CAN YOU REALLY RECYCLE PEMS BACK TO PEMS AND BE CONFIDENT ALSO ON SURFACE PROPERTIES?

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ABSTRACT

Porous European Mixes (PEMs) are open-graded surface courses with high voids content (20% circa).
About ten millions of square meters of PEMs are going to be definitely laid in Southern Italy (Calabria), but there is still considerable need for additional performance information for the use of Reclaimed Asphalt Pavement (RAP) in premium surface course mixes and this will pose rehabilitation problems.
Therefore research is needed.
In the light of these premises, objectives and scopes were focused on the idea of recycling porous asphalt concretes back into porous asphalt concretes.
Two main issues were addressed: I) what about the bearing properties?; II) what about the friction properties?
In order to investigate on the abovementioned issues an experimental plan was designed.
Mixes with high RAP (reclaimed asphalt pavement) contents were prepared and tested. Design and construction features, including mix design and mixing procedures were addressed.
Mechanical performance was adequate and environmental compatibility was achieved.
The tests carried out are encouraging about the possibility of achieving a satisfactory level of surface performance.
Practical applications and perspectives in rehabilitation, maintenance, and research are outlined.

1. INTRODUCTION

As is well known, porous European mixes, PEMs, are a type of coated macadam in which the aggregate skeleton is designed to contain, as-constructed, an air void content usually in excess of 20%. They act as a wearing course 50mm-thick on impermeable base courses and have well-known points of strength: reduction of splash and spray, mitigation of outdoor noise (high porosity, low flow resistivity), optimization of skid resistance at high speeds in wet conditions (high macrotexture).

In contrast, PEMs have several points of weakness: low bearing properties, clogging, variation of volumetrics over the time, variation of noise, texture, friction, and permeability performance over the time.
By considering the amount of porous surface course laid in the Italian main road network, the recycling of PEMs back to new permeable wearing course is a perspective that call for research in the light of the pressing need for sustainability of pavement construction and rehabilitation [1][2][3][4][5][6][7].

The objectives and scopes of the research were confined into the formalization of strategies and technical procedures for recycling PEMs back to permeable wearing courses.
Two main issues related to the recycled porous asphalt were addressed and discussed in this paper: Are the bearing properties of the recycled asphalt fulfilling? And what about the friction properties?

In order to investigate the above-mentioned questions, an experimental plan was designed and carried out under the auspices of the research project of national interest, PRIN 2008, Research Project “Drenante da drenante”. This National project is under development at the universities of Reggio Calabria and Cosenza (Italy).

In what follows, in section 2 the sustainability of the PEM recycling is discussed. In section 3 the potential for satisfactory surface properties the recycled mixture is discussed. The results of the experiments are discussed in section 4. Finally the conclusions are drawn.

2. THE SUSTAINIBILITY OF THE PEM RECYCLING

A sustainable pavement can be defined as a safe, efficient, economic, environmentally friendly pavement meeting the needs of present-day users without compromising those of future generations [8]. The concept of “sustainability” involves environmental, economical and societal aspects, see fig. 1.

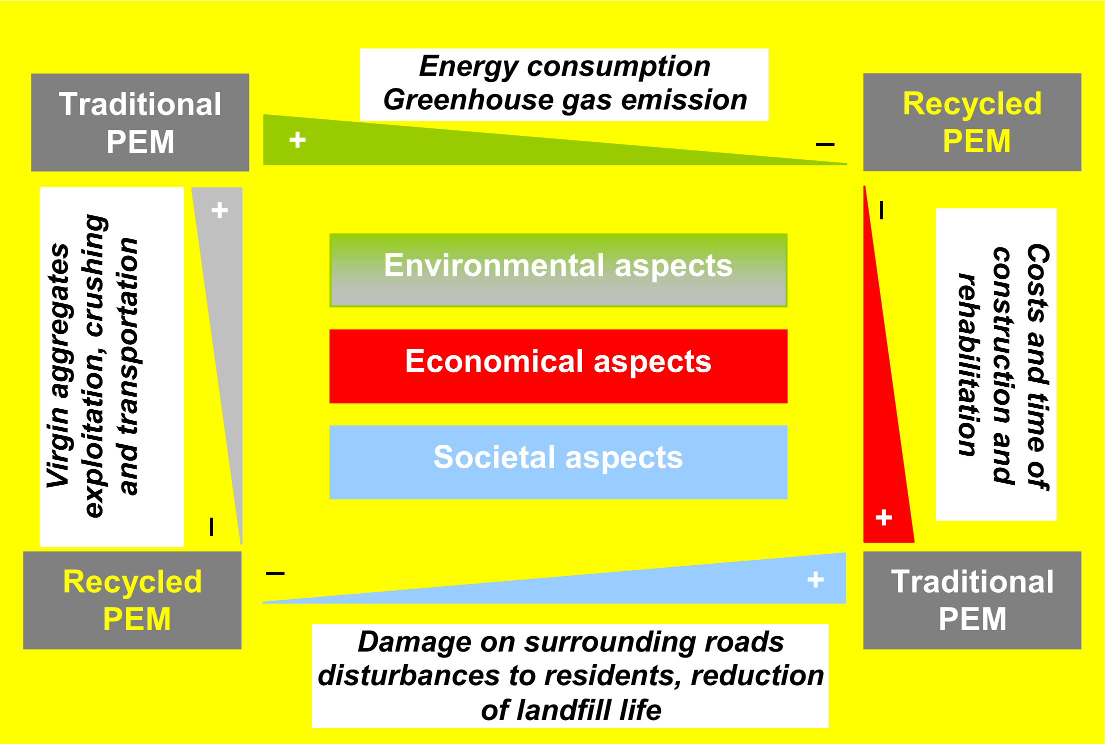


Figure 1 – Sustainability of PEM recycling

The sustainability of the use of the Reclaimed Asphalt Pavement (RAP) in premium surface courses was analysed by considering the three aspects above-mentioned.

Recycling leads to economic, social and environmental benefits for agencies, users and society not only during construction time but over the long term.

From an environmental standpoint, the recycling of asphalt pavement agrees with a sustainable development in terms of conservation of resources and energy and reduction of atmosphere emissions [9][10]. It is noted that conventional aggregates are a non-renewable natural resource, furthermore their use in asphalt concrete production involves quarries extraction, crushing and transportation.

Regarding energy consumption and greenhouse gas (GHG) emissions, the recycling of PEMs back to PEMs can allow to reduce energy consumption and greenhouse gas emission (GHG). Usually the energy consumption related to road construction or rehabilitation is based on the fuel consumed during construction and transport of materials but also the reduced need for extraction and processing of virgin materials must be considered in the energy consumption analysis [11].

In comparison with the traditional mill and overlay treatment, PEM recycling is more sustainable, lowering the energy consumption of about 16% and the GHG emission of 22% [12][13][14].

In recycling PEMs back to PEM, the following additional issues must be considered: i) there is a need for an environmental code of practice regarding gaseous emissions from hot mix plant recycling and HIPR (hot in-place recycling); ii) laboratory studies confirmed that emissions and eluates from recycling porous asphalt concretes do not appear to cause any increased environmental or health and safety at work problems; anyhow, it is important to understand the influence of each procedure on the health and safety of workers.

The economic balance pertains to the reduction of the costs of new construction and rehabilitation projects. PEM recycling allows to realize savings through the reduction of hauling distances, reduced virgin material quantities, and elimination of landfill fees for the disposal of waste materials. In addition, a lowering of the construction time can be also obtained.

The social dimension is often the least defined, and is “more often implied rather than explicit” in transportation literature [15]. Some societal benefits are achieved through the use of recycled materials in pavements. These benefits include the possibility to perform more rehabilitation works for the same cost, less damage caused to surrounding roads due to construction activities, the fewer disturbances to surrounding residents, the prolonged landfill life [16][17].

3. SURFACE PROPERTIES

As is well known, RAP is commonly recycled in the construction of the deeper layers of road pavements (RAP as unbound aggregate in subbase) [18].
Due to RAP inhomogeneity and possible drawbacks in fatigue cracking resistance, RAP percentages commonly used for wearing courses are remarkably lower (10÷15%) [19].

When higher percentages of RAP are used, a thorough homogenization of the RAP is required [20][18].

International literature on the use of the RAP in wearing courses remarks two key-factors which can affect the derivation of the optimal amount of RAP to add: the mineralogical selection of the RAP aggregates and the extraction technique of the RAP.

[21] studied the selection of the RAP in terms of mineralogical quality of aggregates and their polishing resistance. SMAs (stone mastic asphalts) and DGAs (Dense Graded Asphalt concretes) were tested, combining aggregates with high polishing resistance with various percentages of RAP (0-15-25-40%, limestone aggregates, with low polishing resistance). Results demonstrated that RAP percentages lower 15% did not affect the polishing resistance of asphalt mixtures. Furthermore, it was found that the maximum percentage of RAP which can be used in the production of wearing courses, without negative effects on friction, is approximately 30%. Finally it is necessary to emphasize that in this study mechanical performances weren't examined.

[22] examined how the extraction process can influence RAP gradation. Two different methods of extraction were involved: conventional full depth method (scrapping) using a backhoe to scrap the pavement and a modern milling method. As expected, the percentage retained on 14mm sieve decreased in both cases. It was higher for the (modern) milling than for the scrapping case.

In [23] an application of "hot in-place recycling" to PEMs was described. Milling depth was 3-cm. A 5-cm compacted layer of porous asphalt concrete was placed. Recycled mixture contained 40% of virgin aggregates and 60% of RAP. This fact allowed to recycle all the milled RAP. The Permeability of the recycled PEM ranged from 0.2 cm/sec to 0.5 cm/sec (where the lower specification limit is 0.2 cm/sec [24]).

In [25] European HMA Mixture Design Practices for tire-Pavement Noise Reduction were examined. In particular the allowable percentage of reclaimed asphalt pavement (RAP) to be used in PA surface courses was said not to exceed 10% by total mass of the mixture if the RAP contains modified bitumen and/or a modifier. Furthermore, according to the authors, for binder and base courses, the percentage should not exceed 20% by total mass of the mixture.

4. EXPERIMENTS

Experiments were carried out at the universities of Reggio Calabria and Cosenza (Italy). Two different laboratories (DIMET at Mediterranea University - a, and DIPITER at Calabria University – b) took part to the abovementioned national project PRIN 2008 (see figures 2 and 3).

Figures 2 and 3 illustrate the synopsis of the research plan. Figures 4 to 9 and table 1 summarize results. Figures 4 and 5 refer to the analysis of the RAP. In more detail, figure 4 illustrates RAP gradation before and after the extraction and shows the main tests carried out on the recovered asphalt binder. Furthermore, figure 5 illustrates the richness modulus of the reclaimed pavement [26][27][28][29]. In order to allow the production of the two-layer porous asphalt, TLPA, around the 82% of RAP (from PEM) was used. Different size gradations of RAP were mixed in order to fulfil functional properties (permeability and drainagebility), grading requirements, volumetrics, mechanical requirements, and desired thickness of both the top and the bottom layer. The bituminous mixtures (top layer and bottom layer) were tested in order to investigate on composition, volumetrics, functional and mechanical performance.

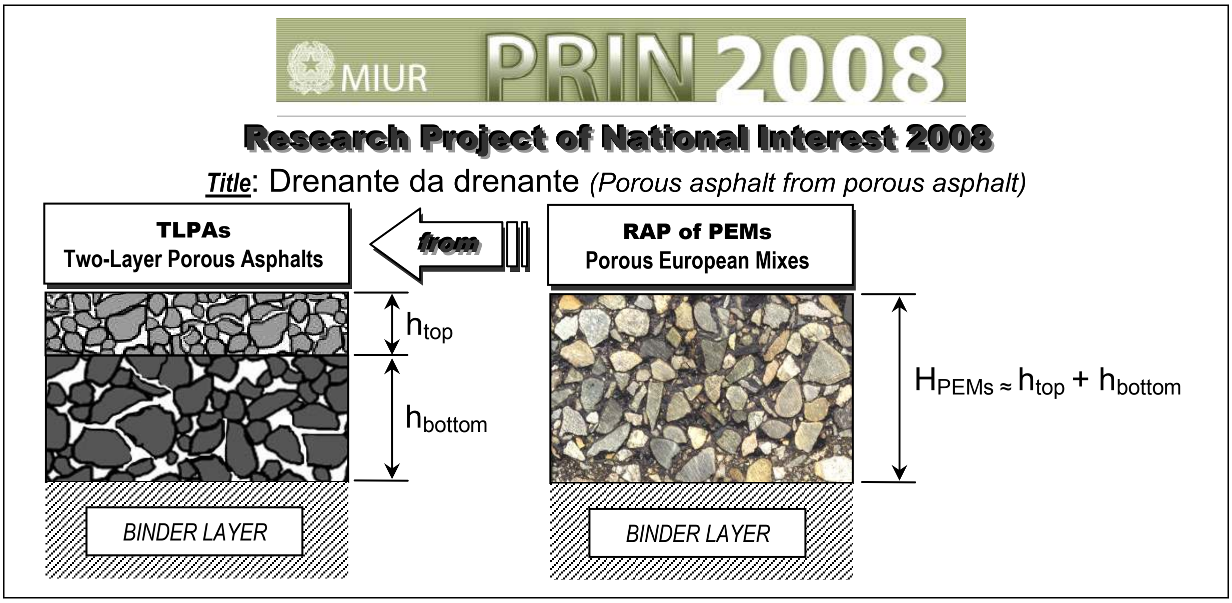
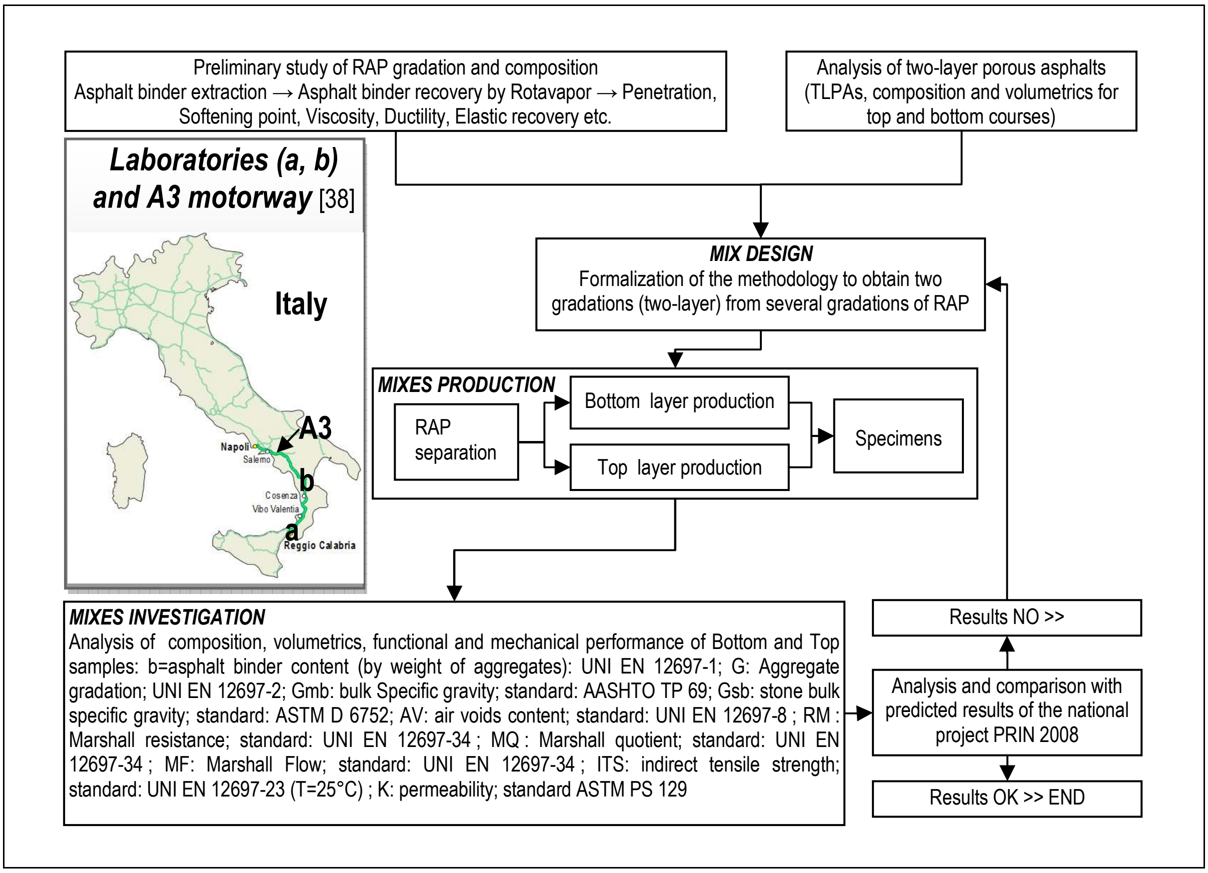


Figure. 2 – Schematic of the National Research Project PRIN2008 entitled "Drenante da drenante" ("Porous asphalt from porous asphalt)"



Analysis of composition, volumetrics, functional and mechanical performance of Bottom and Top samples: b=asphalt binder content (by weight of aggregates): UNI EN 12697-1; G: Aggregate gradation; UNI EN 12697-2; Gmb: bulk Specific gravity; standard: AASHTO TP 69; Gsb: stone bulk specific gravity; standard: ASTM D 6752; AV: air voids content; standard: UNI EN 12697-8 ; RM : Marshall resistance; standard: UNI EN 12697-34 ; MQ : Marshall quotient; standard: UNI EN 12697-34 ; MF: Marshall Flow; standard: UNI EN 12697-34 ; ITS: indirect tensile strength; standard: UNI EN 12697-23 (T=25°C) ; K: permeability; standard ASTM PS 129

Figure. 3 – Synopsis of experiments and analyses

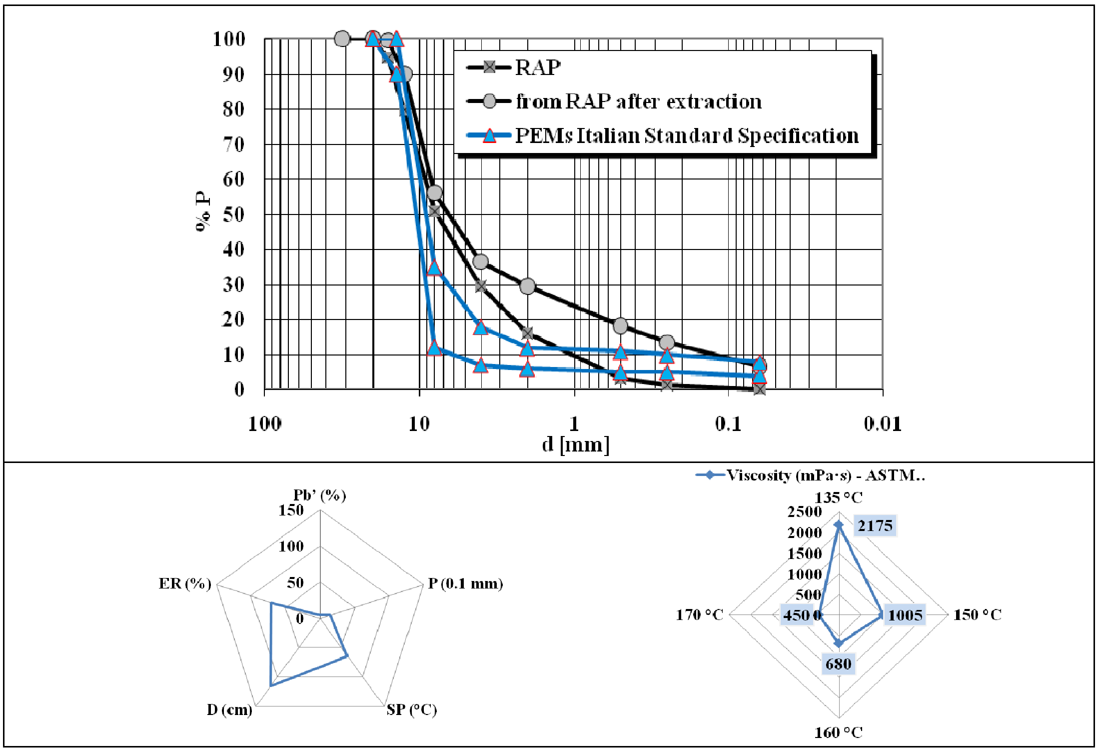


Figure 4 – RAP characteristics (gradations of RAP and from-RAP aggregates (above); Recovered asphalt binder characteristics (left and right, below)

Symbols. P_b': Asphalt binder content by weight of aggregate (%,EN 12697-6), P: penetration (0.1 mm, EN 1426-7); SP: Softening point (°C, EN 1427-7); D: Ductility at 25 °C (cm, ASTM D113-86, CNR B.U. N. 44/74); ER: Elastic Recovery = (d/200)*100 (%, EN 13398-3); d: distance between half-threads (mm)

Owing to the complexity of the research project many cycles of experiments were needed. Results are summarized in terms of main results for two trials (first and second trial). Composition and volumetrics (figures 5-6 and table 1), surface and functional properties (figures 7 and 8), mechanical performance (figure 9) are below illustrated. In table 1 the aggregate gradations obtained for the top and bottom layers are compared with Italian standard specification for porous European mixes (PEMs).

Table 1 - Aggregate gradations

Sieve Size [mm]	*1th trial*		*2nd trial*		*PEMs (Italian specs)*	
	BOTTOM	*TOP*	*BOTTOM*	*TOP*		
20	100	100	100	100	100	100
16	100	100	98	100	90	100
12.5	77	100	68	100	-	-
8	56	59	26	74	12	35
6.3	52	28	22	68	-	-
4	36	14	21	26	7	18
2	18	11	16	16	6	12
0.5	12	7	11	12	5	11
0.25	9	6	9	9	5	10
0.063	6	4	5	5	4	8

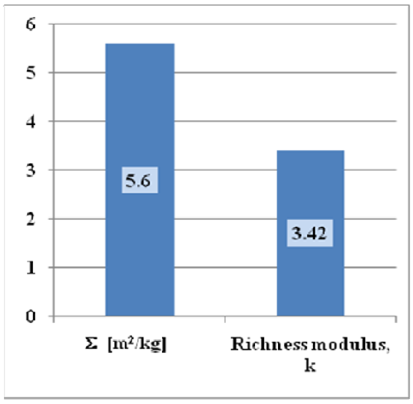


Figure 5 - Specific surface area of aggregates and richness modulus of RAP

In Figure 5: $k = P_b/(\alpha \cdot \Sigma^{0.2})$; P_b= Asphalt content by weight of mix (%); $\Sigma = 0.25G + 2.3S + 12s + 135f$ (G: > 6.3mm; S: between 6.3 and 0.315mm; s: between 0.315 and 0.08mm; f: < 0.08mm); $\alpha = 2.65/G_{SE}$; $G_{SE} = (100-P_b)/((100/G_{mm})-(P_b/G_b))$; G_{SE}: effective specific gravity of aggregate; G_{mm}: Maximum theoretical specific gravity of the HMA mixture; G_b: bitumen specific gravity [26][27].

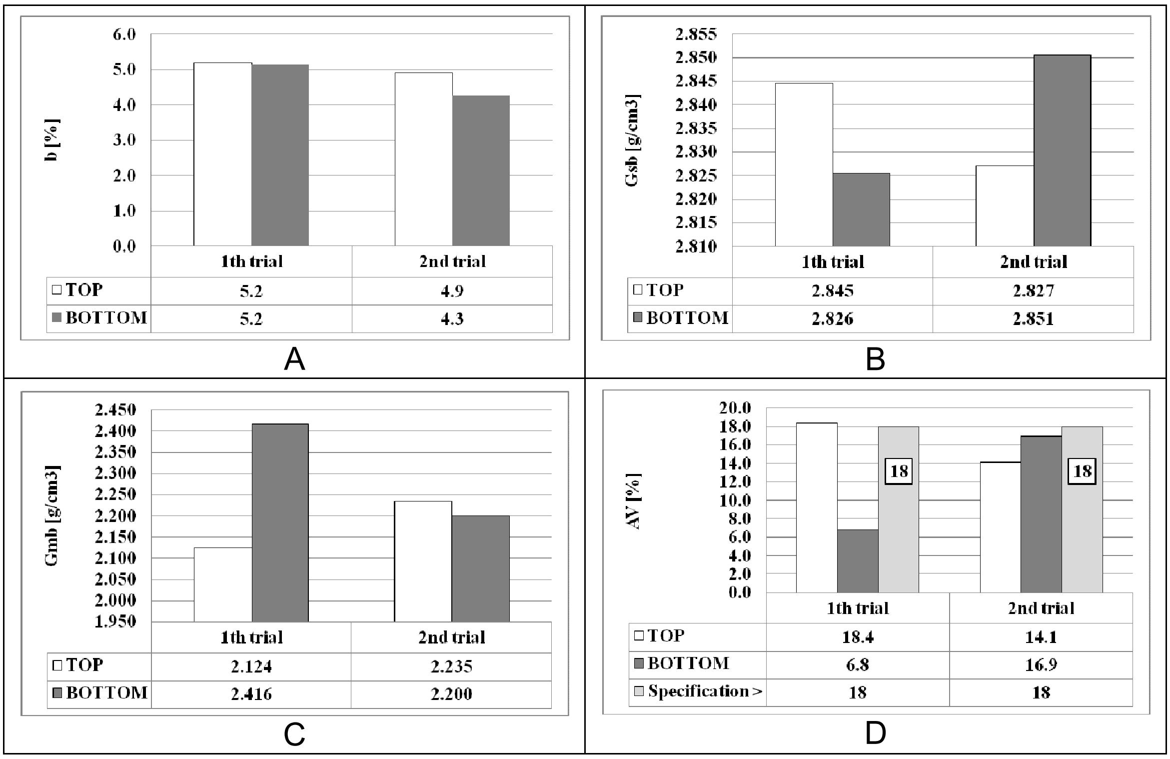


Figure 6 – Composition and Volumetrics of top and bottom mixes

Figure 6 (from A to D) illustrates the composition and volumetric characteristics we obtained for the first and 2nd trial. These results confirm that in the second trial the range of air voids content was closer to the target than in the first trial. In the first trial the permeability of the bottom layer resulted unsatisfactory (see figure 7). Air voids content was around 5-9% and aggregate gradation showed and excess of sand.

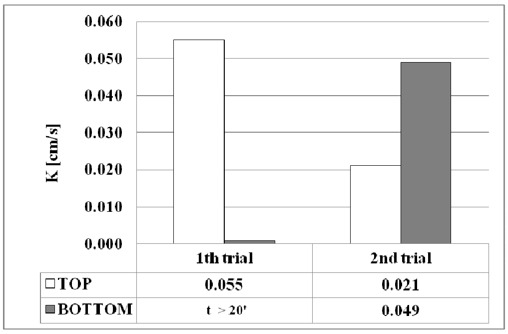


Figure 7 - Permeability – 1^{st} *vs.* 2^{nd} trial

The analysis of surface texture [30][31] confirmed that the bottom layer resulted an intermediate configuration between a dense-graded and an open-graded course (see figure 8). On the contrary, top layer showed an air voids content of 16-20%. In both the cases, the relationship between permeability and air voids content resulted consistent with [32][33].

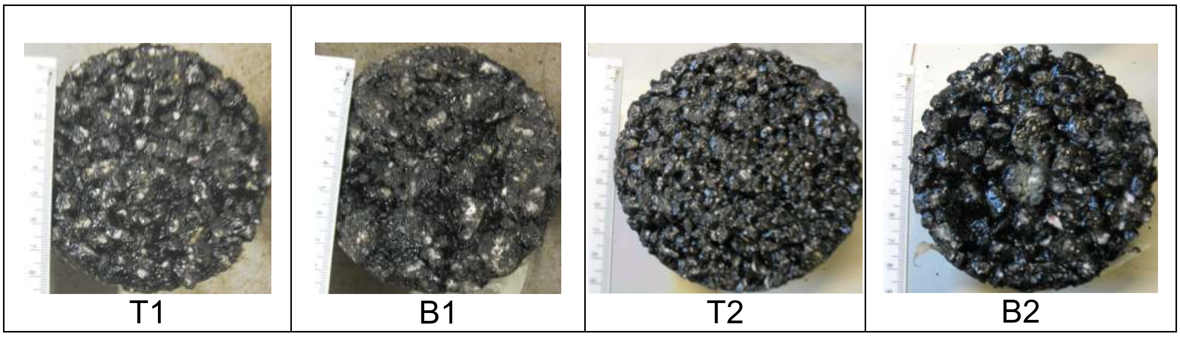

T1 B1 T2 B2

Figure 8 - Surface of Marshall samples: Top layer Ti and Bottom layer Bi for first trial (i=1) and 2^{nd} trial (i=1,2)

Mechanical performance was assessed through Marshall and indirect tensile strength tests (ITS, see figure 9). The European standard UNE-EN 12697-23:2004 test was used for evaluating the indirect tensile resistance of the mixtures. Temperature was 25°C and velocity was 50.8 mm/min. Cylindrical specimens were broken by applying a compressive load along the vertical diameter. Indirect tensile resistance was determined by the expression $ITS=2P/(\pi \cdot D \cdot h)$, where ITS is the indirect tensile strength (N/mm^2), P is the applied load (N), D is the specimen diameter (mm) and h is the specimen thickness (mm).

Mechanical performance of both the layers resulted satisfactory. It is important to remark that the following sources of variability were involved and considered. Although RAP was derived always from the same stockpile obtained from the cold milling the same pavement, RAP Management (fractionating, stockpile management practices, etc.), material heterogeneity (RAP Asphalt Content & Gradation) and other sources of variations caused RAP variability, [34][35][36][37]. In the second trial the bottom layer gained a higher air voids content (air voids content about 17%), while in the aggregate gradation the excess of sand resulted quite negligible. These facts affected permeability which increased (k ranged from 0.04 to 0.06 cm/s). Texture requirements were assessed in terms of sand height and fulfilled PEM requirements.

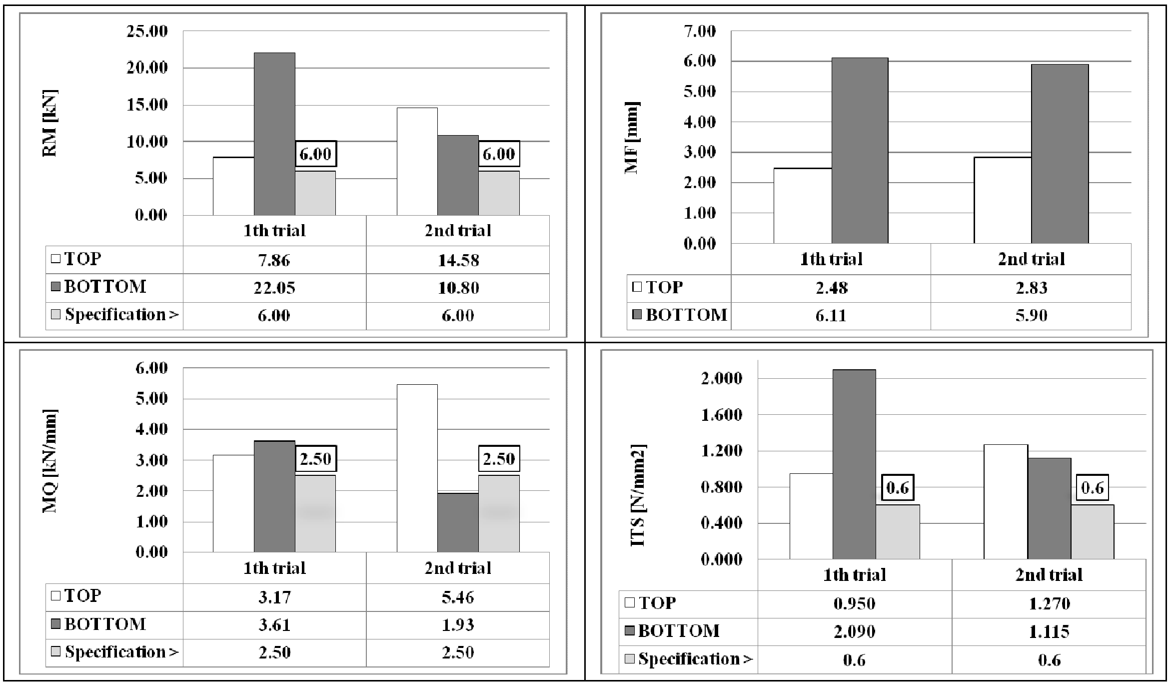


Figure 9 - Marshall stability (RM), flow (MF), quotient (MQ) and indirect tensile strength (ITS)

5. CONCLUSION

Several millions of square meters of porous European mixes are going to be laid in South Italy.

As a consequence, the successive rehabilitation will pose technical problems and environmental issues pertaining sustainability.

In the light of these premises, objectives and scopes were focused on the idea of recycling porous asphalt concretes back into porous asphalt concretes and two main issues were addressed, pertaining bearing properties and friction properties of the rehabilitated wearing course.

In order to investigate on the abovementioned issues an experimental plan was designed and carried out. Sustainability was analysed. Around the 80% of RAP was used and a two-layer porous asphalt was derived from the reclaimed asphalt pavement.

Recycled mixes were produced and tested at the DIMET and DIPITER laboratories.

Mechanical performance and surface texture were quite satisfactory. Functional performance resulted encouraging. Tests carried out are promising about the potential in terms of surface performance.

Future research will aim at gaining an enhanced knowledge of surface vs. traditional performance balance.

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