New Low Noise Pavement Surfaces by the use of Crumb Rubber

Pietro Leandri, Massimo Losa, Patrizia Rocchio
University of Pisa – Department of Civil and Industrial Engineering (DICI) – ITALY

Summary
The principal advantage of introducing some percentages of crumb rubber in production of asphalt mixtures is related to pavement environmental sustainability, since this process allows to recycle a significant amount of industrial waste; there are some other advantages related to this process that are the improvement of asphalt mixture mechanical properties and durability as well as friction on pavement surface. These new low noise pavement (LNP) surfaces are realized by using the warm mix asphalt (WMA) technology that allows a significant reduction of mixing and compaction temperatures of asphalt concretes. The benefits of using WMA technology may include reduced fuel usage and pollution, and improved working conditions.
This paper presents key findings of the Phase I of the Life NEREiDE project. The project has the aim of evaluating the advantages of using crumb rubber in construction of LNP surfaces, specifically designed to reduce rolling noise by optimizing surface texture, by using both the wet and the dry processes. In the Phase I of the NEREiDE project the mechanical and functional performances of the new LNP surfaces were compared by using the two technologies in order to assess their respective potentials for use as viable alternatives to other traditional LNP surfaces aimed to improve pavement sustainability by reducing environmental, social and economic impacts. Results of laboratory and on site tests, carried out on a specifically built field trial, clearly show that these new LNP surfaces can have optimal mechanical and functional performance in comparison to results obtained with traditional LNP surfaces.

PACS no. 43.50.Lj

1. Introduction

Low Noise Pavements (LNP) are an interesting and economical solution where traffic noise reduction is necessary; rolling noise emissions are for cars already predominant at very low speeds (30÷40 km/h) and source related noise abatement measures are generally much more expensive than propagation related measures. Several types of LNP can be identified and classified into two main groups: texture optimized types (gap graded) and porous types (open graded) [1] [3] [2].
The use of crumb rubber (CR) from end of life tyres (ELT) in asphalt surfaces can affect positively performance of mixtures, particularly in terms of friction, tyre/road noise reduction, water resistance as well as reduction to permanent deformation [4] [5]. Anyway, the principal advantage widely recognized of introducing some percentages of CR in asphalt mixtures is principally related to the opportunity to recycle scrap tires and to reduce their waste disposal; in this sense, it represents a valid environmentally sustainable product.
Generally, the asphalt mixtures containing CR are mixed and compacted at high temperatures; this aspect conflicts with the actual needs of eco-efficiency and sustainability that require a reduction of energy consumption and pollution. In order to reduce the mixing and compaction temperatures of mixture containing CR the use of Warm Mix Asphalt (WMA) additives is necessary. The use of WMA additives reduce environmental impacts by allowing mixture production at least 30° lower than conventional HMA with no premature failures[6].
The Life NEREiDE project wants to evaluate the advantages of using CR from ELT in construction of new LNP surfaces (gap and open graded) specifically designed to reduce rolling noise by optimizing surface texture and volumetric characteristics[7][8]. The new LNP surfaces are realized by using both the wet and the dry processes and WMA technology. To assess their potential for use as a viable solution to enhance

environmental, social and economic sustainability of asphalt pavements, the project will compare the mechanical and functional performances of the resulting mixes, evaluated by laboratory and on-site tests carried out on field trials. This article shows key findings of the Phase I of the project.

2. Description of experimental program

The program included a first step of mix design to define the aggregate size gradations, the optimum asphalt contents and workability characteristics of the mixes; in the second step, laboratory and field tests were carried out to evaluate mixtures performance.
The six typologies of wearing course, composed of 2 reference mixtures (1 gap and 1 open graded) and new LNP surfaces (2 gap and 2 open graded), were laid on an experimental road section (roughly 2400 m long) with the specific aim of reducing traffic noise on a urban road in the Municipality of Massarosa (Lucca); the wearing course was 4 cm thick:

- Reference gap graded surface course 0-10 produced by using hot mix technology (Ref Gap).
- Reference open graded surface course 0-10 produced by using hot mix technology (Ref Open).
- Gap graded surface course 0-8 containing CR produced by using the DP and WAM technology (Gap Dry).
- Open graded surface course 0-8 containing CR produced by using the DP and WAM technology (Open Dry).
- Gap graded surface course 0-8 containing CR produced by using the WP and WAM technology (Gap Wet).
- Open graded surface course 0-8 containing CR produced by using the WP and WAM technology (Open Wet).

In order to check field performance of mixtures, pavement sections were tested to evaluate surface characteristics in terms of friction and texture.

3. Mix design

Mix design was realized by the volumetric method. The optimum asphalt contents were identified by optimizing the air void contents and mechanical characteristics.

3.1 Aggregate gradations

Given the considerable difference between the specific gravity of CR and natural aggregate, the grain size distribution of the mixes was composed by calculating volumetric proportions of the different materials (Table I). The grain size distributions of the mixtures are showed in Figure 1 and Figure 2. The new LNP surfaces have similar aggregate gradation for the open and gap typologies, with the purpose to appraise the effects produced by the different methodologies of usage of the CR in the mixtures. The aggregate gradations of reference and LNP surfaces are characterized by different values of the aggregate nominal size; in particular the maximum aggregate size is equal to 8.7 mm and 9.1 mm for the Ref Gap and Ref Open mixes and it is equal to 6.0 for the new LNP surfaces mixes. The Gap Dry and Open Dry mixes contain respectively 3.0% and 1.0% of CRM by weight of mineral aggregates, corresponding to 6.5% and 2.3% by volume, in replacement of mineral aggregates of the same size.

Table I. Aggregate blending.

Proportions by Volume (%)						
Typology of mixture	Basalt 4/10	Basalt 4/8	Basalt 2/6	Sand	CR	Mineral Filler
Reference GAP	57.0	-	10.0	22.0	-	11.0
GAP Dry	-	60.0	23.5	-	6.5	10.0
GAP Wet	-	74.0	-	16.0	-	10.0
Reference OPEN	82.0	-	-	10.0	-	8.0
OPEN Dry	-	85.7	-	5.0	2.3	7.0
OPEN Wet	-	85.0	-	8.0	-	7.0

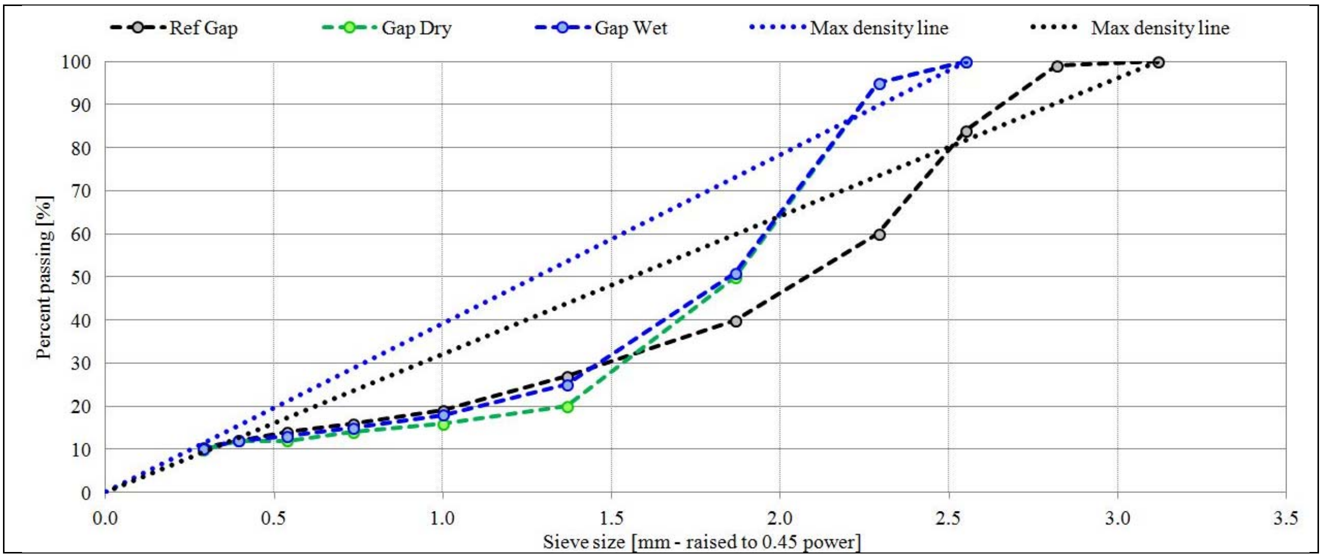

Figure 1. Aggregate size gradations of gap graded mixes.

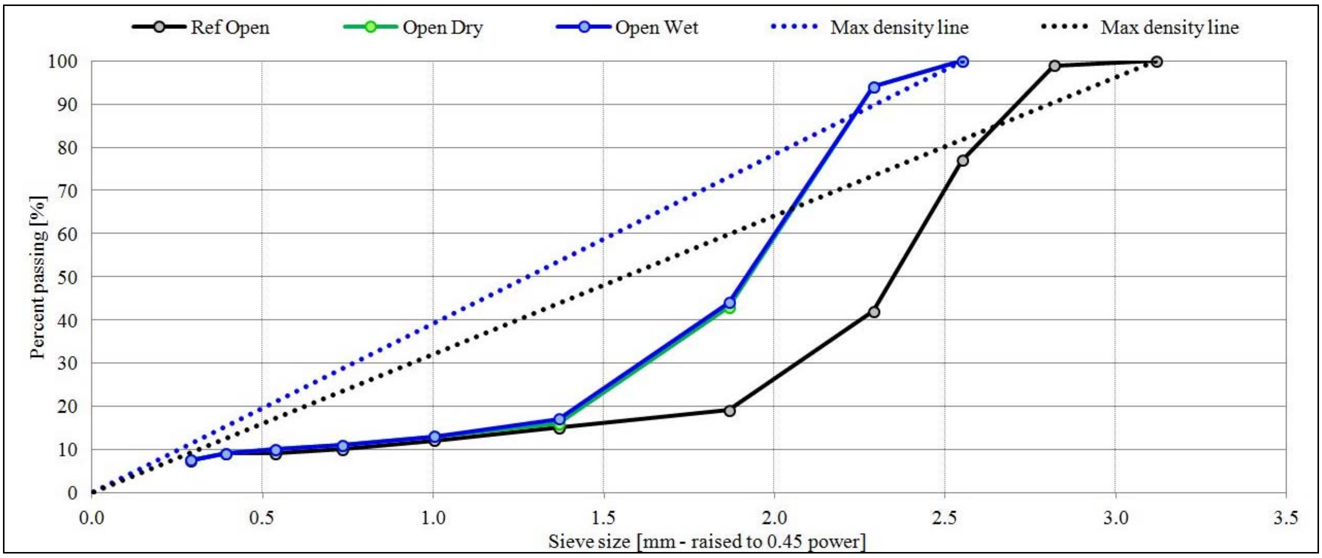

Figure 2. Aggregate size gradations of open graded mixes.

3.2 Volumetric properties

The aggregates of the reference mixtures were mixed with 50-70 penetration grade Polymer Modified Asphalt (PMA) whereas aggregates of the Gap Wet and Open Wet mixtures were mixed with Asphalt Rubber (AR) and the aggregates of the Gap Dry and Open Dry mixtures were mixed with a specific PMA.

In order to reduce the mixing and compaction temperatures of LNP surfaces, the AR and the specific PMA were enriched with viscosity reducing additives. The AR consists of 20% CRM by weight of binder and the remaining 80% of 50-70 penetration grade pure bitumen.

The optimum Asphalt Content (AC) of the mixes was determined by Superpave Giratory Compactor (SGC) assessing the volumetric characteristics and mechanical characteristics of mixtures with different asphalt contents. The volumetric characteristics of the mixes at optimum AC are showed in Table II.

The mixtures underline a great percentage of bitumen in comparison to the mixtures of reference, relatively to the mixtures containing rubber which show 3% smaller percentage of the voids in comparison to that of reference mixture. This is due to the presence of the CR and to a smaller maximum diameter of the aggregate.

Table II Volumetric properties at optimum AC.

	Number of gyrations	AV [a] (%)	VMA [b] (%)	VFA [c] (%)
Ref Gap $AC_{optimum}$=5.5%[d]	$N_{initial}$=10	13.9	25.0	44.5
	N_{design}=50	6.9	18.9	63.5
	N_{max}=130	3.0	15.5	80.5
Gap Dry $AC_{optimum}$=8.0%	$N_{initial}$=10	13.0	28.4	54.3
	N_{design}=50	7.2	23.6	69.6
	N_{max}=130	4.5	21.5	78.9
Gap Wet $AC_{optimum}$=8.0% [d]	$N_{initial}$=10	12.9	29.0	55.4
	N_{design}=50	6.6	23.8	72.3
	N_{max}=130	3.5	21.3	83.5
Ref Open $AC_{optimum}$=4.5% [d]	$N_{initial}$=10	30.1	37.7	20.0
	N_{design}=50	24.2	32.4	25.3
	N_{max}=130	21.1	29.6	28.8
Open Dry $AC_{optimum}$=5.5% [d]	$N_{initial}$=10	26.5	36.3	26.9
	N_{design}=50	20.9	31.4	33.6
	N_{max}=130	18.1	29.0	37.7
Open Wet $AC_{optimum}$=5.5% [d]	$N_{initial}$=10	26.5	36.4	27.2
	N_{design}=50	20.7	31.4	34.1
	N_{max}=130	17.8	28.9	38.4

[a] air voids.
[b] voids in mineral aggregate.
[c] voids filled with asphalt.
[d] optimum asphalt content as percentage of mass of aggregates.

3.3 The mixture workability

In order to evaluate the effects produced by the reduction of mixing and compaction temperatures on the mixture workability, the friction resistance should be measured by the Gyratory Pressure Distribution Analyzer (GPDA) during compaction. In the studies[9][6]the parameters N_w and CFI have been proposed to evaluate asphalt mixture workability using volumetric data routinely collected during current mix design and quality control testing. The N_w is defined as the number of gyrations required to reach w%·G_{mm} corresponding to w% air voids, where w% is the mean percentage of the voids at $N_{initial}$ and N_{design} (G_{mm} is the theoretical maximum density of mixture). w% is equal to 8% and 27% for the gap and open mixes. The CFI is defined as the Construction Force Index, which is the area under the resistive effort (R_e) curve from $N_{initial}$ to w%·G_{mm}. A mixture with lower N_w and CFI is characterized by better performance in terms of volumetric characteristics and workability. The values of these parameters were determined at 130 and 175°C for each mixture (Table III). Since the volumetric and workability characteristics at 130°C are still comparable to those at175°C, in particular for DP, the temperature of 130°C can be considered the optimum compaction temperature for the new LNP surfaces.

Table III. Workability parameters.

Type of mix	Temperature (°C)	N_w (n)	CFI (kPa·n)	AV at N_{design} (%)
GAP Dry	130	21	206	5.1
	175	21	205	5.1
GAP Wet	130	20	216	4.9
	175	17	179	3.9
OPEN Dry	130	33	342	21.1
	175	30	303	20.3
OPEN Wet	130	38	411	21.7
	175	28	292	20.3

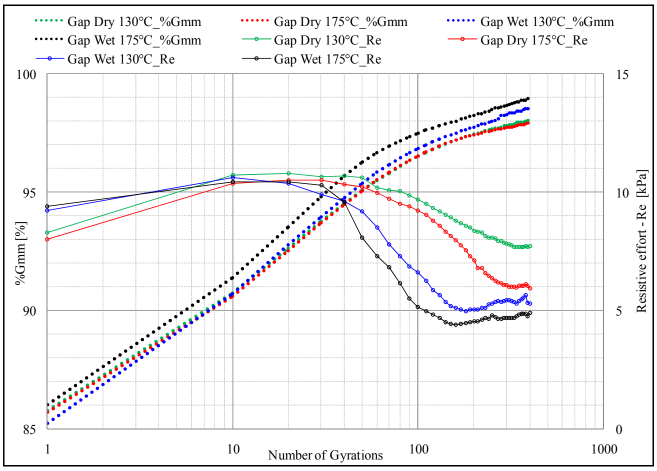

Figure 3. GPDA results of gap graded mixes.

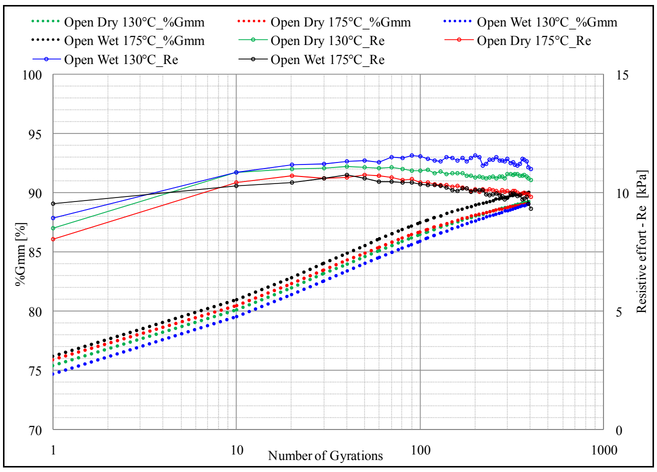

Figure 4. GPDA results of open graded mixes.

4. Mechanical characteristics

In order to characterize the mixes from a mechanical point of view, Indirect Tensile Strength Tests and Rutting Resistance Tests were carried out on specimens compacted by the SGC.

4.1 Indirect tensile strength and moisture sensitivity

Indirect Tensile Strength (ITS) measurements were carried out at the temperature of 25°C, according to EN 12697-23. ITS values (Table IV) for all the mixes are higher than the minimum value required by the national standards for gap and open graded asphalt mixes to be used as wearing courses. In the detail, the mixes by WP show ITS values higher than those of the mixes by DP.

Table IV. Indirect Tensile Strength Test results.

Type mix	ITS_d (N/mm^2)	ITS_w (N/mm^2)	ITSR (%)	Threshold value	
				ITS_d (N/mm^2)	ITSR (%)
Ref GAP	0.96	0.86	90	≥ 0.6	≥ 80
GAP Dry	0.69	0.61	88		
GAP Wet	0.96	0.84	88		
Ref OPEN	0.49	0.41	84	≥ 0.4	≥ 80
OPEN Dry	0.54	0.50	93		
OPEN Wet	0.67	0.59	88		

In order to evaluate moisture susceptibility, the Indirect Tensile Strength Ratio (ITSR), according to EN 12697-12, was determined. This is represented by the ratio between ITS of samples after conditioning in water (ITS_w) and ITS of unconditioned samples (ITS_d). The results obtained (Table IV) clearly show that no problems pertaining to moisture susceptibility arise for all the mixes.

4.2 Rutting resistance

The rutting resistance was determined by the Hamburg Wheel Tracking Test according to AASHTO T-324. Tests have been carried out at the temperature of 50°C and it concluded at 20000 passes or when the maximum allowable rut depth limit (12.7 mm) is achieved. The level of compaction was defined to the target of 7.0%±1% (93%·G_{mm}± 1%) for gap graded mixtures and to N_{design} for open graded mixture. These parameters were evaluated by the tests performed:

- Creep slope: a measure of the rutting potential after post-compaction consolidation.
- Stripping slope: a measure of the accumulation of moisture damage.
- Stripping inflection point (SIP): rut depth at which the creep slope and stripping slope intercept.

The results obtained are reported in Table V. The reference mixtures and the mixtures by DP do not show any significant problems pertaining to moisture susceptibility and to accumulation of permanent deformation. On the contrary, the mixtures by WP, in particular the Gap Wet, show some stripping problems. Such results highlight the necessity for the mixtures WP to use anti-stripping additive to reduce the accumulation of permanent deformation because of the effect of water (stripping).

Table V. Hamburg Wheel Tracking Test results.

Rutting parameters		Ref GAP	GAP Dry	GAP Wet	Ref OPEN	OPEN Dry	OPEN Wet
Creep Slope	(mm/passes)	1.28E-04	1.85E-04	8.62E-04	1.66E-04	1.35E-04	3.31E-04
Strip Slope	(mm/passes)	-	-	2.34E-03	-	-	1.29E-03
Rut depth @ SIP	(mm)	-	-	8.4	-	-	9.1
Number of passes @ SIP	(mm/passes)	-	-	7320	-	-	16031
Number of passes @ 12.7 mm	(mm/passes)	> 20000	> 20000	9347	> 20000	> 20000	> 20000
Rut depth @ 20000 passes	(mm)	5.5	6.9	> 12.7	8.4	6.7	> 12.7

5. Field performance

Performances of the experimental wearing courses were evaluated in terms of surface characteristics, in terms of friction and macrotexture. Measurements were taken one month after laying.

5.1 Macrotexture

Surface macrotexture was determined on 2D pavement profiles recorded by using a mobile laser profilometer which allows the continuous recording of the pavement profile at sampling intervals of 1 mm. The Mean Profile Depth (MPD) was evaluated from the profile and the Estimated Texture Depth (ETD) was calculated on the experimental section[10]. Figure 5and Figure 6 show the values of macrotexture expressed in terms of ETD, averaged at every 10 m, together with the Mean Texture Depth (MTD) threshold values required on urban roads. The reference mixtures show macrotexture values higher than those of the new LNP surfaces. This is due to the greater aggregate nominal size.

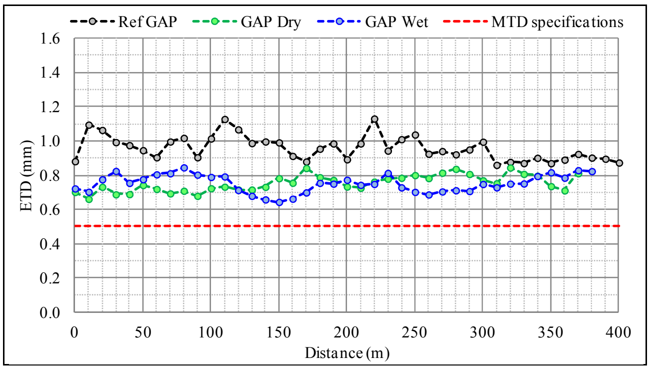

Figure 5. Macrotexture profiles of gap graded mixes.

Using the recorded profiles, the one-third octave band mean texture spectrum (L_{tx}) was calculated, according to the ISO/CD 13473-4 and 5 procedures[11].

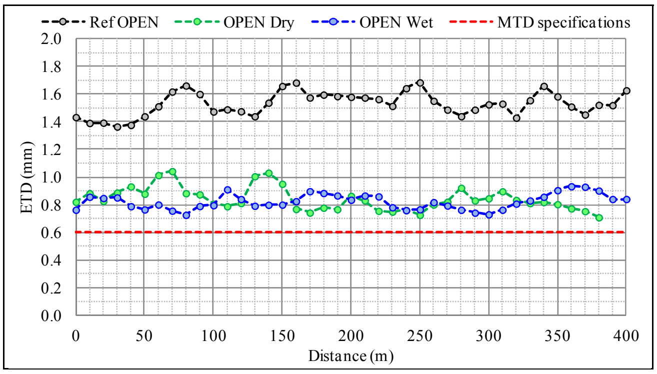

Figure 6. Macrotexture profiles of open graded mixes.

Figure 7 and Figure 8 show the texture spectrum of the experimental wearing courses. In order to obtain a low noise asphalt surface, which is capable of reducing noise emissions at the tyre/road, the texture spectrum should have the following characteristics [4]:

- the highest L_{tx} value should be found in the wavelength (λ) field below 10 mm;
- L_{tx} values should tend to minimum values in the wavelength field λ>10 mm.

Figure 7 and Figure 8 clearly show that the new LNP surfaces better fulfill these requirements than the reference surfaces; in particular, as an effect of the greater aggregate gradation nominal diameter, the reference mixtures show higher texture levels than the new LNP mixtures.

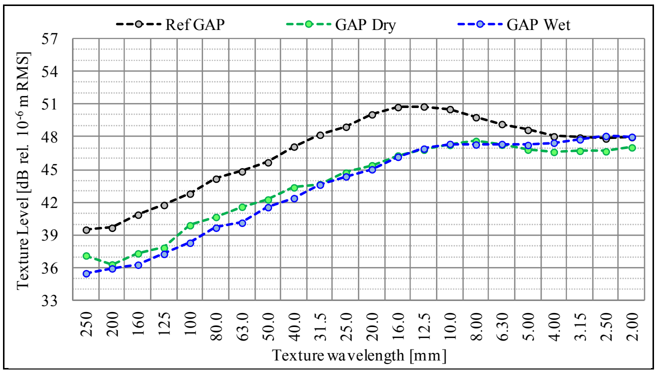

Figure 7. Texture spectrums of gap graded mixes.

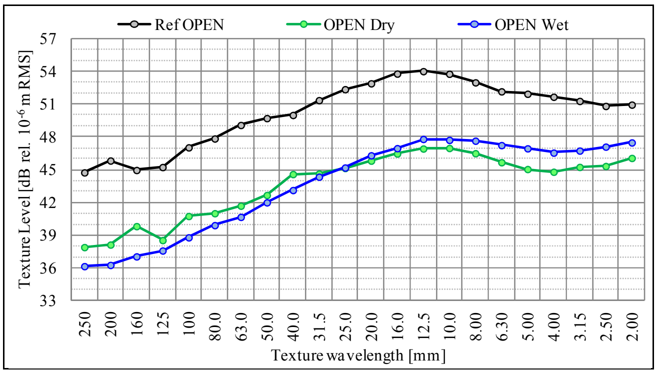

Figure 8. Texture spectrums of open graded mixes.

These results were confirmed by estimation of rolling noise by using theoretical model proposed in[12]. The model allows reliable estimation of rolling noise at a certain speed as a function of composition and volumetric characteristics of the mixes (D_F, D_{95}, AV, VMA). The rolling noise is expressed in terms of Close Proximity Index (CPXL), according to the ISO/CD 11819-2 procedure. In Table VI are shown the estimated CPXL for the mixes. CPXL values estimated at 50 km/h for the new LNP surfaces revealed a reduction, as compared to the reference surfaces, of roughly 2 dB(A) and 1 dB(A) for the Gap graded and Open graded mixes.

Table VI. Estimated CPXL values at 50 km/h.

Type mix	D_{95} [a]	D_F [b]	AV	VMA	$CPXL_e$ [c]	$\Delta CPXL_e$ [d]
	(mm)	(mm)	(%)	(%)	(dB(A))	(dB(A))
Ref GAP	8.2	2.741	6.9	18.9	93.8	-
GAP Dry	6.3	2.735	7.2	23.6	92.0	-1.8
GAP Wet	6.3	2.771	6.6	23.8	92.1	-1.7
Ref OPEN	7.7	2.578	24.2	32.4	91.0	-
OPEN Dry	6.6	2.675	20.9	31.4	89.8	-1.1
OPEN Wet	6.6	2.677	20.7	31.4	89.9	-1.1

[a] sieve size to which a 95% of aggregate is passing
[b] fractal dimension of aggregate grading
[c] estimated CPXL value
[d] difference between $CPXL_e$ of ref mixes and $CPXL_e$ of new LNP surfaces

5.2 Friction

Friction measurements were carried out by using the Skiddometer BV11. The test was carried out at a speed of 20 km/h, by adequately wetting the pavement in order to create the 1 mm thick water film.

Using the PIARC model, and after suitably calibrating the model parameters for the specific device utilized in these tests [13], the Friction Number (F60) of the International Friction Index (IFI) was determined on the basis of friction and macrotexture values.

Figure 9 and Figure 10 show F60 measured values, averaged at every 10 m, together with the friction threshold likewise expressed in terms of F60; these latter were determined from the national standards for a newly built gap and open asphalt surfaces, which are characterized respectively by a Speed Constant (Sp) equal to 45.2 km/h and 56.6 km/h.

The results show the good friction levels which can be obtained by using CR in the production of LNP surfaces, which are higher than those required by the technical specifications. Compared to the reference mixtures, the new LNP surfaces show lower friction levels, especially in the case of open graded mixes. This is due to the greater aggregate nominal size which leads to higher macrotexture values and consequently to greater friction levels.

The Open Dry and Open Wet mixes are characterized by similar friction levels, whereas the Gap Wet mix shows lower friction levels than Gap Dry mix. This can be due to the greater adhesion of the AR to the aggregate determining lower friction levels at one month after laying, since after this short period the AR cannot be removed from the vehicles and therefore it can be coated the aggregates.

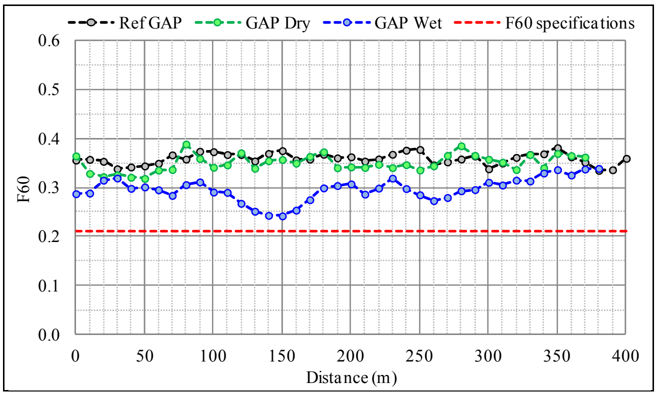

Figure 9. Friction performance of gap graded mixes.

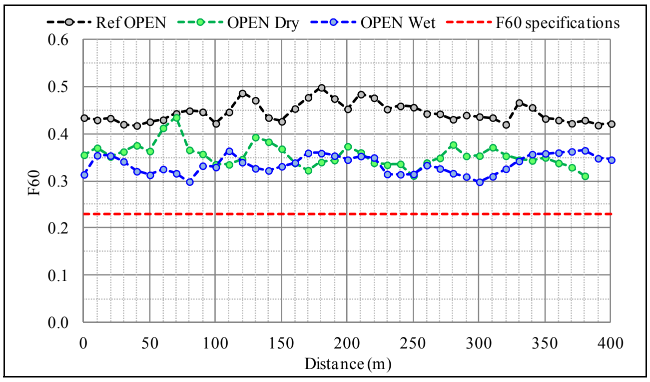

Figure 10. Friction performance of gap graded mixes.

6. Conclusions

This paper presents key findings of the Phase I of the Life NEREiDE project. The project has the aim of evaluating the advantages of using CR in construction of new LNP surfaces, specifically designed to reduce rolling noise by optimizing surface texture, by using both the wet and the dry processes and WMA technology. In this phase of the project the mechanical and functional performances of the new LNP surfaces were compared in order to assess their respective potentials for use as viable alternatives in urban contests to other traditional LNP surfaces aimed at improving pavement sustainability by reducing environmental, social and economic impacts.

- The results of laboratory and on site tests showed that:

- given the presence of the CR and to a smaller maximum diameter of the aggregate, the new LNP surfaces are characterized by a greater optimum AC.
- The assessment of volumetric and workability characteristics of the new LNP mixes, by a SGC equipped with the GPDA, shows a workability at 130°C which is still comparable to that at175°C. The temperature of 130°C can be considered the optimum compaction temperature for these new LNP surfaces. This result allows a reduction of 30-40 °C of the mixing and compaction temperatures as compared to traditional LNP surfaces, with significant benefits in terms of pollution and energy consumption.
- The new LNP mixes show similar ITS values which are higher than the minimum values required by the national standards for the traditional LNP surfaces. No problems pertaining to moisture susceptibility arise for all the mixes.
- The reference mixtures and the mixtures by DP do not show any significant problems pertaining to accumulation of permanent deformation, whereas the mixtures by WP show some stripping problems. For the mixtures by WP, it is useful to use anti-stripping additive in order to reduce the accumulation of permanent deformation because of the effect of the stripping.
- The reference mixes show macrotexture values higher than those of the new LNP mixes, consequently at the greater nominal diameter of the aggregate gradations.
- CPXL values estimated at 50 km/h for the new LNP surfaces revealed a reduction, as compared to the reference surfaces, of roughly 2 dB(A) and 1 dB(A) for the Gap graded and Open graded mixes. It is important to highlight the benefits, in terms of tyre/road noise reduction, which can be obtained by using new LNP surfaces in the urban context as a viable alternative, in terms of environmental compatibility and economy, to other traditional LNP surfaces.
- The friction levels recorded, in terms of F60, were higher than those required by the technical specifications for newly constructed traditional LNP surfaces. Compared to the reference mixtures, the new LNP surfaces show lower friction levels. This is due to higher macrotexture values.

References

[1] M. Losa, P. Leandri, R. Bacci: Mechanical and Performance-Related Properties of Asphalt Mixes Containing Expanded Clay Aggregate. Journal of the Transportation Research Board 2051 (2008)23-30.

[2] M. Losa, P. Leandri, R. Bacci: Empirical Rolling Noise Prediction Models Based on Pavement Surface Characteristics. Road Materials and Pavement Design 11 (2010) 487-506.

[3] M. Losa, P. Leandri: A comprehensive model to predict acoustic absorption factor of porous asphalt mixes. Materials and Structures 45(6) (2012) 923-940.

[4] Y. Liu, S. Han, Z. Zhang, O. Xu: Design and evaluation of gap-graded asphalt rubber mixtures. Materials and Design 35 (2012) 873-877.

[5] M. Losa, P. Leandri, M. Cerchiai: Improvement of pavement sustainability by the use of crumb rubber modified asphalt concrete for wearing courses. International Journal of Pavement Research and Technology 5 (6) (2012) 395-404.

[6] P. Leandri, P. Rocchio, M. Losa: Identification of the more suitable warm mix additives for crumb rubber modified binders. Proc. ICTI 2014, 111-118.

[7] http://www.nereideproject.eu

[8] P. Leandri, M. Losa, P. Rocchio: Life NEREiDE - new low noise pavement surfaces. Proc. ICSV 2017.

[9] A.J. Hanz, H.U. Bahia: Asphalt Binder Contribution to Mixture Workability and Application of Asphalt Lubricity Test to Estimate Compactability Temperatures for Warm Mix Asphalt. Proc. 92nd Annual Meeting of the Transportation Research Board, 2013.

[10] M. Losa, P. Leandri, R. Bacci: Measurements of Pavement Macrotexture with Stationary and Mobile Profilometers. Proc. MAIREPAV 2007, 313-318.

[11] M. Losa, P. Leandri: The Reliability of Tests and Data Processing Procedures for Pavement Macrotexture Evaluation. International Journal of Pavement Engineering 12 (1) (2011) 59-73.

[12] M. Losa, P. Leandri, G. Licitra: Mixture Design Optimization of Low-Noise Pavements. Transportation Research Record 2372 (2013) 25-33.

[13] P. Leandri, M. Losa Peak friction prediction model based on surface texture characteristics. Transportation Research Record 2525 (3) (2015) 91-99.