Asphalt Rubber: policy disclosure in Italy

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ABSTRACT. *In the present paper, it is presented a proposal for an evaluation systemic approach aimed at the characterization of Asphalt Rubber Hot Mixes (ARHM). This constituted the input to develop a careful scientific-technical assessment process to assure the quality control of ARHM. In particular, this kind of approach allows i) to take immediate action to technical production and laying of ARHM that should also guarantee "traditional" Italian road materials specifications ii) to develop AR expertise in terms of mechanical performance (stiffness, fatigue resistance and permanent deformation resistance) and functional properties (noise and skid resistance), trying to bridge the gap of knowledge with the international experience of forty years of successful use iii) to develop innovative scientific research to provide original contributions to engineering road materials investigation.*

KEYWORDS:*Evaluation systemic approach, Asphalt Rubber Hot Mixes, Wet process*

1. Introduction

Asphalt Rubber (AR) is a mixture of hot asphalt and crumb rubber derived from waste scrap tires (ASTM D-6114). This type of blending process is called “wet”. It was invented in the United States in the State of Arizona in the late 1960’s. AR is commonly used as binder for wearing course hot mix asphalts in order to improve smoothness and skid resistance and to reduce cracking and traffic noise. While in many countries all over the world it is used extensively and successfully in the highway paving industry, in Italy AR technology is quite new and first applications were made in 2006 (Santagata *et al.*, 2008).

The study presented in this paper came about as a result of the ever-growing demand for high performances in the field of road constructions, which lead investigation into asphalt binder properties, surpassing the current traditional empiricist approach in favor of a more specific characterization. Particularly, the interest in developing this scientific investigation is aimed at driving the worth of industrial utilization of asphalt binders over traditional asphalts, and systemizing its classification, based on the most innovative specifications. Adding to all this, there is also an environmental concern linked to the possibilities of re-using a significant amount of reclaimed tires given by Asphalt Rubber Hot Mixes (ARHM).

This paper focuses on an evaluation systemic approach aimed at the characterization of ARHM, describing the first steps adopted to have Asphalt Rubber “made in” Italy: a global strategy which strongly involved the, at the moment, unique Italian producer of Asphalt Rubber binder (*Asphalt Rubber Italia*), CIRS (*Experimental Interuniversity Road and Airport Research Centre*) representing the most important scientific entities in Italy and some local agencies.

2. Systemic approach

2.1. *Formulation of Asphalt Rubber binder*

Experience has shown that by properly combining the waste product of ground tire rubber (Crumb Rubber Modifier - CRM) with asphalt at high temperatures the resultant Asphalt Rubber binder will have many improved superior engineering properties. Such improved engineering properties include reduced fatigue and reflection cracking, greater resistance to rutting, improved aging and oxidation resistance and better chip retention due to thicker binder films (Partl *et al.*, 2009; Santagata *et al.*, 2007; Souza *et al.*, 2005; Zborowski *et al.*, 2004; Potgieter *et al.*, 2002; Kaloush *et al.*, 2003; Cook *et al.*, 2006; Kumar *et al.*, 2005; Bertollo *et al.*, 2004). Also Asphalt Rubber pavements have demonstrated to have lower maintenance costs (Way, 2000; Jung *et al.*, 2002), lower noise generation (Pasquini, 2009; Antunes *et al.*, 2006a; Leung *et al.*, 2006), higher skid resistance and better night-time visibility due to contrast in the pavement and stripping (Antunes *et al.*, 2005).

Asphalt Rubber binders have specific and unique characteristics. Several studies have underlined that the enhanced performance depends on the higher percentage of asphalt rubber within the hot mix and on the percentage of crumb rubber used in the asphalt rubber binder prepared by the wet process (Way, 2003).

Conventional binder tests have shown how the CRM modified binders are extremely dependent on the processing conditions, particularly to what concerns the temperature and time of reaction. The time required to disperse, blend and react the crumb rubber is dependent on a number of factors including the chemistry of the asphalt cement and crumb rubber as well as the temperature of the blended material. The same tests put in evidence as the content of CRM is determinant in binder's consistency and elastic behavior (Antunes *et al.*, 2004; Antunes *et al.*, 2006b).

The main effort to manage the production of AR in Italy consisted in adapting the consolidated AR technology knowledge from abroad to the Italian reality (raw materials, weather, environment, specifications, etc), starting by mixing several bitumen-base (virgin asphalt) with several type and size of crumb rubber, before finding the "optimal" blend to be tested in an industrial scale.

In laboratory, several virgin asphalt (penetration classes: 40/50, 50/70 and 70/100) and high percentages of crumb rubber (higher than 15%) were blended into a homogeneous asphalt-rubber system at a temperature of 190°C, which then reacted at 180°C for a minimum of 45 minutes. Then, the blend characteristics were compared with the specification required by ASTM D-6114 which defines Asphalt Rubber binder (Table 1).

Tests	Requirements	
Viscosity Brookfield @175ºC: cP (ASTM D2196)	Min. 1500	Max 5000
Penetration @25ºC: 1/10 mm (ASTM D5)	Min. 25	Max 75
Resilience @25ºC: % (ASTM D 5329)	Min. 20	
Softening Point, Ring&Ball: ºC (ASTM D36)	Min. 54.5	

Table 1. *Requirements for Asphalt Rubber binder design (ASTM D 6114)*

These limits along with the results attained for each percentage of crumb rubber blended into the bitumen allow the determination of the "optimal" content of crumb rubber, which is usually the percentage that improves the softening point temperature, resiliency and ductility.

The results show that increasing the CRM percentage corresponds to increasing the softening point, resilience and viscosity values as depicted in Figures 1 and 2.

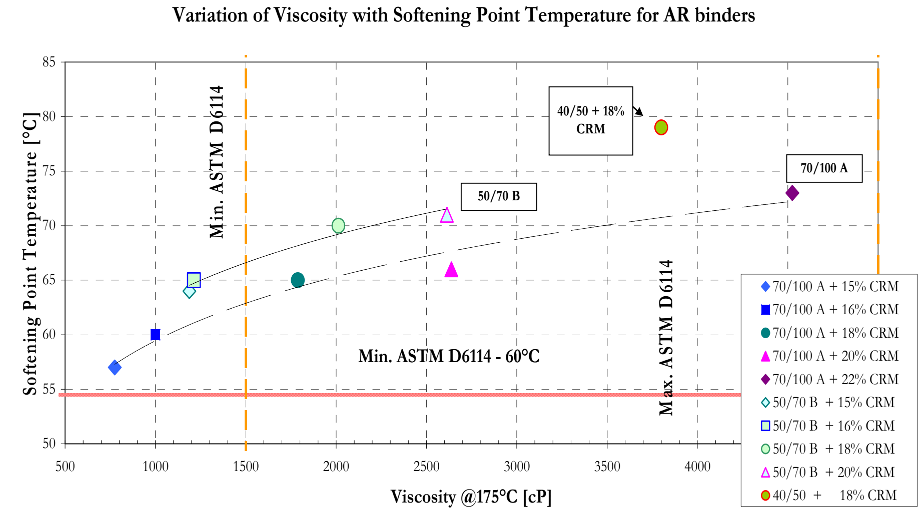

Figure 1. *Variation of viscosity with the softening point for Asphalt Rubber with different percentage of CRM*

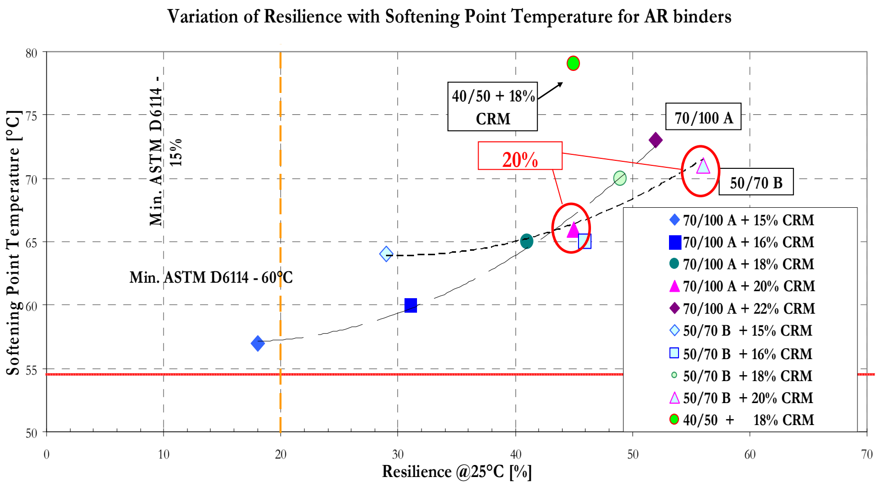

Figure 2. *Variation of resilience with softening point for Asphalt Rubber with different percentage of CRM*

It can be seen that some asphalts are more compatible with CRM than others and thus binder design pre-testing is necessary to determine that the proper asphalt grade is being used to formulate the asphalt rubber.

Taking in consideration the results above and the Italian weather and ambient contest, three blends are now commonly produced at the AR industrial producing plant: 40/50 with 18% CRM, 50/70 with 20% CRM and 70/100 with 20% CRM, depending on the use.

2.2. *Characterization of Asphalt Rubber mixes*

Following the Arizona Department Of Transportation (ADOT) specification, in Italy, the AR producer began experimenting with two asphalt rubber mixes: an open graded mixture (ARFC) and a gap graded mixture (ARAC) (Scofield, 1989). To fully utilize AR properties, two aggregate gradations, that would provide a high voids in the mineral aggregate (VMA), have been adopted as shown in Table 2.

AR MIX	Open Graded ARFC		Gap Graded ARAC	
Sieves (mm)	Min	Max	Min	Max
16	100	100	100	100
12.5	93	100	83	97
10	88	100	68	82
8	68	82	54	68
4	23	37	25	37
2	3	15	12	24
0.5	2	10	7	15
0.063	0	3	0	3
AR Binder	8.5%	9.5%	7.5%	8.5%

Table 2. *Italian ARFC (Open Graded) and ARAC (Gap Graded) Gradations*

To what concerns the study of ARHM, the adopted approach consisted in developing theoretical and experimental parallel activities, with the main purpose of:

– to disclose experimental findings to encourage the use of ARHM in the Italian road network in the awareness of potential technical, environmental and economic benefits;

– to develop innovative and relevant topics to provide original contributions to scientific research.

In particular, it was provided technical support during the production of asphalt rubber mixes to assure that ARHM respect Italian “traditional” standard specifications. This support was divided in time by monitoring the characteristics of several materials produced and implemented for many applications on the road in recent years. The intent is to gather as much information as possible to set up a large database, which allows the establishment of real performance-type specifications.

At the same time, advanced research on AR materials through innovative test methods have been developed.

3. Operative support for road applications

In this chapter the technical activities conducted within the routine characterization of asphalt rubber mixes are illustrated. This activity is geared to provide immediate answers to ARHM producers and potential users of these innovative materials in the Italian market. In that sense several productions of ARHM were analyzed in terms of composition (aggregate gradation and AR binder content), volumetric properties (void content) and mechanical performance (Marshall Stability, indirect tensile strength, loss of strength after immersion in water).

As an example, some results obtained during the characterization of AR gap graded – ARAC (Figures 3, 4, 5, and 6) and AR open graded – ARFC (Figures 7, 8, 9, 10) are shown.

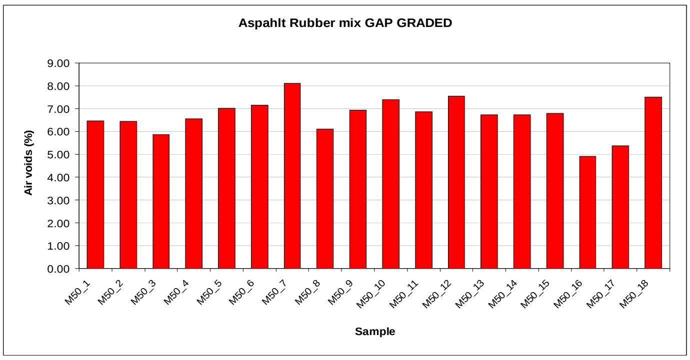

Figure 3. *Volumetric properties of a Gap Graded AR mix*

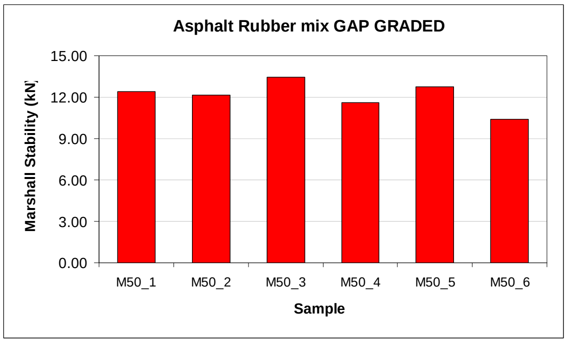

Figure 4. *Marshall Stability of a Gap Graded AR mix*

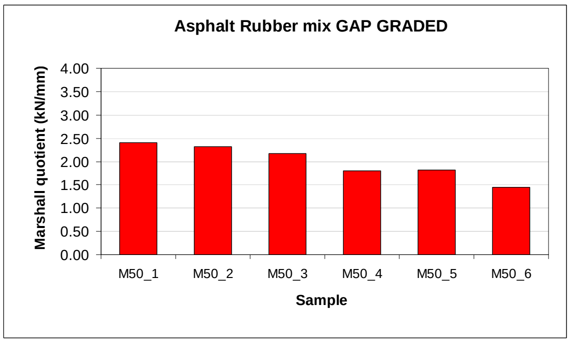

Figure 5. *Marshall Quotient of a Gap Graded AR mix*

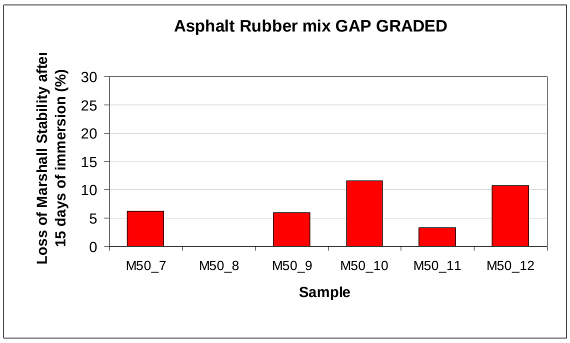

Figure 6. *Loss of Marshall Stability of a Gap Graded AR mix*

Obviously, the results presented refer only to two specific materials, gap and open graded, respectively, packaged with a particular compaction methodology and compaction energy. In that sense, this results represent only a model of the type of data obtained during this phase of the study. In particular, it is possible to notice the good repeatability of results for each tested material. These studies were repeated systematically over the years on the production in order to verify also the quality of the process.

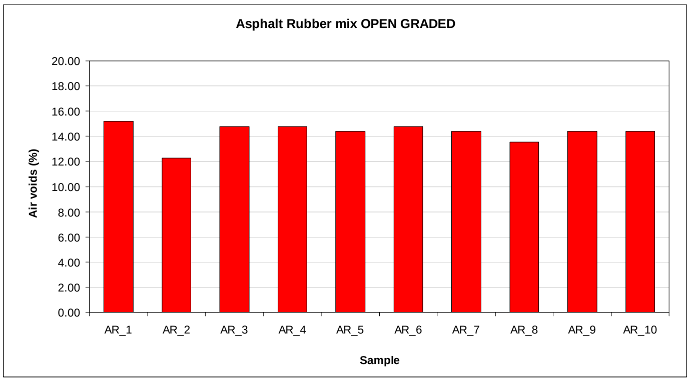

Figure 7. *Volumetric properties of an Open Graded AR mix*

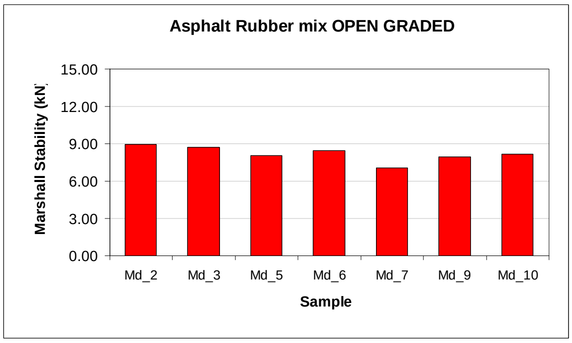

Figure 8. *Marshall Stability of an Open Graded AR mix*

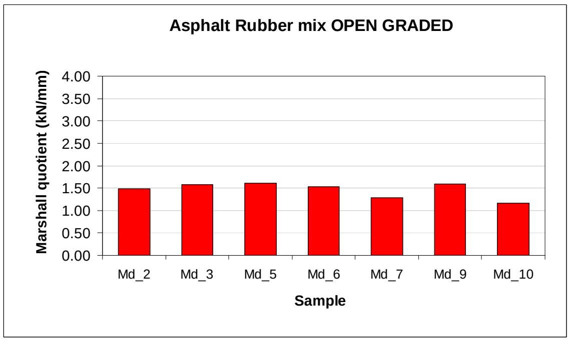

Figure 9. *Marshall Quotient of an Open Graded AR mix*

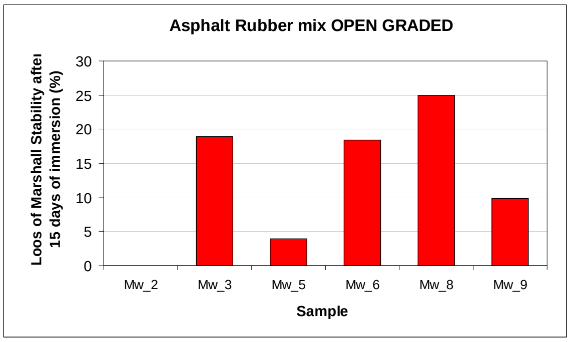

Figure 10. *Loss of Marshall Stability of an Open Graded AR mix*

The detailed and rigorous monitoring of these requirements allowed making a continuous optimization of ARHM and also AR binders. In addition, this extensive data enable to make a preliminary draft of a specification for ARHM following both Italian standard specification for “traditional” road materials and international AR requirements. Table 3 is an example of adaptation of different standards of specifications to develop AR gap graded (ARAC) mixture optimized taking into account the specificities of the Italian reality.

Italian specifications, even those more advanced, follow the current traditional empiricist approach and only provide a marginal concept of performance of a material (such as stiffness, fatigue and permanent deformation). This fact is mainly due to the lack of a database that has a significance level and statistical feedback in terms of real performance so it is not always possible to prescribe certain standards. Producers are not familiar with non empirical tests and it is often the same thing to for Agencies. The introduction of ARHM in the Italian market opened a new scientific approach to road materials and, with the technical and scientific support of CIRS, the first Standard Specifications for Italian ARAC and ARFC were made in 2007. These specifications are constantly changing since the monitoring of AR materials in laboratory and under real traffic flows is still in progress.

Test condition	Test method	Unit	Requirements	
			Binder course	Wearing course
Compaction	EN 12697-34	n° of blows	50	50
Requirements				
Marshall Stability	EN 12697-34	kN	> 9	> 9
Marshall quotient	EN 12697-34	kN/mm	1,5÷3,0	1,5÷3,0
Air voids	EN 12697-8	%	5 – 8	5 – 8
Loss of Marshall Stability after 15 days of immersion	CNR n. 149/92	%	≤25	≤25

Table 3. *Italian Traditional requirements for ARAC (Gap-Graded)*

Nowadays, it is considered that for an objective evaluation of the performance of road materials, specifications should refer to performance-related test methods that can effectively evaluate the real potential of the material. In the near future, therefore, the aim is that these rules begin to be understood as a requirement and replace those that are traditionally and empirically used. In this sense, it is extremely important to introduce the concept of "performance" of a material, which includes its mechanical and functional characterization.

In this light, the proposed specifications require to evaluate certain performance parameters of the ARHM taken from the site and compacted in the laboratory until reaching the voids produced in situ. These parameters must be representative of the visco-elastic properties and the cracking resistance of the mixes, according to EN 12697 series, in order to provide useful numerical elements for the design and reference values for non-destructive in situ testing.

4. Advanced performance characterization

As already introduced, there are many studies in the international literature focused on the mechanical performance (stiffness, fatigue and rutting) and functional properties (noise and friction) of ARHM. In order to bridge the gap of knowledge with the international experience, the same kind of approach was applied in Italy, and the performance achieved by these kind of materials was assessed experimentally through standardized testing protocols. This choice is considered appropriate in consideration of local particularities mainly related to the different characteristics of raw materials (bitumen and aggregates).

The laboratory and in situ collected data for AR mixes and the comparison with more traditional materials will allow the drawing up performance-related specifications with obvious impact to the quality of road infrastructure.

The advanced characterization concerns two main aspects: mechanical and functional properties.

4.1. *Mechanical properties*

The mechanical behavior of AR materials have been analyzed by means of the evaluation of three main properties: stiffness modulus, permanent deformation and fatigue behavior. Several productions of ARHM have been analyzed from this point of view and the study is still ongoing. As an example, the Authors show the results obtained during the performance characterization of some ARHM.

Materials under study were first characterized in terms of stiffness performance. In Figure 11 it is possible to observe the results for some of the investigated materials. These results were determined by means of indirect tensile configuration tests, according to European EN 12697-24, at 20 ° C.

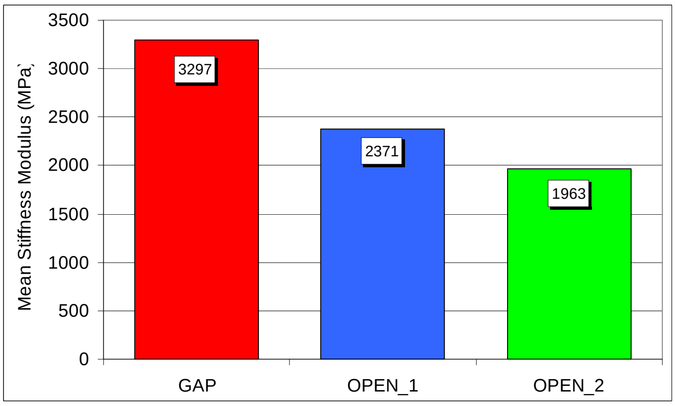

Figure 11. *Indirect Tensile Stiffness Modulus of several AR mixtures @ 20°C*

It should be noted that the ARAC (Gap Graded) mix is characterized by an air void content of about 6.5% while ARFC (Open Graded) mix was optimized in order to reach values between 15% and 20%. Bearing in mind also the great amount of binder that is used in ARHM, these mixes are characterized by a significantly high VMA (Voids in Mineral Aggregate) that further penalize the stiffness properties of ARHM. In this sense, the properties of the AR binder shall ensure that the entire ARHM can still have good rheological performance.

In particular, ARFC (open) shows obviously lower stiffness due to the higher percentage of voids. However, stiffness modulus values of Open Graded ARHM are always greater than those observed for conventional porous asphalts (Canestrari et al., 2007), despite the higher binder content and VMA. This aspect confirms the relevant rheological properties of asphalt rubber binder.

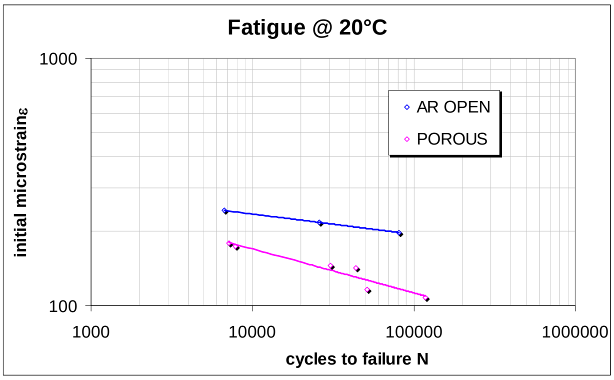

Figure 12. *Fatigue behavior of an ARFC Open Graded AR mixture*

For each tested material, the fatigue behavior was also analyzed on the basis of dynamic tests in indirect tensile configuration according to EN 12697-24. As an example, Figure 12 represents the fatigue curve of the ARFC (OPEN_1) previously introduced. The results are compared with those obtained in the case of a conventional porous hot mix (void content = 20%) prepared with SBS modified bituminous binder.

Even though porous layers provide a limited contribution to the fatigue resistance of the whole pavement, the results presented above clear indicate that the mix made with Asphalt Rubber binder offers significantly better performance than a material not prepared with AR binder and having similar volumetric properties. This fact seems to confirm the remarkable properties of asphalt rubber binder.

The advanced systemic approach described in this chapter finally provides the evaluation of rutting resistance. This property has been assessed by rutting tests performed according to BS 598:110 at 60 ° C. This evaluation is essential because asphalt rubber mixtures, having high binder contents, are potentially more prone to permanent deformation-related distresses. The assessments carried out on different materials have had a huge success: even in comparison with referenced materials with strong rutting resistance (Canestrari et al., 2007, Santagata et al., 2007), ARHMs have showed very high rutting resistance. Indeed, the deformation obtained after several hours test duration was found to be negligible (less than 1 mm), putting in evidence, once again, the valuable rheological properties that AR binder confers to the ARHM (Figure 13).

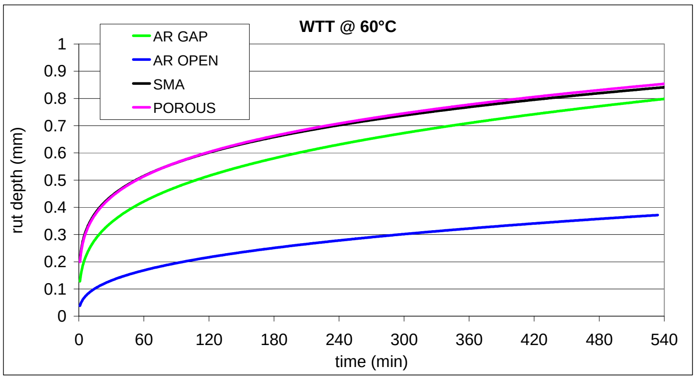

Figure 13. *Rutting behavior of AR mixtures*

4.2. *Functional properties*

In the evaluation of performance of AR mixtures, it is essential to monitor the also functional properties (friction and noise) by paying special attention to the evaluation of rolling noise reduction. This problem is nowadays an increasingly strong issue that often affects the choice of materials for road pavement wearing courses.

The evaluation of functional properties have been done both in situ, through the measurement of surface characteristics and the evaluation of noise levels along the side of the roadway, and in laboratory, through the determination of sound-absorption properties of materials studied.

As an example, it is interesting to show the results obtained during the acoustic characterization of ARHM, both gap and open graded, in two different trial sections.

4.2.1. *Trial sections*

A Gap Graded and an Open Graded AR mixes were laid down on an urban trial section about 700 m long in Florence. The thickness of both wearing courses was 30 mm. The section covered with ARAC (gap graded) is composed of two lanes (one for ordinary traffic and one reserved for buses) while ARFC (open graded) trial section has only one lane.

Another trial section realized with a Gap Graded AR wearing course was constructed on an urban way about 1000 m long in Imola. Asphalt Rubber material was staggered with some short sections of a traditional HMA wearing course selected as reference surface for traffic noise survey. The thickness of the new ARAC wearing course was 30 mm.

4.2.2. *In situ acoustic analysis*

Noise levels recorded along the side of sections constructed with the studied materials were related with noise levels recorded at the same time on near different sections covered with traditional asphalt concretes and interested by quite the same traffic load.

The acoustic characterization of materials under study was carried out performing noise measurements surveys, each lasting one week, according to the Italian technical specifications. Measurement boxes, according to Class 1 of EN 60651 and EN 60804, were fixed at about 4 m high to lampposts situated along the side of the experimental roadway (Figure 14).

Measurement boxes were able to determine the A-weighted equivalent sound level Leq for each measuring hour and the results were summarized in one mean A-weighted sound pressure level for night (Leq,wn) and day (Leq,wd) periods, as shown in the example of Figure 15.

In order to make the comparative study of the "in situ" acoustic measurement objective, it was supported by traffic investigation. Each investigation was carried out for 24 hours once a week, during the traffic noise finding weeks, recording the number of vehicles and the corresponding speed and length.

Figure 14. *Measurements boxes*

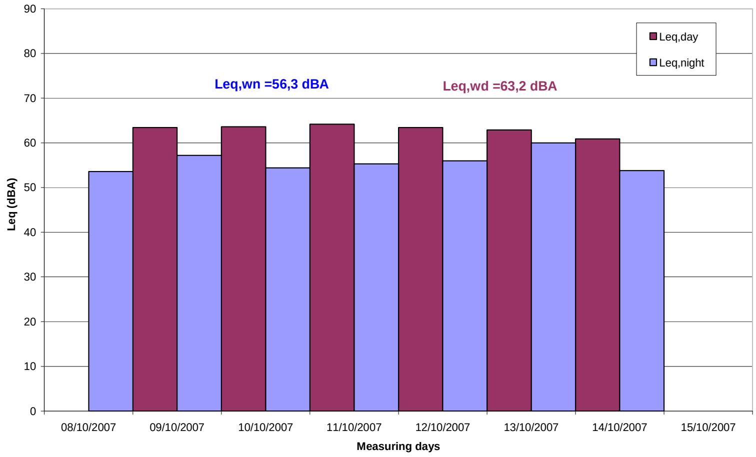

Figure 15. *In situ noise measurements (one week)*

Observing the experimental results obtained for the trial section of Florence (Table 4), it could seem that noise level recorded for the reference material was not comparable with that of asphalt rubber mixtures because of the not negligible difference of traffic flow and speed between the different sections. But actually, the measurement box corresponding to reference material was placed at a greater distance from traffic stream than those mounted along the asphalt rubber experimental sections in such a way that the distance counterbalanced the different traffic conditions. In fact, it is possible to estimate through, for example, the Italian CNR prediction model (Canale *et al.*, 1986) that the greater noise level recordable for the reference material due to the higher traffic flow and speed is roughly counterbalanced by the greater distance between measurement box and traffic stream.

	ARAC (gap)	ARFC (open)	Reference
Leq,wd (dBA)	65.1	63.2	67.9
Leq,wn (dBA)	57.9	56.3	61.5
Traffic (vehicles/day)	6694	5656	8967
Mean speed, day (km/h)	37.7	40.8	48.3
Mean speed, night (km/h)	42.0	44.9	58.3
Heavy vehicles (%)	10.16	2.05	3.51

Table 4. *“In situ” acoustic results – Florence trial section*

Thus, ARAC mix proved to be about 3 dB(A) quieter than a traditional dense graded asphalt concrete principally thanks to the asphalt rubber binder employed. It has to keep in mind that 3 dB(A) noise reduction corresponds to halving traffic flow or doubling the distance between the source and the receiver.

A further 2 dB(A) noise reduction was demonstrated to be achieved through the employment of open graded AR mixture that is able to combine acoustic benefits arising from AR binder with those obtainable from high air void content in terms of sound absorption capabilities. Moreover, this mix is characterized also by a reduced maximum chipping size that further enhanced rolling noise reduction properties.

Results obtained from in situ acoustic and traffic investigations for the trial section of Imola are presented in Table 5.

	ARAC (gap)	Reference
Leq,wd (dBA)	66.5	72.7
Leq,wn (dBA)	60.4	66.4
Traffic (vehicles/day)	9305	12396
Mean speed, day (km/h)	74.3	74.2
Mean speed, night (km/h)	77.5	77.3
Heavy vehicles (%)	5.52	5.53

Table 5. *"In situ" acoustic results – Imola trial section*

Differently to what happened for the previous case, the noise pressure levels recorded were not directly comparable. In fact, the two sections were characterized by the same mean vehicle speed and heavy vehicle content but different total traffic flow, 25% lower for ARAC material owing to an intermediate intersection.

Moreover, the sound measurement box corresponding to ARAC section had to be placed at a distance from traffic stream (Figure 16 on the right) sensibly greater than that of reference material road section (Figure 16 on the left).

Thus, in the same way as the previous situation, it is possible to estimate that the difference between noise level in ARAC section and in reference material section has to be reduced of about 3 dB(A) considering these two aspects. Taking into account the previous considerations, ARAC proved again to be about 3 dB(A) quieter than a traditional dense graded asphalt concrete having quite the same void content and maximum chipping size. As a consequence, this noise reduction, corresponding to halving the traffic flow, has to be imputed to the use of the asphalt rubber binder that confers more elastic properties to the bituminous mixture.

Figure 16. *Measurement boxes position – Imola trial section*

4.2.3. *Laboratory acoustic results*

The acoustic laboratory experimental program consisted in the determination of the sound absorption coefficient α of the investigated materials by means of the impedance tube (Figure 17) according to the EN ISO 10534-1.

Samples subjected to sound absorption investigation were 95 mm diameter cylindrical specimens cored from slabs prepared in laboratory with the Roller Compactor (EN 12607-33). Slabs were prepared with materials taken during the construction of the respective experimental road sections. The thickness and air void content of the slabs were preferably chosen equal to those obtained in situ.

Each sample was subjected to 7 different test frequencies: 400, 500, 630, 800, 1000, 1250 and 1600 Hz.

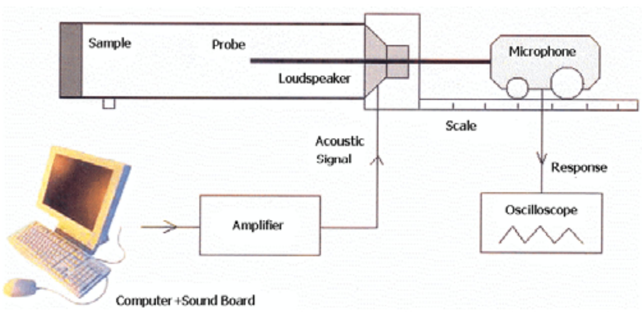

Figure 17. *Sound absorption test setup*

The Open Graded mixture showed a not pronounced sound absorption coefficient notwithstanding the 14% air void content (Figure 18). This fact seems to confirm that a void content lower than 15% is not able to guarantee good absorption properties because the pores are probably not totally interconnected between them. Moreover, the selected reduced maximum chipping size probably enhanced the air flow resistance of the material limiting sound absorption characteristics.

SOUND ABSORPTION COEFFICIENT α							
Specimen	Frequency (Hz)						
	400	500	630	800	1000	1250	1600
OG-ARsitu_1	0.17	0.29	0.38	0.38	0.23	0.10	0.07
OG-ARsitu_2	0.10	0.18	0.34	0.31	0.25	0.05	0.05
OG-ARsitu_3	0.19	0.20	0.35	0.32	0.14	0.03	0.04
OG-ARsitu_4	0.11	0.23	0.45	0.31	0.15	0.03	0.03
OG-ARsitu_5	0.16	0.25	0.34	0.24	0.09	0.05	0.06
mean values	**0.15**	**0.23**	**0.37**	**0.31**	**0.17**	**0.05**	**0.05**

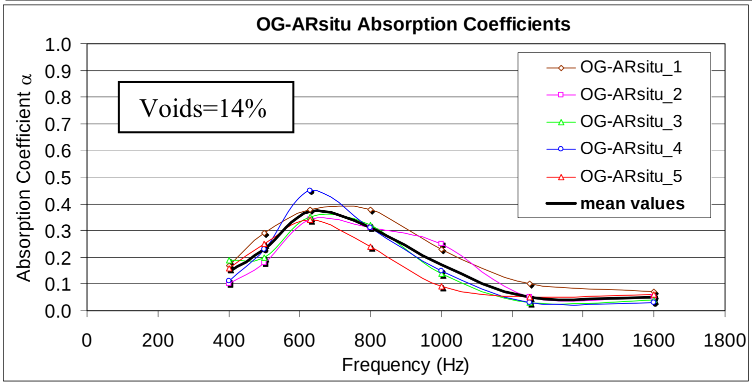

Figure 18. *Absorption coefficients of Open Graded AR mix*

Furthermore, it is very interesting to note that ARFC – Open Graded bituminous mixtures demonstrated a low peak frequency of absorption corresponding to 630 Hz (Figure 18). According to (Sandberg *et al.*, 2002), this may be due to the higher tortuosity, i.e. a pores-shape parameter, that arise from the reduced maximum chipping size coupled with to the high binder content that created narrow channels linking up pores.

As a matter of fact, the not elevated sound absorption coefficients recorded for the ARFC material indirectly proved that the very good anti-noise performance demonstrated in situ by this mixture is principally due to the acoustic properties, in terms of reduction of rolling noise generation, arising from the adding of asphalt rubber binder.

Finally, low absorption coefficients were showed by the Gap Graded AR mixture (Figure 19). This fact proved once again that the asphalt rubber binder is the main author of the acoustic benefits demonstrated by this kind of mixture .

SOUND ABSORPTION COEFFICIENT α							
Specimen	Frequency (Hz)						
	400	500	630	800	1000	1250	1600
GG-AR_1	0.11	0.14	0.14	0.25	0.10	0.04	0.03
GG-AR_2	0.13	0.18	0.12	0.29	0.02	0.07	0.09
GG-AR_3	0.10	0.15	0.18	0.20	0.11	0.01	0.04
GG-AR_4	0.08	0.12	0.18	0.29	0.08	0.05	0.04
GG-AR_5	0.12	0.18	0.20	0.20	0.06	0.05	0.02
mean values	**0.11**	**0.15**	**0.16**	**0.25**	**0.07**	**0.04**	**0.04**

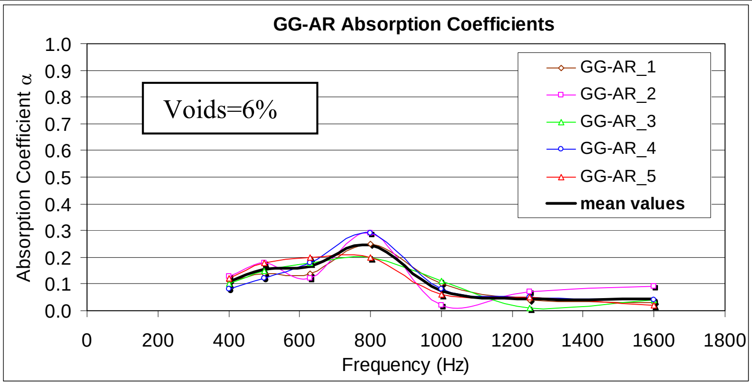

Figure 19. *Absorption coefficients of Gap Graded AR mix*

5. Innovative researches

The characterization of a road material should be completed with the development of advanced studies that will provide original contributions to scientific research. In this regard, several research items have been developed in the recent years, aimed at the evaluation of specific performance-related properties through innovative test methods.

As an example, it is possible to mention studies on the durability of Asphalt Rubber mixes with particular interest to water damage. This aspect is being investigated through two innovative testing methods (Pasquini, 2009, Partl *et al.*, 2009, Santagata *et al.*, 2009): the CAST, implemented in the EMPA laboratories; and the PATTI test, specifically modified for the determination of the adhesion and cohesion properties of bitumen-aggregate system.

In particular, CAST equipment allows testing of laterally deformation constrained donut shaped specimens under simultaneous action of cyclic mechanical loading, temperature changes and water exposure. Tests are performed in a conventional, temperature controlled, servo-hydraulic tension-compression machine. (Figure 20).

As an example, Figure 21 shows a typical output of a strain-controlled fatigue test performed at 10 Hz and with temperature cycles. The complex modulus E* and phase angle of the material are calculated based on a finite element model of the test.

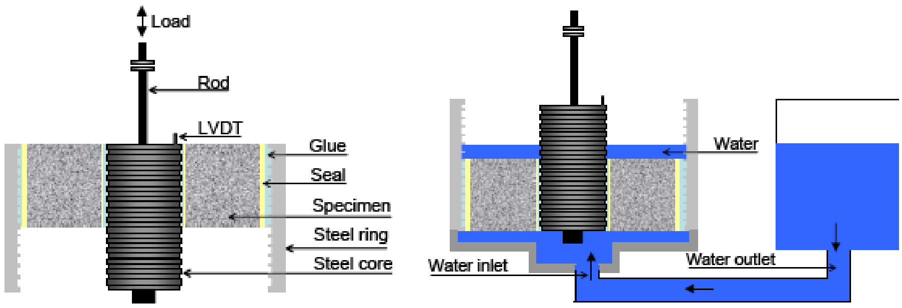

Figure 20. *CAST setup for dry test (left) and wet test (right)*

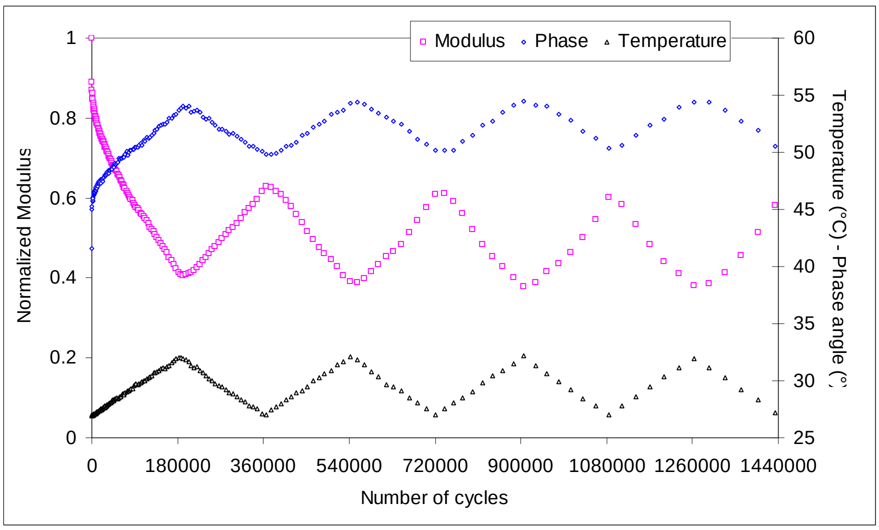

Figure 21. *CAST fatigue test experimental output*

The CAST results demonstrated that open graded mixtures with asphalt rubber binder had not only superior fatigue resistance but also significantly reduced moisture sensitivity as compared to traditional porous or semi-porous asphalt mixtures.

6. Conclusions

Progress in the use of recycled materials has been appreciable in the highway community over the last 20 years. However, further development is dependent on more cooperation among various disciplines: industry and government, highway engineers and environmental specialists.

In this paper, the Authors presented a complete proposal for an evaluation systemic approach aimed at the characterization of Asphalt Rubber mixtures (ARHM) and useful for areas where the Asphalt Rubber wet process technology has recently been introduced.

The selected approach provides parallel activities that give immediate answers for ARHM producers and applicators but that are also able to develop relevant scientific research.

The results so far obtained, and in part presented in this paper, are constantly in progress as there is also a continuous research for mixture production optimization. In any case, they clearly showed the enhanced performance of Asphalt Rubber mixtures in terms of mechanical and functional properties.

Despite the huge literature focusing on Asphalt Rubber study, this work shows how it is still possible and essential to enhance research addressing specific issues in order to implement and update the knowledge to date consolidated.

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7. Bibliography

Antunes I., Giuliani F., Sousa J.B., “Caracterização Reológica de Betumes Modificados com CRM Sujeitos a Envelhecimento Artificial”, *1st European Road Congress*, Lisbona, 2004.

Antunes I., Giuliani F., Sousa J.B., Way G., “Asphalt Rubber: Il Bitume Modificato con Polverino di Gomma di Pneumatico Riciclata”, *Varirei - V International Congress of Valorization and Recycling of Industrial Waste*, L’Aquila, 2005.

Antunes I., Way G.B., Sousa J., Kaloush K., "The Successful World Wide Use of Asphalt Rubber", *16th Convegno Nazionale SIIV*, Cosenza, 2006a.

Antunes I., Giuliani F., Sousa J.B., "Chemical Modification of Asphalt Rubber with Polyphosphoric Acid" *Asphalt Rubber 2006 Conference*, San Diego, 2006b.

Bertollo S.M., Bernucci L.B., Fernandes J.L., Leite L.M., "Mechanical Properties of Asphalt Mixtures Using Recycled Tire Rubber Produced in Brazil – A Laboratory Evaluation", *83rd TRB Annual Meeting*, Washington, 2004.

Canale S., Ventura F., "Rumore da traffico e progettazione stradale – metodologie di previsione e possibilità di attenuazione", *Autostrade*, Vol. 2, 1986.

Canestrari F., Bocci M., Ferrotti G., Pasquini E., "Mechanical characterization of environmentally friendly mixtures" *International Conference on Advanced Characterization of Pavement and Soil Engineering Materials*, Athens, 2007.

Cook M.C., Bressette T., Holikatti S., Zhou H., Hicks R.G., "A Full Scale Experiment on Asphalt Rubber Modified Pavements in California", *10th International Conference on Asphalt Pavements*, Quebec City, 2006.

Jung J., Kaloush K.E., Way G.B. «Life Cycle Cost Analysis: Conventional versus Asphalt Rubber Pavements», 2002, Rubber Pavement Association.

Kaloush K.E., Witczak M W., Sotil A.C., Way G.B., "Laboratory Evaluation of Asphalt Rubber Mixtures Using the Dynamic Modulus (E*) Test", *82nd TRB Annual Meeting*, Washington, 2003.

Kumar P., Chandra S., Bose S., "Comparative Study on Stone Matrix Asphalt Mixes with Different Stabilizers", *84th TRB Annual Meeting*, Washington, 2005.

Leung F., Tighe S., Macdonald G., Pento, S., "Noise Reducing Asphalt Pavements: a Canadian Case Study", *10th International Conference on Asphalt Pavements*, Quebec City, 2006.

Partl M.N., Pasquini E., Canestrari F., Virgili A., "Analysis of water and thermal sensitivity of open graded AR mixtures", submitted to *Construction and Building Materials*, 2009.

Pasquini E., «Advanced characterization of innovative environmentally friendly bituminous mixtures», Ph.D. Thesis, 2009, Università Politecnica delle Marche.

Potgieter C.J., Sadler D.E., De Villiers E.M., "Bitumen Rubber Asphalt: Report on the Long Term Performance in South Africa", *9th International Conference on Asphalt Pavements*, Copenhagen, 2002.

Sandberg U., Easement J.A., *Tire/Road Noise Reference Book*, Kisa, Informex, 2002.

Santagata F.A., Canestrari F., Pasquini E., "Mechanical characterization of asphalt rubber - wet process" *4th International SIIV Congress*, Palermo, 2007.

Santagata F.A., Antunes I., Canestrari F., Pasquini E., "Asphalt Rubber: Primeiros Resultados em Itália" *Estrada 2008, V Congresso Rodoviário Português*, Estoril, 2008.

Santagata F.A., Cardone F., Canestrari F., Bahia H.U., "Modified PATTI test for the characterization of adhesion and cohesion properties of asphalt binders" *The 6th*

International Conference on Maintenance and Rehabilitation of Pavements and Technological Control MAIREPAV6, Torino, 2009.

Scofield L.A., «The History, Development, and Performance of Asphalt Rubber at ADOT», Report Number AZ-SP-8902, December 1989, ADOT.

Souza R., Himeno K., Kobayashi A., "Evaluation of Japanese Asphalt Binders and Asphalt Mixtures after Mixing Ground Rubber", *3rd International SIIV Congress*, Bari, 2005.

Way G.B., "OGFC Meets CRM. Where the Rubber meets the Rubber. 12 Years of Durable Success", *Asphalt Rubber 2000 Conference*, Vilamoura, 2000.

Way G.B., "OGFC Meets CRM. Where the rubber meets the rubber 15 years durable success", *Asphalt Rubber 2003 Conference*, Brasilia, 2003.

Zborowski A., Sotil A., Kaloush K.E., Way G.B., "Material Characteristics of Asphalt Rubber Mixtures", *83rd TRB Annual Meeting*, Washington, 2004.