The First Brazilian Experience with In Situ Field Blend Rubber Asphalt

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ABSTRACT: The main objective of the present study is to present the results of the first rehabilitation project in Brazil using asphalt rubber (in situ blend). A section, 25 kilometers long of the state highway RJ-122, Rio de Janeiro, was chosen. Asphalt Rubber "gap graded" and asphalt rubber "open graded" mixes were used. The original structural and functional characteristics of the pavements, as well as the rehabilitation design procedure used to calculate the overlay thickness are described. A brief cost analysis of the new procedure shows the advantage over the conventional overlay composed of a granular layer and an asphaltic concrete surface layer. Furthermore HVS tests demonstrated the validity of the design solution

KEYWORDS: *gap graded, open graded, asphalt rubber, in situ blend, asphalt rubber, HVS*

1. The Choice of the Road

The present paper provides a complete insight of the first Brazilian experience with an in situ field blend asphalt rubber mixture that took place in the state of Rio de Janeiro. The initial idea was to choose a road that would allow the authors to highlight the advantages of this new process, from the technical point of view and also through a cost/benefit analysis. The DER-RJ (Rio de Janeiro State Highway Department) had decided to invest into new technologies, mainly the promising asphalt – rubber mixtures.

The RJ-122 highway was paved in the seventies; its surface became extensively cracked, making the riding unsafe and uncomfortable for the users (Figures 1-3). Furthermore, the shoulders were lacking in many areas along the highway. The traffic volume is high and mainly of trucks. For those reasons, RJ-122 was chosen for applying this new field blend asphalt rubber technique.

Figure 1. *The old pavement before the rehabilitation job.*

Figure 2. *A close-up view of the cracked pavement.*

Figure 3. *Construction of gap graded layer.*

The following starting conditions were detected:

- According to the methodologies currently used in Brazil (DNIT- National Department of Transportation Infrastructure), the solution for the rehabilitation of the pavements pointed out either to a complete reconstruction of the surface and base layers and part of the sub-base layer, or to recycling the surface and base layers by adding chemical stabilization or crushed stone followed by an asphaltic overlay.
- A very old highway with highly a cracked surface layer, with base and sub-base layers consisting of soils often out of highway specifications.
- High volume traffic with a great proportion of trucks (average daily traffic of 1,923 heavy vehicles).

2. Design Made by CONSULPAV

For the rehabilitation design of the RJ–122 highway, the consulting firm CONSULPAV suggested the use of an asphaltic binder modified by recycled rubber pneumatic tires in situ. This was an alternative to the traditional bituminous mixes. The rubber – modified bitumens have been successfully used in the states of Arizona and California, USA, in the last 40 years. The results are surfaces of high flexibility and large capacity for avoiding cracking as in highly degraded pavements. In the last 10 years, very satisfactory experiments were also conducted in Portugal with these rubber modified asphalts.

This previous experience led CONSULPAV to suggest this new methodology for a Brazilian highway. The design of the pavement overlay considering a service life period of 20 years was made by applying different analysis methods, and by incorporated a wearing course of “open graded” type.

For the determination of the performance grade (PG) of the asphaltic binder, consideration was given to the average monthly distribution of temperatures all year long in the region. The choice was the temperature Tave.7max = 34.1°C at a confidence level of 95%, resulting in a PG 58-10. Yet, taking into account the slow moving traffic, the final value was adjusted to PG 64-10.

For design purposes, three types of analyses were considered:

a) CALTRANS’ Method, based on many years of experience of the Department of Transportation of California. It is based fundamentally on deflections under load action.

b) Empirical- Mechanistic Method, as proposed by SHELL Company. The objective is to control deflection at the top of the foundation soil in order to minimize permanent deformations and to control tensile strain and stresses at the bottom of the bituminous layers to minimize cracking of such layers [1], [2] and [3].

c) Empirical – Deterministic Method, developed by CONSULPAV for Recycled Asphalt Pavements. In this method an effort is made to control stresses at the bottom of reinforcement layers in order to minimize crack reflection.

The following design was suggested for the RJ – 122 highway:

a) Asphalt rubber layer with 2.5 cm and an open graded type mix, containing about 8.5% of the modified binder with a PG 64-16. The tack coat was SBS and SBR modified.

b) Asphalt rubber layer with 4.5 cm and a gap graded type mix, constraining about 8.5% of the modified binder, which will drain the water from the open graded mix layer.

c) Tack coat layer.

d) Reshaping layer with a conventional HMA mixture overlaid onto the original pavement in order to provide the correct slope for the water flowing from the open graded mix layer.

e) Binder layer.

f) Localized treatment of highly degraded areas and building of shoulders and drainage items.

The shoulders should follow the technical characteristics presented below:

a) Excavation of 50 cm.

b) Leveling and compaction of the bottom of the excavation.

c) Base and sub base layers composed of graded crushed stone.

d) Priming.

e) Asphalt rubber with layer with 4.5 cm and a gap graded mix.

3. The Construction Process

In spite of the current overlay design procedure recommending the renewal or recycling of base and surface layers, and a new surface layer of at least 10 cm, the technical staff of DER-RJ adopted an asphalt-rubber solution as per CONSULPAV experience, as detailed below:

- Leveling off or Reshaping using a conventional asphalt concrete in the intermittent sections;
- Gap graded mix (binder layer), 4.5 cm - thick;
- Open graded mix (wearing course), 2.5 cm – thick.

The following figures show a sequence of some interesting aspects of the construction process, enhancing the capacity of the asphaltic layer to absorb crack reflection, the process of producing rubber crumbs, the process of adding rubber crumbs to the conventional asphaltic binder and the construction procedure.

4. Preparation of the Rubber Crumbs

The rubber crumbs used for the asphalt rubber mixture was derived from scrap tires as shown in Figures 4-7.

Figure 4. *Discarded passenger car tires to be milled*

Figure 5. *Extension of tires heels from discarded tires of trucks.*

Figure 6. *Discarded tires of trucks selected for milling*

Figure 7. *Running belts fed with tire bands of discarded tires*

5. Building Procedure of Asphalt Rubber – in situ Blend

Figures 8-10 show some of the key processing steps in adding the crumb rubber from scrap tires to the asphalt to make the asphalt rubber binder and paving of the asphalt rubber hot mix.

Figure 8. *Transfer of rubber crumbs to the storage bin, weighing and adding to the asphalt using an adequate machine.*

Figure 9. *Collecting the modified binder (viscosity of 5,000 cP at 175°C for several laboratory tests).*

Figure 10. *Compaction of asphaltic mixture*.

6. Structural and Functional Characteristics of Pavements

In October 2011, a survey of the structural and functional characteristics of the rehabilitated pavement of RJ – 122 highway was performed in order to verify the technical conditions at the completion of work.

Data from the survey were treated statistically for a better characterization and to determine “conformities” and “unconformities” within specifications.

The following parameters were observed:

- Maximum deflection (Df_1), which represents the deformability of the pavement structure as a whole;
- Deflection at 1.20 m (Df_7) from central point, which represents the subgrade deformability;
- Radius of Curvature of the deflection Basin (R), which indicates the characteristics of deformability and modular compatibility of the surface and base layers, and is defined by the following expression:

$$R=\frac{6250}{2(d0-d25)}$$

where:

$2(d_0-d_{25})$ is the difference between the maximum deflection and the deflection at 25.0 cm from the load application point multiplied by 2;

R= radius of curvature in meters (m).

- International Roughness Index, IRI (m/km), which refers to the riding quality and safety standards for the users;
- Skid resistance – “grip number” (GN), continuously measured;
- Microtexture of the Pavement´s Surface – Sand Patch Height, HS (mm).

7. Desirable conditions that define the best structural and functional qualities of pavements.

As for the structural parameters, the following characteristics and general conditions are sought:

- Maximum deflection (Df_1) smaller than the design value, which is the Allowable or Permitted Deflection (D_p) determined for a 20 years period of time;
- Deflections Df7 smaller than 10 x 0.01 mm, which corresponds to excellent structural conditions of sub grade under the pavement being studied;
- Radius of Curvature greater than 100 m, which indicates that the surface layers present moduli ratios compatible with the base layer.

Table 1. *Paving Deflections – Falling Weight Deflectomer - FWD (1.700 measurement points).*

Df_1 (0.01mm)	**%**	**Radius ≤ 100 (m)**	**Df_7 > 10 (0.01mm)**
≤ 35	49%	0%	0%
35 - 45	17%	0%	0%
45 - 65	24%	0%	1% nonconformity
65 - 80	7%	0%	1% nonconformity
> 80	3%	1% nonconformity	0%

Where:

Df_1, deformation under the load (1/100 mm)

Df_7, deformation at 150 cm from loading point (1/100 mm)

Allowable or Permitted Deflection (D_p): 65 x 0.01 mm

Radius of Curvature (m)

$$R = \frac{6250}{2(d_0 - d_{25})}$$

For roughness in the longitudinal direction, values less than 2m/km characterize excellent conditions of riding quality and safety for the users; and values between 2 and 2.7m/km are still considered as good riding conditions.

Table 2. *Pavement Roughness – Laser Profilometer RSP (IRI) – (3,404 measurement sections).*

IRI (m/km)	%
≤ 1,5	70%
1,5 - 2	20%
2 - 2,7	8%
> 2,7	2% nonconformity

Where:

IRI, International Roughness Index (m/km).

In respect to the intrinsic characteristics of the wearing course of the open graded mixture, the expected function refers to high skid resistance or GN greater than 0.72, and open microstructure or HS between 0.7 and 1.2 mm.

Table 3. *Skid Resistance Test – Grip Tester (6,767 measurement sections).*

GN	%
≤ 0,52	0% nonconformity
0,52 - 0,72	4%
> 0,72	96%

Where:

GN – Grip Number.

Table 4. *Micro texture of Pavement – Sand Belt (25 measurement points).*

HS (mm)	%
≤ 0,7	4% nonconformity
0,7 - 1,2	96%
> 1,2	0% nonconformity

Where:

HS – Average Height of Sand Patch (mm).

8. General Considerations

The pavement of the highway RJ-122 has structural and functional characteristics of the highest ranking in the federal and state networks. This is justified by the following statistical parameters:

- Ninety percent of the deflection measurements were smaller than the permitted value for the design life of 20 years, and only 1% of the radii of curvature were less than 100 meters.
- As the IRI values of the longitudinal roughness are concerned, 70% are smaller than 1.5 m/km, and 20% between 1.5 and 2.0 m/km. Toll roads, which exhibit very good conditions, show IRI values from 2.5 to 3.0 m/km.
- The skid resistance measured continuously by the Grip Tester reached the excellent goal of 96% of grip number greater than 0.72, and only 4% between 0.52 and 0.72.
- In addition, the sand patch tests (HS) have shown a micro texture typical of an open graded mixture for 96% of the measurements.

9. Physical Characteristics of Asphalt Rubber

The following tables present the characteristics of the asphalt rubber and the properties of the gap graded mixture.

Tables 5. *Characteristics of asphalt – rubber gap graded mixture.*

Item	**Viscosity 175º(CP)**	**Penetration (mm)**	**Softening Point (℃)**	**Elastic Recovery (%)**	**Asphalt Content (%)**
Limit	1500 to 5000	20 to 75	≥ 54	≥ 25	7.5 to 8.5
Average	3335	35.3	68.5	30.0	7.9
Deviation	667	5.9	2.2	2.5	0.4
M + σ	4002	41.3	70.7	32.6	8.3
M - σ	2667	29.4	66.2	27.5	7.6
Nonconformity					

Tables 6. *Characteristics of asphalt – rubber gap graded mixture.*

Item	**Degree of Compaction (%)**	**Tensile Strength (MPa)**	**Sieve $\frac{3}{8}$ (% pass)**	**Sieve nº 4 (% pass)**	**Sieve nº 200 (% pass)**
Limit	97 to 101	≥ 0.65	65 to 80	28 to 42	0.0 to 2.5
Average	98.7	0.86	77.0	30.7	2.4
Deviation	1.8	0.06	4.2	7.5	1.0
M + σ	100.5	0.91	81.2	38.2	3.4
M - σ	96.9	0.80	72.8	23.3	1.4
Nonconformity	10.5		8.3	32.0	19.9

Having performed these tests, the asphalt was classified as a PG (88, -22) which is beyond the design range established.

10. Calculation of the Structural Coefficients

During the pavement rehabilitation job of RJ-122 highway, studies were made in a systematic manner that has shown the efficiency of the action of each step done. The following technical remarks are made, consequently:

- A thickness of 1.0 cm of gap graded mix for the rehabilitated pavement resulted in a structural equivalency of 2.60 cm of the conventional asphaltic concrete as determined by the current design methods still used in Brazil.

- A thickness of 1.0 cm of open graded mix for the rehabilitated pavement resulted in a structural equivalency of 4.25 cm of the conventional asphaltic concrete as determined by the current design methods still used in Brazil.

Following is a summary of the study to determine the structural coefficients of the gap and open graded asphaltic mixtures layers.

The new asphaltic mixtures made with high viscosity binders obtained by adding rubber crumbs (in situ field blend procedure) required structural equivalency studies to compare these new mixtures with conventional asphaltic mixtures according to DNIT Specifications. A special study was made regarding the structural behavior of sections of the RJ-122 highway for the gap graded and open graded new mixtures.

To begin with, a deflection survey was made, in December of 2009, of the whole length of road, from Guapimirim County (crossing with BR-116) and Cachoeiras de Macacu County (crossing with RJ-116) before the rehabilitation job.

Later on, in December 2010, after the preliminary jobs (deep excavations and leveling at some locations) and preparing an experimental length of pavement with gap graded mixture 4.5 cm – thick, a new deflectometry survey took place between the 28.1 and 30.3 kilometer marks.

The average values of measured deflection under the action of load (Df1), expressing the structural response of the pavement as a whole or total deformability, are shown in the table below.

Table 7. *Comparison of deflections before and after; experimental stretch (km 28.1 to km 30.3) – gap graded mixture.*

Df_1 ($x\ 10^{-2}$ mm)	**Date**
116.01	Dec. 2009 (before construction)
64.01	Dec. 2010 (after construction)

These data permit the calculation of a structural coefficient of gap graded mixture using the procedures specified by DNER PRO-269/94 and DNER PRO-011/79. The first procedure uses the following equation:

$$HR = -19{,}015 + \frac{238{,}14}{\sqrt{D_{adm}}} - 1{,}357.h_{ef} + 1{,}016.I_1 + 3{,}893.I_2 \quad [1]$$

Where:

HR Thickness of pavement overlay in centimeters (4.5 – cm thick of gap graded mix for RJ-122)

D_{adm} Allowable deflection (x 10^{-2} mm) (at RJ-122, it was 64.01 x 10^{-2} mm, measured after the pavement rehabilitation)

I1, I2 Parameters that depend on the soil type (at RJ-122, soil type II; hence I1, =1, I2 = 0)

Hef Effective thickness (cm), obtained though the equation:

$$H_{ef} = -\ 5.737 + (807.961/D_c) + 0.972xI_1 + 4.101xI_2 \qquad [2]$$

Where:

Dc Characteristic Deflection (x10-2 mm) (at RJ-122, the value is 116.01x10-2 mm before rehabilitation)

By using the mentioned equation, it was possible to determine, as per DNER PRO-269/94, the following values of effective (hef) and overlay thicknesses (HR):

$$\text{Hef} = 2.2 \text{ cm and HR} = 8.8 \text{ cm} \qquad [3]$$

Therefore, knowing the overlay thickness (HR) of a conventional asphalt mix needed to obtain a given decrease in deflection, and knowing that it was needed 4.5 cm of the gap graded mixture, the structural equivalency obtained was 1.0 cm of gap graded mix corresponding to 2.6 cm of the conventional asphalt concrete, hence ignoring any residual structural value of the highly cracked old pavement.

An analogous procedure of analysis was used for an open graded mixture, and the structural coefficient of 4.25 obtained relative to a conventional asphaltic concrete. Figure 11 shows the pavement before and after overlay.

Figure 11. *View of road before and after the rehabilitation job.*

11. Accelerated Pavement Testing

With the intent of predicting the future performance of the rehabilitated pavements, accelerated pavements tests (APT) were conducted at RJ-122 using a Large Scale Traffic Simulator. The large scale accelerated pavement tests consist of applying a controlled axle load equal to or larger than the legal maximum allowable load for a given pavement structure in order to determine the response and performance of this structure under controlled, accelerated conditions in a limited time span. The use of large scale accelerated pavement tests enhance the field monitoring of pavements, making the job reliable in a short time span.

The traffic simulator (Figure 12) consists of a highway half-axle with dual wheel and loads up to 15 tons, which corresponds to a total single wheel axle load of 30 tons, which moves longitudinally along an axis with displacements of up to 9 meters, with a transversal displacement of up to 1 meter. The traffic simulator may perform up to 1,000 passages of the load per hour in a given test section.

In this way, by combining the longitudinal displacement speed of the half-axle with the other resources of the equipment, like transversal displacement or applied load, the consequences of the expected local traffic loading on the existing pavement structure can be reproduced in a short period of time with a high accuracy.

The large scale traffic simulator was placed on two test sections for evaluating the pavement´s performance. One test was carried out at approximately the 28 kilometer mark, whereas the other took place at the 12 kilometer mark. The design service life in terms of the equivalent single-axle load traffic was surpassed with the combination of 113,063 passages of the 6.7 ton single load (13.4 ton axle loads) followed by 79,017 passages of the 8.6 ton single load (17.2 ton axle loads) for the first test section (assuming a 5^{th} power law fatigue relationship). The pavements exhibited a behavior that satisfied all project parameters for the 20 year design period during the APT tests (Table 8), even though a significant load was applied. Similarly, the design service life in terms of the equivalent single-axle load traffic was surpassed with the combination of 100,007 passages of the 8.64 ton single load (17.2 ton axle loads) followed by 49,993 passages of the 8.95 ton single load (17.9 ton axle loads) for the second test section.

Figure 12. *Large Scale Traffic Simulator at RJ-122.*

Table 8. APT at RJ-122 results.

Parameter	Test-Section 1		Test-Section 2		Limits
	Initial	Final	Initial	Final	
Deflection	38x0.01mm	49x0.01mm	48x0.01mm	58x0.01mm	< 64 x0.01mm
Cracking	0%	0%	0%	0%	< 20 %
Permanent Deformation	0 mm	2.1 mm	0 mm	5.0 mm	< 7 mm
Microtexture – British Pendulum	55	51	52	52	VRD > 47
Macrotexture – Sand Patch	0.70	0.65	0.70	0.66	0.6 – 1.2 mm

12. Cost Analysis and Conclusions

Both the conventional (Figure 13) as well as the adapted designs using the asphalt rubber mixtures (Figure 14) are presented next. In addition, the costs in U.S. dollars (1 real = 0.49781 U.S. dollars) for each material are presented in table 9 for the conventional solution and in table 10 for the adapted solution using the SICRO, from DNIT, and DER/RJ as references.

Figure 13. *Pavement profile, conventional solution (10 years' service life).*

Table 9. *Cost Analysis of the conventional rehabilitation solution (service life 10 years).*

Layer	Cost (US$/m^3)	Layer Height (cm)	Cost (US$/m^2)	Total (US$/m^2)
HMA	298.69	10	29.87	59.74
Crushed Store Base	29.87	25	7.47	
Recycling	74.67	30	22.40	

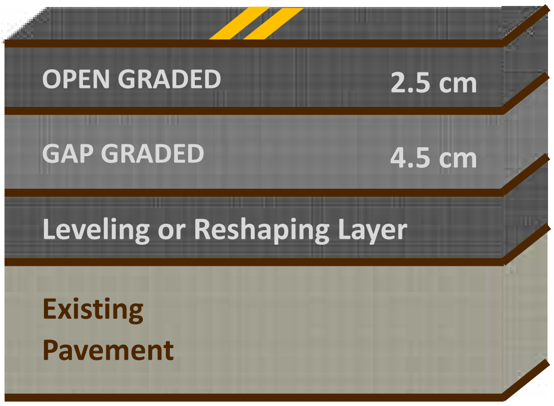

Figure 14. *Pavement profile, adapted – Solution (20 years' service life).*

Table 10. *Cost Analysis of proposed rehabilitation solution.*

Layer	Cost (US $/m^3)	Layer Height (cm)	Cost (US $/m^2)	Total (US $/m^2)
Open graded	398.25	2.50	9.96	36.84
Gap graded	398.25	4.50	17.92	
Leveling	298.69	varies	8.96	

When considering the volumes of materials for both the traditional surfacing techniques and those used in the gap graded and open graded mixes, and using the reference costs mentioned previously, a cost reduction averaging 38% was obtained at the experimental pavement construction of RJ-122 state highway.

Based on the actual performance of the road thus far, the back analysis done with FWD measurement and also based on the extensive HVS testes executed in two sections it can be concluded that the asphalt rubber gap graded an open graded mixes are performing very well and within what was expected from these kinds of mixes. The cost analyses and the demonstrated performance thus far warrant the conclusion that asphalt rubber rehabilitations are the least expensive maintenance and rehabilitation strategy now in Brazil and obviously with the best cost benefit ratio.

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14. Bibliography

[1] SHELL Research And Technology Center; Shell Global Solutions (Bands 2.0, Visar 3.0 SPDM

[2] Software and User Manuals"; Amsterdam, May 1998

[3] SHELL – "Shell Pavement Design Manual – Asphalt Pavements and Overlays for Road Traffic". London, 19.