface. By analyzing the values of MPD, the maximum heights have been recognized in San Giorgio di Piano, probably due to the minor aggregate loss after the laying of the full basalt mixture.

Table 3. Texture indexes: results from the 2D and the 3D approach

	Index	Crespellano		San Giorgio di Piano	
		KmodBP (1&2)	KmodBPp (3&4)	KmodBB (3&4)	KmodBBp (1&2)
2D	MPD [mm]	1.06	1.05	1.24	1.27
	R_a [mm]	0.42	0.45	0.48	0.57
	R_{sk}	0.03	-0.46	0.14	-0.15
	R_{ku}	3.09	3.31	2.99	2.41
3D	S_a [mm]	0.47	0.49	0.52	0.60
	S_{sk}	0.05	-0.48	0.15	-0.13
	S_{ku}	4.01	3.25	2.98	2.81

The roughness of the pavement, expressed by "R_a" (ratio area/line) and "S_a" (volume/area) parameters, appears to be higher in San Giorgio di Piano, as confirmed by the MPD results. The statistical Skewness (R_{sk}) and Kurtosis (R_{ku}) indexes express respectively the asymmetry of the distribution roughness curve, and the flattening index of the surface profile. In both pavements the R_{sk} index is close to 0: thus the distribution of peaks and valleys in the texture is symmetric. The Kurtosis index can be lower, greater or equal to 3. If the value of the index is greater than 3, the distribution curve is leptokurtic, so more pointed; moreover, the texture is to be considered less uneven. On the contrary, a value less than 3 indicates a platykurtic curve with a flattened shape, index of an uneven texture. In the examined sites both the materials KmodBB and KmodBBp in San Giorgio di Piano have an index lower than 3, in spite of Crespellano, where there is a discontinuity between the two lanes and the values range up to 4 for KmodBP.

Surfaces with S_{ku} values higher than 3 show lower values of MPD, S_a, and R_a: this fact renders the sparse presence of large aggregates, which causes smoothing of the texture. According to the previous indexes, the site

of San Giorgio di Piano, with the full basalt mixture, turns out to have hypothetically the largest surface in contact with the tires.

A more detailed study on the contact between the tire and the pavement surface can be carried out developing the 3D laser data. By these data it is possible to represent a digital model of the surface texture: it allows evaluating the variations of the emerged area in relation to the water volume held in the pavement surface air voids.

The water layer is assumed to rise up uniformly on the scanned section. Considering that layer as a planar section secant to the scanned area, it is possible to plot a specific graph as shown in Figure 5. By considering the scans for each site, it is possible to identify an area which expresses the material surface behaviour in the presence of water. The blue region is the sum of the four curves of KmodBP and KmodBPp mixtures, whereas the red one refers to KmodBB and KmodBBp. In both cases, the mixtures with crumb rubber are located in the lower part of the region.

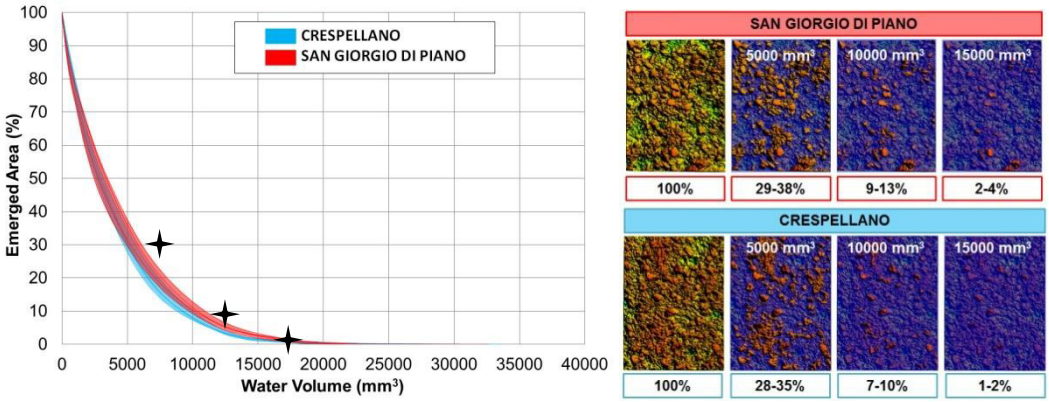

Fig. 5. (a) emerged area related to the water volume for both sites; (b) different percentages of emerged areas are presented for different constant volumes of water (0, 5000, 10000 and 15000 mm^3)

The graph can be read in two ways: the first allows to calculate the amount of water that can be stored by a given percentage of emerged area. The second way, allows to know which pavement presents the higher percentage of emerged area in contact with the tire, with a constant volume of water.

In San Giorgio di Piano, the emerged area percentage is always higher than in Crespellano. Assuming a stable water flow condition, in San Giorgio di Piano the surface road pavement provides a greater road water storage than in Crespellano and a larger tire/pavement contact area. This higher percentage of emerged areas in basaltic mixtures, instead of the basaltic and porphyritic ones, was expected as a greater roughness was previously encountered.

In order to better evaluate the advantages of the three-dimensional data, other indicators have been adopted. According to the ISO 25178, the collected data have been used to calculate areal and volumetric parameters for a better classification of the pavement texture components (peaks, valleys and the core roughness profile) through the construction of the Abbott curves. As it is defined in the standard and shown in Figure 6, the parameters S_{pk}, S_{vk} and S_k have been calculated trough the mentioned curves for the entire scanned area.

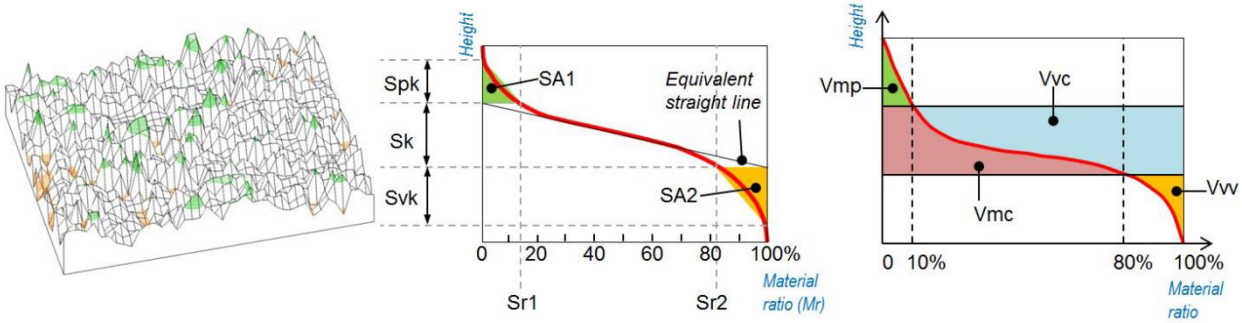

Fig. 6. (a) 3D representation; (b) the Abbott curves and their related areal parameters; (c) volumetric parameters [7]

These parameters represent the pavement surface of the peaks, valleys and the core, respectively. With an Abbott curve it is also possible to calculate the volumetric parameters defined as two bearing ratio thresholds set by default to 10% and 80%.

Table 4. Texture parameters retrieved from the Abbott curves

	Index	Crespellano		San Giorgio di Piano	
		KmodBP (1&2)	KmodBPp (3&4)	KmodBB (3&4)	KmodBBp (1&2)
On Areas [mm]	S_k	1.53	1.69	1.65	2.02
	S_{pk}	0.58	0.46	0.62	0.60
	S_{vk}	0.55	0.78	0.57	0.70
On Volumes [ml/m^2]	V_{mp}	29.50	24.75	29.00	31.55
	V_{vc}	703.50	733.00	828.50	867.50
	V_{mc}	523.00	576.50	565.00	692.50
	V_{vv}	66.30	83.65	64.65	84.30

Two material volume parameters and two void volume parameters are defined as shown in Figure 6: V_{mp} (peak material volume), V_{mc} (core material volume), V_{vc} (core void volume), and V_{vv} (valley void volume). In Table 4 the indicators for the four microsurfacings are reported.

The water content can be assessed by the volumetric analysis of Abbott's curve. All the empty air voids fillable by water, are the sum of the parameters V_{vc} and V_{vv}. In Crespellano this sum amounts to an average value of 790 ml/m^2, while in San Giorgio di Piano that value is much greater and equal to 920 ml/m^2.

According to the Kurtosis index values, in Crespellano the texture is less uneven than in San Giorgio di Piano. According to these characteristics the V_{vc} parameter decreases, which expresses the presence of voids in the core main fraction. In Crespellano, still, the presence of a more open texture leads to a smoother surface, because the values of S_{pk} and V_{mp}, both related to the peak height, are lower.

5. Acoustic analysis with the Statistical Pass-By Method

The SPB method allows measuring the pass-by noise produced by vehicles on a stretch of road. Thus it is possible to quantify the actual tire/road noise by means of the Statistical Pass-By Index (SPBI), obtained by a statistical procedure. The traffic noise, however, is the result of several components: the aerodynamic noise, the propulsion noise, the tire/pavement noise and the noise reflected from the road pavement. These components vary with the vehicle speed: the sound produced by the engine is predominant at low speeds, whereas when exceeding 50 km/h the tire/pavement noise dominates. The contribution of the aerodynamic noise is significant when the vehicle speed exceeds 120 km/h. Road pavement affects the noise generation through the characteristics of the surface texture, such as amplitude, orientation and wavelength, the sound absorption properties and the pavement stiffness under the tire/pavement contact. The contribution of the tire is due to the stiffness of the rubber, the type of compound, age and wear, the profile, the size, the tread pattern and the tread voids configuration. Figure 7 shows the various noise generation and noise amplification mechanisms due to tire/noise interaction [8].

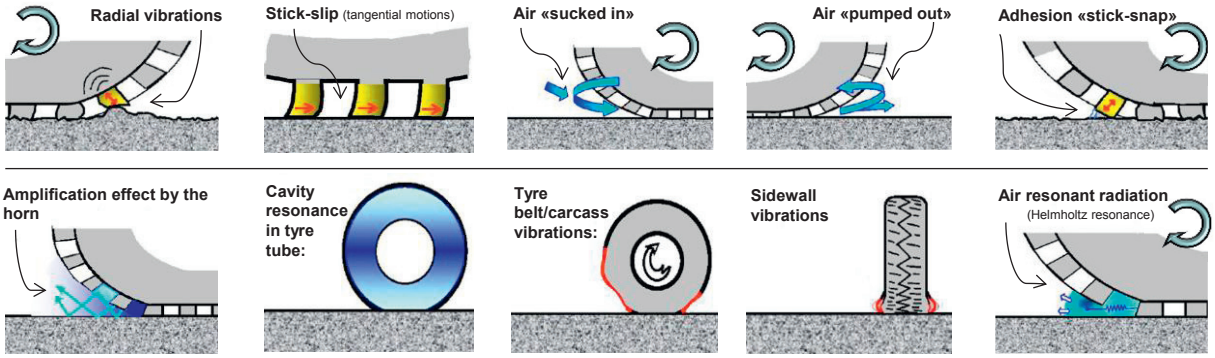

Fig. 7. sound generation mechanisms (top) and sound amplification mechanisms (bottom) [9]

By these acoustic tests it is possible to evaluate how the microsurfacing mixture affects the tire/pavement noise reduction in the experimental sites. The results of the tests are reported in Table 5: a SPBI reduction equal to 2.2 dB(A) can be observed in San Giorgio di Piano for the KmodBBp surface, compared to the previous asphalt pavement, while for the KmodBB one the reduction is equal to 0.7 dB(A). In Ozzano dell'Emilia the tests returned more similar results for both KmodBP and KmodBPp mixtures, with a reduction respectively equal to 1.5 dB(A) and 1.6 dB(A). In Crespellano, the A-weighted sound pressure levels Lveh, related to one of the vehicle categories, have not undergone significant modifications and, therefore, the SPBI indexes remain substantially unaltered.

Table 5. Acoustic results with the Statistical Pass By method (UNI ISO 11819-1)

		Crespellano		Ozzano dell'Emilia		San Giorgio di Piano	
		KmodBP	KmodBPp	KmodBP	KmodBPp	KmodBB	KmodBBp
Light vehicle Lveh [dB(A)]	Pre	71.3	70.7	69.4	69.9	75.8	75.0
	Post	71.3	70.6	67.8	69.4	75.5	74.2
Heavy vehicle Lveh [dB(A)]	Pre	79.8	79.5	77.8	80.2	84.8	84.5
	Post	79.8	79.7	76.4	77.4	83.7	79.7
SPBI [dB(A)]	Pre	73.4	72.9	71.4	72.9	78.1	77.4
	Post	73.4	72.9	69.9	71.3	77.4	75.2

The causes of this lack of noise level decreasing may be several: construction conditions and external temperature can be included among them. At the construction stage, in fact, a sudden decrease in air temperature has occurred and it may have affected the actual emulsion settlement conditions: as a result of this, in Crespellano a major aggregate loss occurred in the following days, when comparing it to the other two sites. This aggregate loss can also be seen with laser scanner tests, which have returned a lower MPD value in Crespellano than in the other sites. Nevertheless, a certain aggregate loss is usually expected and it is typical for the cold-laid microsurfacing. In Crespellano, that loss was higher than in the other sites, but still acceptable and restricted enough not to affect the pavement skid resistance and roughness characteristics, as BPN and HS test results have shown.

Since a vehicular traffic flow can be considered as a linear source of noise, a 3 dB decrease is comparable to the doubling of the distance from the sound source [10]. It can therefore be assumed that a lower decrease, as it occurred with the 2.2 dB(A) decrease in San Giorgio di Piano and the 1.6 dB(A) decrease in Ozzano dell'Emilia, may correspond to an intermediate noise reduction condition.

With regard to the surface texture, the designed slurry microsurfacings are more porous than the pre-existing traditional road pavements: the presence of more air voids favors the reduction of the effects of noise generation mechanisms, since they tend to decrease the air overpressure in the tire tread voids [4], as long as the macrotexture is limited to the 1-10 mm range (Figure 8). This condition is verified for all the designed mixtures and it is indirectly confirmed by all the HS test results.

Figure 8 shows the qualitative relationship between noise and surface texture, in terms of shape, homogeneity, spacing and orientation of the aggregates. According to Dondi (2012) [12], adding aggregates with cubic shape and homogeneous orientation to the assembly creates more grain contacts and better particle interconnection.

The microsurfacing texture in San Giorgio di Piano has a homogeneous aggregate distribution and, on a quality level, may be similar to the one represented in the first lines of the Figure.

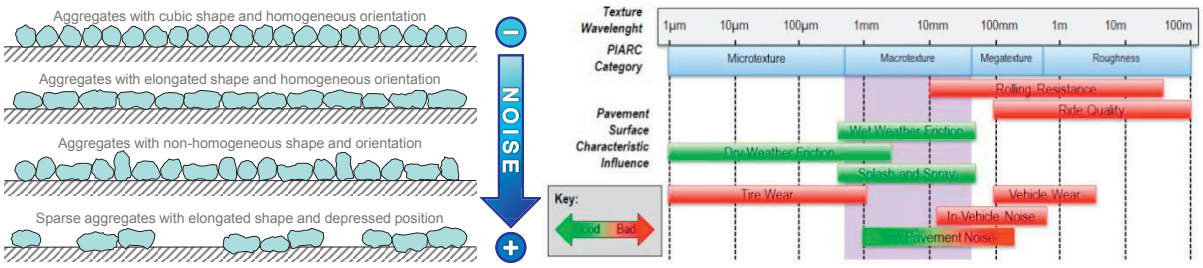

Fig .8. (a) aggregate orientation and noise; (b) relationship between surface texture and noise [2], [11]

On the contrary, in Crespellano the surface texture is less homogenous and may be similar to the one represented in the lower lines of Figure 8. Assuming the surface texture of the existing pavements are similar to each other, in San Giorgio di Piano the noise reduction is higher than in Crespellano, taking into account the respective acoustic boundary conditions.

As the slurry microsurfacing technique is mainly a maintenance intervention with reduced thickness, its expected effectiveness in terms of noise reduction may be less if compared to a sound-absorbing porous asphalt pavement from 5 to 8 cm thick, where voids are more and connected.

Variations of the road pavement stiffness can cause differences in terms of noise levels [13]. Assuming that the presence of crumb rubber has reduced the surface stiffness for the microsurfacing containing rubber it can be stated that the addition of this waste to the mixtures is contributing to the noise reduction.

6. Conclusions

Researchers have developed cold mixtures for slurry microsurfacings which combine adequate functional requirements of skid resistance with environmental characteristics related to the mitigation of acoustic externalities and to the use of a crumb rubber as a recycled material.

Slurries are an economic maintenance solution capable of extending the life-cycle of the pavement by restoring a significant contribution in terms of safety (skid resistance) and providing, in this case, noise reduction.

Test results have attested the correlation between surface texture and tire/pavement noise. Moreover, three-dimensional laser scanner has turned out to be an useful tool for the roughness characterization of these surfaces.

Further laboratory and in situ tests are planned on these materials concerning acoustic performances and the connection between different type of aggregates and bituminous emulsions. More studies are planned about the relation between geometric and statistical indicators of a road surface texture and its noise performances: one of the main targets is to clarify whether a volumetric indicator affects the tire-pavement noise more than others. Further studies are planned about additional solutions for maintenance interventions to restore the surface roughness of the structurally sound pavements.

7. References

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