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A new era for rubber asphalt concretes for the green public procurement in road construction

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Abstract

Delivering a safe and sustainable infrastructure starts from the public procurement approach and from the adoption of good practices that are able to improve the environmental and structural performance as well as to extend the maintenance cycle of the infrastructure itself. Besides the traffic-related impacts, the construction phase of a road generates the largest environmental impacts within its entire life cycle. Hence, procuring road construction and maintenance with a reduced environmental impact is a complex process that should focus, above all, on durability. Since the 60's, Rubberized Asphalt Concretes (RAC) have proven to be consistent technologies for the construction of long lasting, cost effective and quiet asphalt pavements, worldwide. Notwithstanding that, the use of RAC is still rare in Europe, mostly because of cultural limitations rather than technical restraints. In recent years, a national regulation in Spain and the growing concern for environmental noise in Italy have encouraged a regular use of RAC in both countries and new rubberized technologies have developed. An overview of new hybrid wet and dry processes is here presented, providing new synergies between PmBs and CRM that meet the sustainability requirements at the basis of the Green Public Procurement philosophy.

1. Introduction

Innovative technologies with regard to improved energy and material efficiency of asphalt pavement construction are being developed by road industries and research laboratories almost every year. Most of these are aiming to increase the Green Public Procurement approach directing the municipalities towards the design and construction of new greener roads. Goals are: less impacts during production and construction and, from a context-sensitive design point of view, reduced in-service emissions and maintenance.

Life Cycle Analysis tools and methods have been developed to justify some higher initial costs and highlight the benefits of those technologies in terms of:

- abatement/removal of noxious or dangerous materials and emissions;
- reduction of environmental impacts during construction;
- reduction of impacts during the pavement service life.

Today, it is quite common to represent the overall design/construction/in-service impacts by means of CO_2 equivalent Green House Gas emissions and work out comparisons of the alternatives. It is known that most of these gasses - up to 95-98% - will be produced during the service life of the pavement and that their amount is strictly related to the pavement smoothness, thus also to the durability of its surface layers. The construction and maintenance emissions are, although limited to less than 5%, of high time-concentrated impact for the road-workers and for people living, traveling or working within a certain distance from the construction site.

In this scenario the development of new greener materials and technologies will have a substantial effect on the overall impact of the road infrastructure, both in terms of construction emissions and pavement durability, i.e., smoothness and maintenance during its life. If recycled materials are to be used, the environmental balance is positive from the very moment that no virgin materials are supplied and secondary materials are brought in. Hence, the bituminous pavement industry can and should have a great influence on green procurement policies as most of the transportation infrastructure impacts are related to materials such as Reclaimed Asphalt Pavements, Construction and Demolition aggregates and crumb rubber from End-of-Life tyres. These materials are under research assessment it is now decades and their effectiveness in providing more durable and less impacting pavements is reported in an infinite number of publications and reports available worldwide.

From this perspective, this paper deals with new hybrid dry processes in the Rubberized Asphalt Concretes (RAC) approach, providing new synergies between Polymer Modified Binders and Crumb Rubber Modifier that meet the sustainability requirements at the basis of the Green Public Procurement philosophy.

2. Background: the Asphalt Rubber Technology

The use of recycled rubber from end of life tyres (ELT) into asphalt concretes started back in the 60ties and the technology that has widespread more is certainly the so called Asphalt Rubber (AR) one. AR binders are produced with the industrial process invented by Charles McDonald and that is at the basis of the wet process. This process starts with the mixing of the ELT ground rubber with the bituminous binder using mechanical stirring systems working at temperatures ranging between 190 and 218°C for a time interval of 45 to 60 minutes [1-2]. The correct level of interaction between the two constituents is met during the initial stages of the "digestion" process and correspond to the swelling of the rubber particles, to the following formation of a gel structure and to the development of a three component system (rubber, gel and bitumen). In fact, it is known that rubber and bitumen has to interact through mixing for an agitation time longer than 45 minutes at those temperatures, in order to get the needed increase in performance. The following phases of the digestion process, such as depolymerisation (devulcanization) and the dilution of rubber into bitumen, are avoided keeping the maximum mixing time as much as lower than 2 hours. With the aim of maintaining the reaction temperature in the required interval, the bitumen should be preventively heated at slightly higher temperatures falling between 204 and 224°C before adding the rubber powder that is at ambient temperature and thus will reduce the mixing one [1-3-4].

This process, normally used for the production of the Asphalt Rubber, is defined as the high viscosity wet process and leads to the production of a final material that has a number of advantages such as the increase in elasticity and viscosity at high temperatures. The new binder is believed to create a thicker and stronger bituminous coating of the aggregate which reduces the phenomenon of segregation and bleeding in the asphalt mixture [1]. Nevertheless the AR binders have the disadvantage of lacking in storage stability; initially, during mixing, the incorporated rubber particles are lighter than the bitumen and float on the surface, whereas later after mixing, they swell and increase in density thus sedimenting. For this reason, either during the production and storage, these binders require specific tools to keep the rubber particles in motion so has to have them uniformly distributed in the binder volume.

Generally the wet process bitumens are defined as "high viscosity" because the exhibit a dynamic viscosity higher than 1500 cP at the temperature of 177°C as described in the ASTM standard. To reach these high values the AR binders has to be produced with a rubber content ranging between 18 and 22% on the weight of the bitumen [4]. According to the ASTM D6114 standard, the AR is defined as a mixture of asphalt binder, Crumb Rubber Modifier and other required additives where the rubbery component is at least 15% of the whole mixture and has reacted with the hot bitumen as much as to generate the swelling of the rubber particles [5].

In spite of the proven advantages of ARs, as clearly stated in the last few International Asphalt Rubber Conferences, a consistent and firm track in the use of this technology has still to come. For this reason, even if it is well known and widespread, it is still not a common practice in many countries, especially in Europe.

Some of the reasons come from the following disadvantages of the high viscosity wet process:

- the very high production temperatures (higher than 190°C) and long mixing/reaction times (from 45 to 60 minutes);
- the need of usually expensive and complex additional stirring tools at the production plant;
- the need of reheating the binder during storage;
- high binder content leads to higher costs of the pavement (generally more than 20%).

In Europe, with the exception of Portugal and Spain, the use of these materials is limited to experimental sites and tests that have usually confirmed the value of the material, but also highlighted some potential drawbacks related to the higher binder viscosity. It is a few years today that in Spain and Italy new hybrid technologies are emerging in order to overcome these issues and find a synergy between Polymer Modified Binders and rubberized asphalts, while taking advantage of the characteristics of the rubber.

In the following sections, after a detailed overview of the rubber asphalt techniques adopted in Europe, a deeper description of the new Spanish and Italian technologies is given.

3. Use of the Asphalt Rubber in the European Country

3.1. Swedish Experience

In 2006 the Swedish Transport Administration began a project to evaluate Asphalt Rubber pavements for Swedish conditions, based on Arizona experience, where the Asphalt Rubber is a consolidated technique. In 2007 Asphalt Rubber was tested on a number of sections on different roads in Sweden. Asphalt pavements were constructed both with Asphalt Rubber and traditional mixture in order to compare wear and durability. The aim of these studies was to prevent cracking phenomena using AR. From the American experience in fact it was found that the asphalt rubber layer can absorb and evenly distribute the forces imposed by the vehicles. The method today used in Sweden is the so-called wet method, i.e. rubber granulate is mixed with the bitumen. Asphalt Rubber bitumen is then added to the asphalt plant in the traditional manner. The proportion of rubber granulate in the binder is approximately 17-20 pw, which means that the amount of rubber mixed in it is approximately 1.5-2% of the total quantity of asphalt compound based on a content of asphalt rubber bitumen of approximately 8%. The temperature of the bitumen being added must be at least +175 °C and the rubber and bitumen must be allowed to react for at least 30 minutes while being stirred and circulated. The rubber granulate consists in 0/2 mm graded rubber and not containing more than 0.01% of steel or other impurities, nor it contains more than 0.5% of textiles. The rubber granulate must have a specific weight of 1.15 ± 0.05. The moisture content may not exceed 0.2 pw. From the studies conducted on a Gap Graded Asphalt Rubber mix, following the Swedish requirements, the Asphalt Rubber have shown the most positive properties as good resistance to wear and slow crack propagation. The pavement also has shown good durability. Results so far have demonstrated that rubber pavements fully meet today's requirements concerning rubber pavements in terms of stability, flexibility, fatigue and durability, and have somewhat better properties in terms of cracking and resistance to wear. Regarding resistance to wear, however, it is uncertain whether the Prall method (EN 12697-16) correctly describes wear from studs for this "elastic" product [6].

In terms of environmental benefits, Viman et al. have evaluated that the mixing rubber in the asphalt generally appears to reduce the generation of PM_{10} in case of wear from studded tyres, but the reduction is dependent on the design. In particular from these Swedish studies it was found that:

- Ultra-fine particles are formed, as in all experiments involving studded tyres, but the effects of the pavements with rubber mixed in on these particles' concentrations is not consistent.
- The stone material in the first project (quarzitic sandstone), in particular the reference pavement, gave rise to higher particle concentrations than the material in the second project (rhyolite). The size distribution of the PM_{10} also differs somewhat between the stone materials.
- The size distribution of the PM_{10} from the Asphalt Rubber pavements is similar to that from the reference pavements in both projects, but the design appears to affect where in the distribution the reduction mainly occurs [6].

3.2. Portuguese Experience

The first Asphalt Rubber (AR) work in Portugal was completed in August 1999 and consisted in the Rehabilitation (re-surfacing) of the wear layer of EN 104 and EN 105 roads, with a total length of 22 km. For this work 1700 tons of modified bitumen with a high percentage of rubber (18%) obtained through the wet-process were used. From laboratory studies the AR mixture has shown better fatigue resistance than traditional mixture and six years after, the fatigue resistance of the AR is still close to the initial values. From the Valorpneu database, the use of Asphalt Rubber (AR) since 1999 in Portugal was adopted in the construction of 700 km of roads and highways, using 54,000 tons of rubber bitumen. During the past ten years, a change in the typical composition of AR mixtures used in Portugal has occurred. For example, the first type of mix applied in Portugal was a gap-graded AR mixture manufactured by the wet process, using 7% of rubber modified bitumen. Today, gap-graded mixtures are produced with a higher content of bitumen rubber (8% to 9%). On the other hand, there is a wider range of bitumen rubber binders on the Portuguese market, such as in situ manufactured binders with high content of crumb rubber and ex situ manufactured binders with lower contents of crumb rubber.

Since the first application of asphalt rubber mixtures in Portugal, several research studies addressing its performance have been carried out. The effect of the manufacture procedure of the rubber bitumen and of the characteristics of its components (rubber and bitumen) on the mix properties has also been addressed. In particular in the study "*Asphalt Rubber Mixtures in Portugal: Practical Application and Performance*" the authors studied the performance of field and laboratory produced wet process AR specimens. Four point bending beam tests along with rolling wheel rutting tests were performed. The findings indicate that significantly higher strain levels are allowable for a given number of cycles to failure than in conventional asphalt mixes. It was found that the AR stiffness increased significantly during the first six years of service and that the authors' laboratory aging process was able to mimic this performance. The authors felt that both the new and aged AR specimens performed better than conventional mixtures. With respect to rutting, AR deformation resistance increased with aging, as expected with the binder stiffening. In constructing these pavements, it is suggested that the compaction equipment closely follow laydown as these materials cool quickly and that strict compaction temperature guidelines be followed. Asphalt plants using this technique must be specially adapted to control the reaction between the asphalt and the crumb rubber and this reaction must be kept under strict control [7].

3.3. German Experience

A new rubber modification method was developed in Germany with the aims to combine the logistic advantages of the dry method with the controllable quality of the wet method and to add warm mix properties. This was achieved by the pre-treating of the crumbed rubber with a swelling agent, under controlled conditions, at elevated temperature and by adding a warm mix wax additive, which is liquid at the pre-treatment temperature. Swelling agents without health and safety risks during processing and future asphalt recycling, such as non-aromatic mineral oil fractions and vegetable oils are part of the new process. Due to pre-treatment, fewer maltenes are absorbed by the rubber and the colloidal balance and properties of the bitumen are less influenced. The warm mix wax additive gets quickly liquefied and released into the bitumen in the asphalt mixer, decreases the viscosity and allows temperature reductions. Innovative compounds of ground tire rubber, swelling agent and warm mix wax additive were produced by a pre-treating technique [8]. These compounds combine the advantages of the wet and the dry rubber modification method. The rubber modification can be performed by direct addition to the asphalt mixing plant in the needed batch size and avoids the demanding logistics of the wet modification. Pre-treating the rubber decreases to a large extent the risks of insufficient rubber-bitumen interaction and varying binder quality. The described and a few further field tests substantiated that this direct addition allows obtaining asphalt properties that are comparable with the usage of rubber bitumen from the wet modification. Also for the wet modification route, these pre-treated rubber compounds offer advantages as the time window for storage and application of the binder is significantly widened. Butz et al. have confirmed that the combination of this wax additive decreases the viscosity of the binder, improving the handling and compaction behavior of the asphalt mix and allows lower production and paving temperatures. The new rubber compound technology overcomes current drawbacks and limitations of rubber modified asphalt and opens up the possibility to extend the use of this technologically and environmentally beneficial pavement [8].

3.4. French Experience

In France, after 10 years of scattered experiments, Porous Asphalt Concrete (PAC) mixes are expected to solve the problems of aquaplaning, water projection, noise reduction and the mirror effect at night. To reduce the problems related to porous asphalt winter condition, a French study has proposed a new porous asphalt mixture composed by an Asphalt Ground Rubber mix. In order to characterize this mixture, the laboratory mechanical test and experiments on site have been performed. The studied implemented in France have shown clearly the advantages of Asphalt Rubber Binder in porous mixes in terms of durability, constant draining properties, good behavior under heavy trucks traffic (fatigue and rutting resistance) shearing stress resistance and insensibility to bad weather [9].

Back in the 1990s Colas had developed so-called "noise-reducing" mixes which provide a response to problems of control of traffic noise. Noise-reducing asphalt mix usually has a specific grading curve – 0/6 or 0/10 mm – to help forming a communicating network of air voids, which represents from 15 to 30% of the mix volume. It was above all towards the turn of the century that significant progress was made. The so-called "second generation" noise-reducing mix, Rugosoft®, combined high skid-resistance with enhanced ability to absorb vehicle rolling noise: the attenuation of noise emissions can be as great as 7 decibels (compared with a very thin asphalt concrete wearing course, i.e., a division by five of the acoustic power). In 2005 Colas went a step further with the "third generation" noise-reducing mix, Nanosoft®. The optimized grading of this product enables a noise reduction of up to 9 decibels compared to a 0/10 very thin asphalt concrete, while preserving excellent anti-skid properties. The evaluation of test specimens of different thicknesses also helps to determine the optimum dimensional ranges for in situ application. The grading curve has also been optimized for the design of Nanosoft®. During the development of this process the contributions of atypical additives such as specific elastomers (cf. running tracks) or rubber and other variants enhancing sound wave absorption were also evaluated. The results has shown a reduction of 7 decibels emission comparing Colas'mixtures with a traditional asphalt layer [10].

4. Polymer modified binder combination with rubber: the Spanish Experience

4.1. Main Technology Characteristic

The General Technical Specifications for Road and Bridge Works of the Spanish Ministry of Public Works and Transport, introduces the possibility of using bitumen or mixes modified with rubber, as long as they comply with the required specifications. SIGNUS Ecovalor, in collaboration with the department of Civil Engineering-Transport of the Polytechnic University of Madrid, has recently concluded a research aiming to the development of a formulation and to the production of rubber modified bitumen complying with the criteria specified in the reference legislation for roads. One of the main goals of the project was to produce some specific guidelines for the production of the rubber bitumen meeting the requirements of the Spanish specifications. It is well known that the characteristics of rubber bitumen depend on the origin and granulometry of the rubber, on the base bitumen and on the polymer, not only in terms of its penetration, but also for its chemical characteristics. In order to improve this approach, some reference Spanish binders have been selected having the aromaticy in the range of 76.3% to 63.5%. The asphalt mixture design uses the most common granulometry for rubber powder in Spain, 0-0.8 mm, either with high natural content (47%) and average natural content (38%). Three categories of binders were obtained by using rubber powder from ELTs:

- Rubber Improved Bitumen (rubber content: 10-11 %).
- Polymer and Rubber Modified Bitumen (rubber content: 4-12%).
- High Viscosity Asphalt Rubber with a high powder content (rubber content: 18-22 %).

4.2. Rubber Improved Bitumen

The rubber improved bitumens are based on the regulation of the Spanish Department of Transportations. These bitumens are improved having a higher softening temperature than normal binders. Their nomenclature is composed of the letters BC followed by the penetration range. There are two types: BC 35/50 and BC 50/70. The recommendation is that they can be used in the production of all kinds of bituminous mixtures, for all layer and traffic categories in which the penetration bitumen can be used. Their manufacturing is simple due to their low rubber content (not very high viscosity). However they may decant, so appropriate measures must be taken during their manufacturing and handling. The recommended formulations for these binders are described in table 2 with protocols 1 and 2:

Table 2. Spanish Rubber Improved Bitumen production protocols.

	PROTOCOL 1	
	BC 35/50	
COMPONENTS	PRODUCTION	HANDLING AND STORAGE
Base Bitumen: B 50/70	Temperature: 185 °C	The product may decant. It is necessary to use tanks provided with remover.
Rubber: 0/0.8 mm	Type of mixer: helix, 4.000 rpm	
% Rubber (s/Bitumen): 10%	Digestion time: 60 min	
	PROTOCOL 2	
	BC 50/70	
COMPONENTS	PRODUCTION	HANDLING AND STORAGE
Base Bitumen: B 70/100	Temperature: 185 °C	The product may decant. It is necessary to use tanks provided with remover.
Rubber: 0/0.8mm	Type of mixer: helix, 4.000 rpm	
% Rubber (s/Bitumen): 10%	Digestion time: 60 min	

4.3. Rubber modified Bitumen (PmB C)

For this type of binders, part of their modification is obtained with rubber, since some polymers are normally also included. Their technological characteristics are based on the Spanish DoT specifications. Two rubber modified bitumen are mentioned: PmB 45/80-60 C, and PmB 45/80-65 C. The “C” letter means that they contain rubber from tyres. It must be taken into account that these binders may also decant, so appropriate measures must be taken during their manufacturing and handling. The recommended formulations are described in table 3 with protocols 3 and 4:

Table 3. Spanish Rubber modified bitumen (PmB C) production protocols.

PROTOCOL 3		
PmB 45/80 – 60°C		
COMPONENTS	PRODUCTION	HANDLING AND STORAGE
Base Bitumen: B 110/120	Temperature: 185 °C	The product may decant. It is necessary to use tanks provided with remover.
Rubber: 0/0.8mm	Type of mixer: helix, 8800 rpm	
% Rubber (s/Bitumen): 4-5%		
% Polymer C411 (s/Bitumen): 2.5-3%	Digestion time: 60 min	
PROTOCOL 4		
PmB 45/80 – 65°C		
COMPONENTS	PRODUCTION	HANDLING AND STORAGE
Base Bitumen: B 70/100	Temperature: 185 °C	The product may decant. It is necessary to use tanks provided with remover.
Rubber: 0/0.8mm	Type of mixer: helix, 4.000 rpm	
% Rubber (s/Bitumen): 10%		
% Polymer C411 (s/Bitumen): 2.5-3%	Digestion time: 60 min	

4.4. Rubber modified bitumen of high viscosity (BMAVC)

The high viscosity bitumens are also based on the DoT regulations, and they are hard modified binders. Guidelines are given for the manufacturing of two of them: BMAVC-1 and BMAVC-3. The first one is made with high rubber percentages and reaches a very high viscosity, while the second is manufactured with rubber and polymer and other chemical additives producing a less viscous binder, although well above the conventional values for plain bitumen. A third type of high viscosity binder is also presented and called BMAVC-1b, where “b” means that it is a softer version than BMAVC-1. The reason why it is here included is that, after the regulation approval it has been observed that the BMACV-1 does not offer the required flexibility on areas with very cold winters. The high viscosity rubber binders are specially recommended when a high resistance to cracking is required, even more on semi-rigid pavement and concrete slabs regrowth. These are all binders that tend to sedimentation, so the appropriate measures must be taken during production, storage and handling. The formulations of these binders are shown in protocols 5, 6 and 7.

Table 4. Spanish Rubber modified bitumen of high viscosity (BMAVC) production protocols.

PROTOCOL 5		
BMAVC-1		
COMPONENTS	PRODUCTION	HANDLING AND STORAGE
Base Bitumen: B 35/50	Temperature: 195 °C	The product may decant. It is necessary to use tanks provided with remover.
Rubber: 0/0.8mm	Type of mixer: helix, 4000 rpm	
% Rubber (s/Bitumen): 22%	Digestion time: 60 min	
PROTOCOL 6		
BMAVC-2		
COMPONENTS	PRODUCTION	HANDLING AND STORAGE
Base Bitumen: B 50/70	Temperature: 185 °C	The product may decant. It is necessary to use tanks provided with remover.
Rubber: 0/0.8mm	Type of mixer: helix, 4.000 rpm	

% Rubber (s/Bitumen): 22%	Digestion time: 60 min	
PROTOCOL 7		
BMAVC-3		
COMPONENTS	PRODUCTION	HANDLING AND STORAGE
Base Bitumen: B 110/120	Temperature: 185 °C	The product may decant. It is necessary to use tanks provided with remover.
Rubber: 0/0.8mm	Type of mixer: helix, 8800 rpm	
% Rubber (s/Bitumen): 4-5%		
% Polymer C411 (s/Bitumen): 3.5-4.5%	Digestion time: 60 min	

5. Dry-hybrid Technology: the Italian Experience

5.1. Main Characteristics

The Dry-hybrid technology experimented in Italy in the last few years by the Road research group of the University of Bologna and its first producer, Valli-Zabban SpA, allowed the production of a modified wearing course where the rubber powder is added directly in the mixer, without any significant alteration of the normal production process. The mixer direct incorporation is in continuity with the former dry technique, keeping its advantages – mainly absence of odors – adding those related to the enhancement of the rheological properties of the modified binder adopted in the mix. The rubber powder acts as an active functional filler that is able to increase the modified binder workability in the bituminous mixtures. Their components are volumetrically designed so their distribution within the layer, has a key role either with respect to the abatement of the potential spring-back phenomenon of the compacted material, and with respect of the sought surface characteristics of noise generation reduction at the source (i.e. tire-pavement contact) and noise absorption.

Also, the rubber powder-bitumen compatibility acts as an advantage when bitumen-rich asphalt concretes are produced (e.g. Stone Mastic Asphalts (SMA)). Here the rubber can behave as a stabilizer pairing the traditional cellulose fibers or similar ones. The Dry-hybrid technology follows the principles at the basis of the dry new-generation technology making use of polymer modified bitumen enriched with viscosity reducing additives. The rubber powder is added to the asphalt concrete mixture without changing its original gradation (no substitution of sand) and the production temperatures are those generally used for Warm Mix Asphalts. The fine rubber grading size enables its interaction with the warm bitumen and with the filler that can be partly substituted in the mastic creation. Furthermore, the reduced temperatures of production enable the attainment of larger advantages from the environmental point of view: energy consumptions are abated together with the emissions. Hereafter, the results coming from a research based on this technology will be presented, highlighting the main reo-mechanic characteristics transferred from the rubber powder to the bituminous mastics and to the final mixture. Attention will be paid to the environmental advantages during construction (reduced laying temperatures and emissions) and during the in-service phase (reduced acoustic emissions).

5.2. Rheological Behavior

The development of the Dry-hybrid technology started from a set of trial sites where economically feasible asphalt concretes were produced, laid and monitored from construction to more than 12 months later. In these trial sites the supply of bitumen and rubber were kept constant, while aggregates and their gradations changed according to the available materials. Table 5 shows the asphalt mixtures characteristics for 4 different trial sites. From these mixtures the mastic composition was reproduced in the laboratory and rheologically tested.

Table 5. Dry-hybrid trial sites in Italy: mixtures' gradations and compositions.

Trial site location	Zola Predosa	Zola Predosa	Zola Predosa	Imer	Finale Emilia	Giardini di Coracolle
SMA mixes with %	BIT 6.5 ELT 0.0	BIT 8.5 ELT 1.20	BIT 7.5 ELT 0.75	BIT 7.5 ELT 0.75	BIT 7.5 ELT 0.75	BIT 6.5 ELT 0.0
EN sieves (mm)	Passing (%)	Passing (%)	Passing (%)	Passing (%)	Passing (%)	Passing (%)
8	98.2	98.5	98.1	99.5	99.7	N.A

6.3	85.0	88.1	87.4	91.5	98.4	N.A
4	46.0	51.2	50.5	55.7	61.8	N.A
2	26.0	25.2	24.6	25.4	27.7	N.A
1	19.9	18.2	17.8	17.5	18.8	N.A
0.5	16.3	14.2	13.9	14.0	13.5	N.A
0.25	13.4	9.6	9.5	11.7	9.8	N.A
0.125	10.5	6.7	6.5	8.9	7.6	N.A
0.063	8.0	4.7	4.5	7.0	5.8	N.A
Mix Composition						
Bitumen [%]	6.55%	8.53%	7.51%	7.49%	7.91%	6.55%
Rubber powder [%]	0%	1.20%	0.75%	0.75%	0.75%	0%
Laying temperature [°C]	130°C	130°C	130°C	130°C	130°C	130°C

The Dry-hybrid technology is validated starting from the rheological studies of the mastics obtained mixing the polymer modified binder with traditional limestone filler and rubber powder. The mixing percentages are referred to the gradations and compositions reported in Table 1. From the rheological point of view in the Dry-hybrid technology the rubber powder is an active filler that reduces the thermal sensitivity of the base bitumen.

This can be seen in the master curves of Figure 1, where examples of results from Dynamic Shear Rheometer frequency sweep tests are plotted both for the modulus and the phase angle.

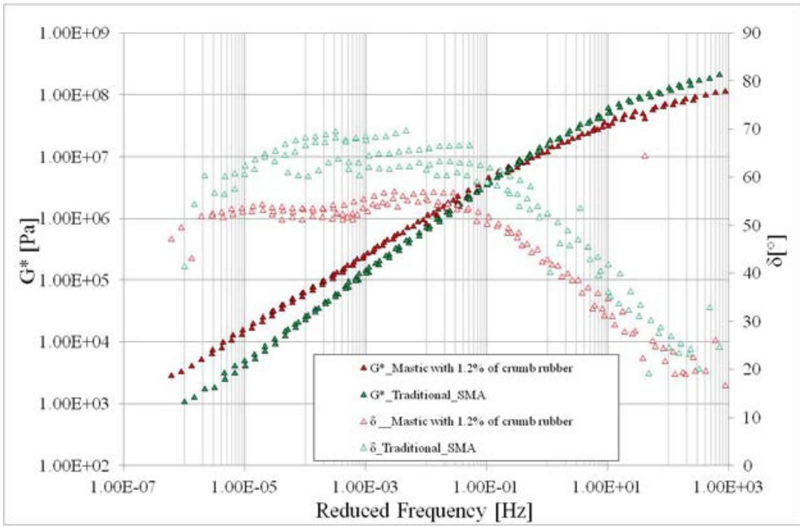

Fig.1 Master Curves of SMA with BIT 8.5 and ELT 1.20 and control SMA mastics.

Considering the control SMA mastic and one of the Dry-hybrid experimental mixes, the addition of a 1.20% of rubber substituting such a small quantity of filler, contribute to the increase of stiffness at high temperatures, favoring the resistance to permanent deformations. Furthermore, the presence of the rubber powder reduces the mastic brittleness at the lowest temperatures. The decrease of the phase angle in rubber mixtures makes their response to deformations at high temperatures more elastic if compared to the one recorded on mastics containing only limestone filler. The traditional SMA mastic shows moduli that are lower at high temperatures and higher at low temperatures than the SMA containing rubber. Therefore, it can be stated that the mastic without rubber is more prone to deform at the highest temperatures and to fracture at the lowest ones.

5.3. Construction Benefits

The rheological studies on the Dry-hybrid mastics allowed the optimization of the rubber powder contents in the SMA mixtures. This process was repeated for the different trial sites in relation to the constituent materials available on each roadwork. Most of the experiments were based on the results of a two lane trial site located in Zola Predosa, not far from Bologna. Here a traditional PmB SMA control warm mixture was laid in a 4 cm compacted layer next to two paved sections containing Dry-hybrid warm mixtures with different constituent proportions as shown in Table 1. Gradation were almost identical and production and laying methods were the same for all mixtures. The benefits of the proposed technology arouse firstly during construction as the material workability and compactability was consistently good from the laying temperature of 130°C down to less than 100°C. No odors or blue fumes were recorded and the workers and technical staff were positively impressed by these unexpected characteristics of mixtures with rubber. Figure 2 shows the three road sections in Zola Predosa and the thermal pictures taken just behind the paver.

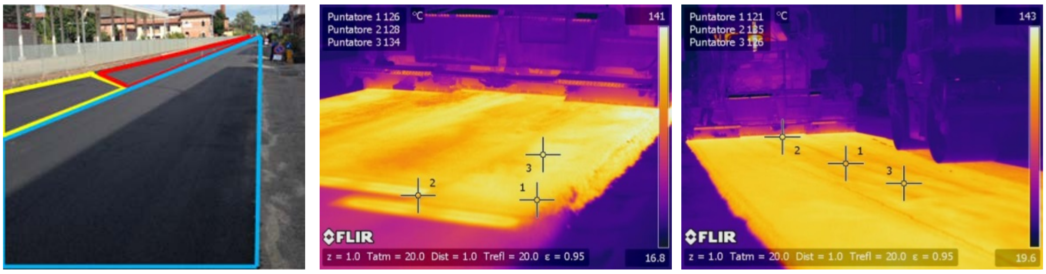

Fig. 2. Zola Predosa experimental road sections (control SMA on the right and two rubber SMAs on the left) and laying temperatures.

5.4. Emissions Reduction

The emissions during laying of the Dry-hybrid asphalt concretes were monitored by means of standardized equipment and methods (Figure 3). The monitoring is still ongoing in additional sites to expand the database and increase the reliability of the analysis.

Fig. 3. Air monitoring equipment and methods during the construction activities.

Based on the outcome of the monitoring activities, the use of rubberized asphalt resulted in a significant, though slight reduction of the incremental health risk for workers. At this stage, given the limited number of monitored sites, it is not possible to prove that the observed benefit has to be associated to site-specific conditions rather than to an actual reduction of the release of PAHs from rubberized asphalts. To understand this aspect, a specific laboratory activity aimed at studying the release of PAHs in controlled conditions from a range of rubberized and standard asphalts is on-going. In the meanwhile, monitoring activities are also planned on a number of additional sites.

The monitoring also showed that the risk for the workers in the observed road paving works was limited. The highest calculated incremental risk resulted, (screedman, standard asphalt) in the order of $3.4x10^{-5}$, which is slightly higher than the generally accepted incremental risk for occupational exposure of $1.0x10^{-5}$, whilst all the workers laying rubberized asphalt were exposed to a risk lower than $1.0x10^{-5}$.

The risk associated to dermal exposure was around one order of magnitude lower than the risk associated to inhalation exposure, ranging from $7.8x10^{-7}$ to $5.6x10^{-6}$.

Although the risk for workers is not alarming, the use of simple Personal Protective Equipment like disposable facial masks equipped with activated charcoal cartridges, of light, disposable suits could easily lower it of one order of magnitude, and it is therefore recommended for this type of activity [11].

5.5. Acoustic Emissions

To complete the environmental investigation a set of acoustic emission tests were performed in-situ (here the Zola Predosa trial site is shown). In particular, the emissions test by tire/pavement interaction were performed according to the Close Proximity Index (CPX ISO / DIS 11819-2) method that includes a pair of microphones positioned near the wheel vehicle at a short distance from the surface layer (Figure 4).

Fig. 4. CPX test in Zola Predosa.

In order to characterize the acoustic behavior of the three road pavement surfaces (SMA, SMA 8.5 ELT 1.2, SMA 7.5 ELT 0.75), the mean Lcpx values were compared (Table 6). Tests were done two month after pavements construction.

Table 6. Zola Predosa Lcpx results.

Lcpx		
Zola Predosa	Average Value dB(A)	Δ dB(A)
SMA	87,4±1,4	-
SMA 8.5 ELT 1.20	86,7±0,5	-0,7±0,8
SMA 7.5 ELT 0.75	86,7±0,6	-0,7±0,8

The average value of Lcpx [dB(A)], with its associated uncertainty, recorded on 52 measured segments (a segment is equal to 3 turns of the wheel, ie 5.85 m) in the SMA portion is 87.4 ±1 , 4 dB (a), with a minimum of 86.1 dB (a), and a maximum of 89.2 dB (a). The average value of Lcpx is equal to 87.4 dB (A). The average value of Lcpx [dB (A)], with its associated uncertainty, recorded on 23 segments measured present in the stretch SMA 7.5 ELT 0.75 is 86.7±0.6 dB (A), with a minimum of 86.1 dB (A) and a maximum of 87.3 dB (A). The average value of Lcpx equal to 86.7 dB (A). The average value of Lcpx [dB (A)], with its associated uncertainty, recorded on 27 segments measured present in the stretch SMA 8.5 ELT 1.2 is 86.7±0.5 dB (A), with a minimum of 85.8 dB (A) and a maximum of 86.9 dB (A). The average value of Lcpx is equal to 86.7 dB (A). The results have shown that there are no significant differences between the two pavements containing rubber powder, both in terms of absolute and differential values. Their acoustic emission is less than the reference SMA. Table 7 reports the differential results obtained considering the pavement adjacent the trial roads as reference, in order to compare the acoustic emission of the existing pavements with the experimental ones.

Table 7. Differentials Lcpx values at 50 km/h speed compared to the existing pavement.

Zola Predosa	Δ dB(A)
OLD SURFACE LAYER	-
SMA	-3.3±0.7
SMA 8.5 ELT 1.20	-4.0±0.3
SMA 7.5 ELT 0.75	-4.0±0.3

The three SMA surface layers have shown an improvement in terms of acoustic emissions compared to the existing pavement: in particular, the two SMA containing rubber powder have both the largest reduction of sound emitted levels.

6. Conclusions

An overview of the European techniques on the use of rubber powder in asphalt mixtures was given. The main studies have shown that, although with some disparities, the wet technique is mostly used, based on the US experience. Although the researches have shown that these materials provide a number of advantages, their production in Europe, with some exceptions, described in this paper, is still far from being a common practice. The reasons of this are mainly due to:

• the lack of demand, of leading companies and governments investing on the use of these materials;

• the environmental and production limits related to the higher viscosity binders.

Therefore, the aim of this paper was to present new techniques for the use of rubber powder in bituminous mixtures, describing:

- the Spanish experience, with design guidelines and production a whole range of modified bitumens containing rubber powder at various extents;
- the Italian experience where a new Dry-hybrid technique was designed and site-proven to overcome the environmental limits traditionally encountered in the high-viscosity modified wet technique.

Both the described techniques have shown that:

- there is enough knowledge and data to include rubber asphalts in the national technical specifications;
- the development of these new technologies made it possible the use of rubber powder improving the rheological characteristics of the layers, reducing the environmental impacts during the road construction and improving the acoustic performance of the pavement surface.

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