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AN ITALIAN RESEARCH ON MECHANICAL PROPERTIES OF ASPHALT WITH TIRE RUBBER

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ABSTRACT: *In Palermo a research study was initiated with following objectives: characterisation of the asphalt with tire rubber; study of pavements overlaid with this type of asphalt; cost estimation of asphalt rubber production process.*
This paper describes the first results achieved in the study concerning the mechanical properties of asphalt with tire rubber for road base and base course.
In this research on dry process, more than 400 specimens have been tested at the DIIV laboratory for analysing the influences of crumb rubber modifier and powdered rubber modifier on the Marshall and indirect tensile test.

KEYWORDS: *asphalt, tire, rubber, dry process, time digestion.*

1. Introduction

In Italy, contrary to other countries, the recycling of waste tires is neither frequent nor intensive method, although a law by decree (called the "Ronchi decree") about waste products was enacted on 1997. The law's aims were the total recycling of waste tires rather than to combustion for obtaining energy and dumping within 2000.

As shown in the figure 1, in 1998 the situation about waste tires was still far from the law's aims. At the moment, rubberized asphalt paving materials are very good solution for the disposal of these waste products.

In West of Sicily some researchers of Department of Road Facilities Engineering (DIIV) have been studying rubber modified asphalt mixes since 2000. They have been encouraged by the realization of a tire grinding (ambient temperature size reduction) plant close to Palermo. At present this plant is the only one working in Sicily.

The DIIV research project is planned to take six years (2000-2005) and its objectives are the following:

- Characterization of rubber modified asphalt mixes: mechanical properties and surface characteristics;
- Design of rubber modified asphalt mixes;
- Construction of various test sections with rubber modified asphalt mixes on in service-roadways;
- Evaluation of roads pavements performance.

This paper shows results about mechanical peoperties of some rubber modified asphalt mixes.

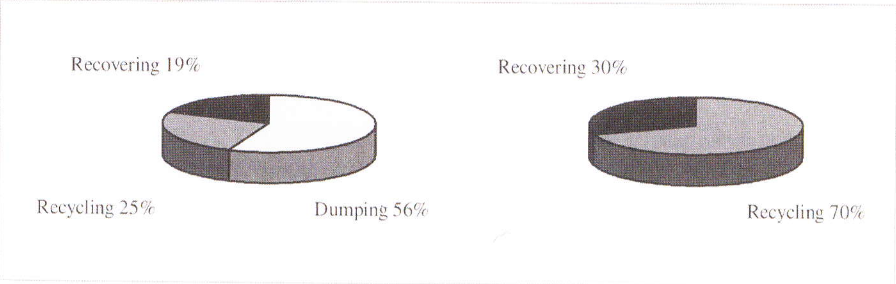

Figure 1. *Situation on 1998 and aims established to be hold within 2000 by "Ronchi decree"*

2. Experimental approach

The survey focuses on mechanical properties of rubber asphalt mixes for road base and base course.These properties were evaluated by Marshall method and indirect tensile strenght.The rubber asphalt mixes were produced by the hybrid dry process that consists in adding rubber to bitumen and aggregate at five contents by weight of aggregates (1; 1.,5; 2; 2,5; 3 percent). The process is defined as hybrid because the procedure to produce *the* mixtures should be able to allow the digestion process of finer rubber fraction. The road base needing a greater aggregates quantity than other courses (base and wearing) shows a higher capacity for disposal of waste tires rubber.

The finer fraction rubber (0.40-0.177 mm) amounts to 15 percent of bitumen weight; the coarser fraction (2.00-0.40 mm) is the remaining part (of rubber).

Truck's tires provide the finer fraction, whereas the coarser one is provided by car's tires.Usually the truck's tires rubber is almost entirely natural and suitable for making colloidal systems with bitumen; car's tires rubber is generally synthetic and shows good mechanical characteristics. The purposes of hybrid dry procedure are the digestion process of finer rubber and the partial digestion of coarser rubber.

The mechanical properties of rubber asphalt and base asphalt mixes (respectively indicated as RAM and AM) were compared. The mixes were prepared using the same aggregates grading, type of bitumen and aggregates (limestone). This approach allowed to evaluate the influence of rubber on mechanical properties.

2.1 Materials for rubber asphalt mixes

The constituents here used for mixes are commonly adopted in Western Sicily and aggregates gradings are typical in Italy.

Test procedures, indicated in the following tables as CNR, are Italian series of standard test procedure based on ASTM and other international series of standard testing procedures

2.1.1 Materials for road base

Table 1. reports the properties of aggregates and table 2 shows the properties of bitumen.used for road base. The aggregates grading used for mixes is reported in figure 2

Table 1. *Properties of aggregates*

Properties	Test	Value
Apparent specific gravity (g/cm^3)	CNR BU63/78	2.77
Specific gravity (g/cm^3)	CNR BU64/78	2.85
Los Angeles Coefficient (%)	CNR BU34/73	27
Porosity (%)	CNR BU67/78	2.81

Table 2. *Properties of bitumen*

Properties	Test	Value
Penetration (10^{-1}mm)	CNR BU24/71	66
Softening Point (°C)	CNR BU35/73	48,5
Ductility (cm)	CNR BU44/74	>100
Penetration index (%)	CNR BU24/71	-1.15

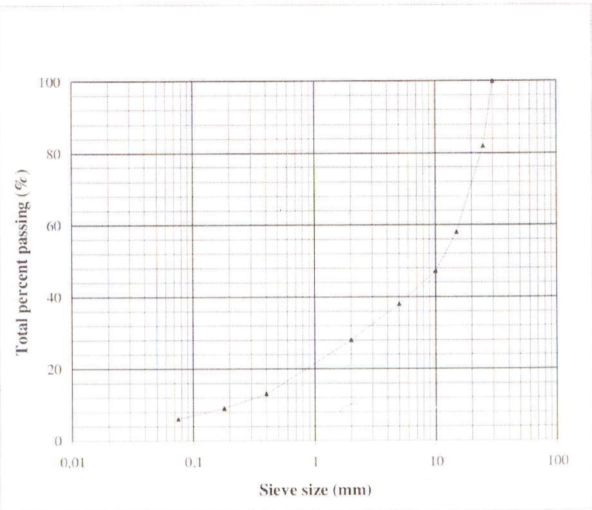

Figure 2. *Aggregates grading used for mixes*

2.1.2. Materials for base course

Table 3 reports the properties of aggregates and table 4 shows the properties of bitumen. The aggregates grading used for mixes is reported in figure 2

Table 3. *Properties of aggregates*

Properties	Test	Value
Apparent specific gravity (g/cm^3)	CNR BU63/78	2.80
Specific gravity (g/cm^3)	CNR BU64/78	2.81
Los Angeles Coefficient B (%)	CNR BU34/73	29
Los Angeles Coefficient C (%)	CNR BU34/73	27

Table 4. *Properties of bitumen*

Properties	Test	Value
Penetration (10^{-1}mm)	CNR BU24/71	66,5
Softening Point (°C)	CNR BU35/73	48,5
Ductility (cm)	CNR BU44/74	>100
Penetration index (%)	CNR BU24/71	-1.15

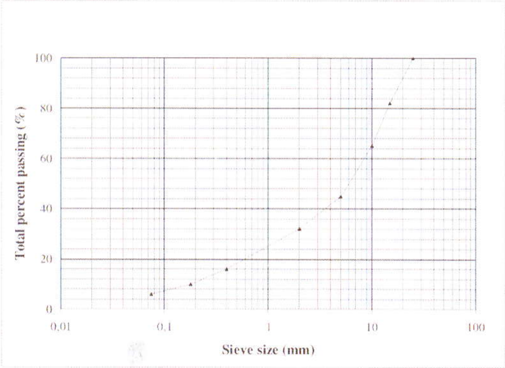

Figure 3. *Aggregates grading used for mixes*

2.2 Laboratory manufacture method

Laboratory production of RAMs and AMs was carried out by manual blending according to different procedures for the mixtures whose mechanical properties were investigated in the research. 69 mixtures were produced and 450 Marshall samples were tested (200 for road base and 250 for base course).

Asphalt mixture (AM) were produced according to a procedure composed of the following 4 steps:

1 Pre-heating of aggregates (temperature=180°C; time=10 hours)
2 Pre-heating of bitumen (temperature=160°C; time=45minutes)
3 Blending of bitumen and aggregates (temperature=170°C, time=15 minute)
4 Blending of bitumen, aggregates and filler (temperature=160°C; time=10 minutes)

Instead longer procedure were adopted for the production of RAMs due to the use of rubber as another constituent of the mixture.

The rubber asphalt mixes needed to be left in the oven at a temperature and for a period adequate to allow the digestion process and to avoid bitumen aging.

Some AM samples were produced with a mixture realized with a procedure similar to that one generally used for RAMs (the mixture was indicated with AM*).

In this way the evaluation of influence of thermal stress on mechanical characteristics could be performed.

2.2.1 Procedure for road base mixture

Road base mixtures were producted according to the hybrid dry process. The steps of procedure were as follows :

2.2.2 Procedure for base course mixture

For base course mixture two different procedures were adopted: the first one was in accordance with hybrid dry process while the second one with wet and dry process

The steps of the first procedure were as follows :

1 Pre-heating of aggregates (temperature=180°C; time=10 hours)
2 Blending of rubber and aggregates (temperature=180°C, time=1 minute)
3 Pre-heating of bitumen (temperature=160°C; time=45minutes)
4 Blending of rubber, aggregates and bitumen (temperature=180°C; time=15 minutes)
5 Blending of rubber, aggregates, bitumen and filler (temperature=160°C; time=2 minutes)
6 Keeping in oven (temperature=180°C; time=1 hour)

The steps of the second procedure were are reported below:

1 Pre-heating of bitumen (temperature=160°C; time=1 hour)
2 Blending of 50% of finer rubber fraction and bitumen (temperature=180°C, time=5 minutes)
3 Keeping in oven of rubber bitumen mix (temperature=180°C; time=30 minutes)
4 Blending of the leftover 50% of finer rubber fraction and rubber bitumen mix (temperature=180°C, time=5 minutes)
5 Keeping in oven of mixture (temperature=180°C; time=2 hour)

This first part of the procedure was followed by the same 6 steps described above reporting the hybrid dry process.

Table 5 shows the rubber gradings of each RAM. The different RAMs are distinguished by mean a suffix expressing the rubber content (in % by weight of aggregates). The total passing percentage are dependent on the percentages of bitumen that are variable from 4 to 7%.

Table 5. *rubber grading*

Mixtures	Sieve Size (mm)	Total percent passing				
		4% bit	5% bit	5.5% bit	6% bit	7% bit
RAM1	2	100	100	100	100	100
	0.40	60	75	82,5	90	100
	0.177	-	-	-	-	-
RAM1.5	2	100	100	100	100	100
	0.40	40	50	55	60	70
	0.177	-	-	-	-	-
RAM2	2	100	100	100	100	100
	0.40	30	37,5	41,25	45	52,5
	0.177	-	-	-	-	-
RAM2.5	2	100	100	100	100	100
	0.40	24	30	33	36	42
	0.177	-	-	-	-	-
RAM3	2	100	100	100	100	100
	0.40	20	25	27,5	30	35
	0.177	-	-	-	-	-

Table 6. *properties of binder by wet process.*

Properties	Test	Value
Penetration (10^{-1}mm)	CNR BU24/71	32
Softening Point (°C)	CNR BU35/73	58
Ductility (cm)	CNR BU44/74	17,53

3. Results and Discussion

3.1 Mixture for Road base

The results obtained from Marshall tests on road base mixture samples are shown in table 7.

The table shows that the highest stability was reached by AM with a 5,5% of bitumen. The acceptable range of bitumen content for RAM resulted to be between 5,5 an 7 % because mixture with lower contents showed characteristics unsuitable for practical applications: the bitumen didn't appear sufficient to bind the aggregates. This circumstance could be enhanced by the presence of rubber particles that absorbed some bitumen.

The RAMs with lower rubber content (1and 1,5) reached their maximum stability at 5,5% of bitumen content. This behaviour is similar to that showed by AMs: decreasing the percentage of rubber the behaviour of RAMs approximates the AMs' behaviour.

The RAMs with higher rubber contents (2; 2,5, 3%) reached their highest stability at 6% content bitumen.

The increase of bitumen raised the probability of interaction between rubber particles and the binder (digestion process).

The highest stability values found for RAMs were comparable to that one obtained for AM*.

Table 7. *results of Marshall tests*

Mixtures	Bitumen (%)	Stability (N)	Flow (mm)	Quotient (N/mm)
AM	5	11.128	3,50	3.178
AM	5,5	12.537	4,56	2.770
AM*	5,5	9.9397	4,30	2.231
AM	5,8	10.834	4,65	2.232
AM	6,5	10.812	4,98	2.179
RAM1	4	11.685	4,00	2.914
RAM 1	5	9.767	5,10	1.931
RAM 1	5,5	9.800	5,67	1.729
RAM 1	6	8.587	6,00	1.431
RAM 1	7	6.869	7,10	971
RAM 1.5	4	11.950	4,07	2.940
RAM 1.5	5	8.498	4.97	1.716
RAM 1.5	5,5	9.007	5,35	1.679
RAM 1.5	6	7.740	5,73	1.349
RAM 1.5	7	6.661	7,27	916
RAM 2	4	10.010	3,78	2.648
RAM 2	5	9.350	5,43	1.729
RAM 2	5.5	7.424	6,27	1.185
RAM 2	6	8.070	6,87	1.183
RAM 2	7	6.759	7,43	911
RAM 2.5	4	9.889	3,65	2.719
RAM 2.5	5	9.608	5,12	1.885
RAM 2.5	5.5	7.402	5,55	1.352
RAM 2.5	6	7.571	6,80	1.113
RAM 2.5	7	6.130	7,57	812
RAM 3	4	8.424	3,73	2.258
RAM 3	5	8.411	5,08	1.658
RAM 3	5.5	6.132	5,70	1.098
RAM 3	6	7.023	6,95	1.014
RAM 3	7	5.281	7,50	707

The observed behaviour is more evident in figure 4 where the measured stability is expressed as a function of %bitumen.

In the range of bitumen content considered acceptable, the stability of each RAM didn't vary remarkably in function of the rubber content as it is shown in the figure 5 where the stability in function of %rubber is reported.

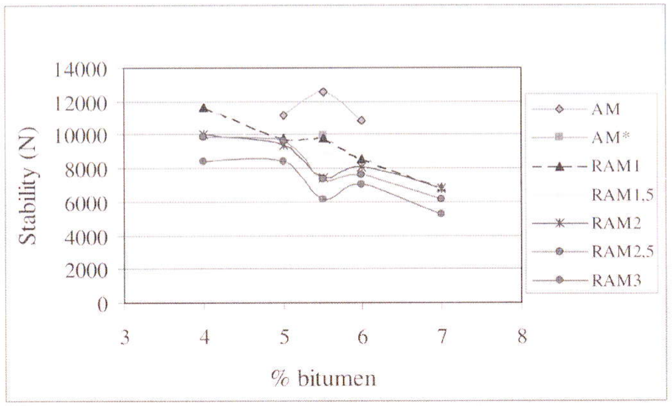

Figure 4. *diagram %bitumen-stability*

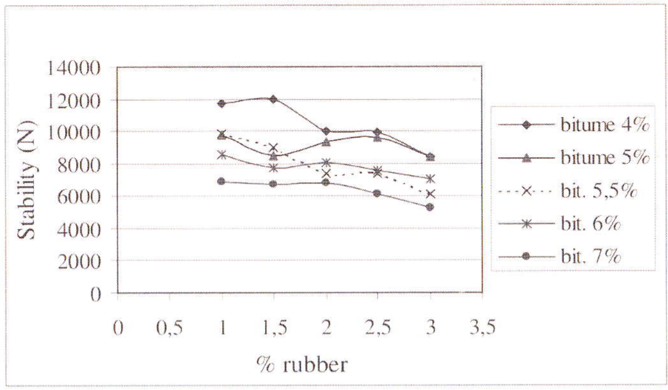

Figure 5. *diagram %rubber-stability*

Table 6 reports also flow values that resulted generally higher for RAMs , however found values are admissible for practical purposes.

Corresponding to an increase of bitumen content the quotients for all RAMs assume comparable values. If such values can be considered acceptable for practical purposes the use of mixture with the highest rubber content would be suggest in order to maximize the capacity of tire rubber recycling.

In table 8 indirect tensile strength values are reported. Measurement were performed only for mixture that were considered more interesting on the base of Marshall test results.

Table 8. *indirect tensile strength values*

Mixtures	Bitumen %	Indirect tensile strength 25 °C (MPa)
AM*	5,5	1,87
AM	5,5	1,73
RAM1,5	4	1,46
RAM 1,5	5	1,93
RAM 1,5	5,5	1,58
RAM 2,5	4	1,29
RAM 2,5	5	1,45
RAM 2,5	5,5	1,55
RAM 2,5	6	1,63
RAM 2,5	7	1,32
RAM 3	5	1,22
RAM 3	5,5	1,23
RAM 3	6	1,35
RAM 3	7	1,25

Indirect tensile strength values of RAMs were generally high and mixture with higher rubber content showed higher values according to the increasing of bitumen content. A threshold in this behaviour can be identified corresponding to the 6% of bitumen content. This circumstance is clear in the figure 6 observing curves representing results for RAM2,5 and RAM3.

Higher is the rubber content of mixture progressively higher must be the bitumen content and such value is always bigger than the bitumen content of asphalt mixtures.

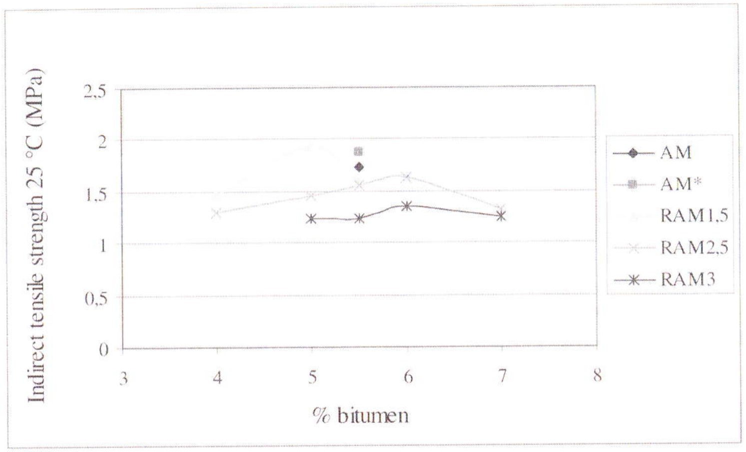

Figure 6. *diagram Indirect tensile strength-bitumen*

3.2. Mixture for Base Course

Tables 8a and 8b report the results of Marshall tests on mixtures for base courses. In the table 8b the RAMs with the index * were produced with the wet-dry process; the other mixes were produced following the hybrid dry procedure as done for the previous mixture.

Table 9a. *results of Marshall test*

Mixtures	Bitumen (%)	Stability (N)	Flow (mm)	Quotient (N/mm)
AM	4,5	12.196	3,50	3.485
AM	5	11.455	3,58	3.200
AM	5,3	14.109	3,00	4.703
AM	5,5	12.843	3,33	3.857
RAM1	4,5	13.349	3,30	4.045
RAM1	5	11.281	3,65	3.091
RAM1	5,5	9.753	3,70	2.636
RAM1	6	11.621	4,53	2.565
RAM1	6,5	9.797	4,30	2.278
RAM 1,5	4,5	12.478	3,73	3.345
RAM 1,5	5	10.000	4,17	2.398
RAM 1,5	5,5	10.280	4,53	2.269
RAM 1,5	6	8.656	4,41	1.963
RAM 1,5	6,5	7.419	4,78	1.552
RAM2	4,5	14.877	3,35	4.441
RAM2	5	11.424	3,90	2.929
RAM2	5,5	9.070	4,30	2.109
RAM2	6	8.873	4,45	1.994
RAM2	6,5	8.711	5,00	1.742

Table 9b. *results of Marshall test*

Mixtures	Bitumen (%)	Stability (N)	Flow (mm)	Quotient (N/mm)
RAM2,5	4,5	14.960	3,27	4.575
RAM2,5	5	14.246	3,43	4.153
RAM2,5	5,5	9.517	4,56	2.082
RAM2,5	6	9.098	5,70	1.596
RAM2,5	6,5	7.014	5,73	1.224
RAM3	4,5	13.122	3,57	3.676
RAM3	5	119.656	3,70	3.234
RAM3	5,5	8.334	5,35	1.558
RAM3	6	6.909	5,67	1.219
RAM3	6,5	6.447	5,70	1.131
RAM*1,5	4,5	11.053	4,12	2.686
RAM*1,5	5	10.642	4,33	2.455
RAM*1,5	5,5	8.840	4,17	2.136
RAM*1,5	6	8.286	4,95	1.707
RAM*1,5	6,5	8.692	5,32	1.635
RAM*2,5	4,5	9.371	3,93	2.883
RAM*2,5	5	8.761	4,67	1.881
RAM*2,5	5,5	8.332	5,87	1.425
RAM*2,5	6	6.822	4,55	1.557
RAM*2,5	6,5	7.035	5,66	1.170

With regard to hybrid wet process the acceptable range of bitumen content for RAM was between 5,5 and 6%. Concerning to the asphalt rubber mixes the maximum stability was reached by the RAM1 with a bitumen content of 6%; while AM reached the highest stability at a 5,5% bitumen content.However stability value recorded for AMs was higher than that one found for RAMs.

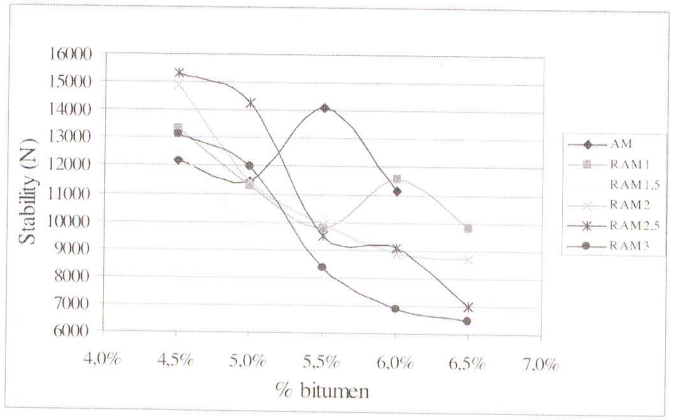

Figure 7. *diagram %bitumen-stability*

Figure 7 shows the stabilty values as a function of % bitumen. Comparing the curves of RAMs with AM two different behaviours can be distinguished. RAM1 shows a trend similar to that of AM with a clearly identifiable maximum , while RAMs with rubber content higher than 1 show continuously decreasing stability values. The observed behaviour for RAM1 was due to the small amount of rubber used for the mix. The rubber blended to the mix was almost entirely finer fraction and so involved in the digestion process, without any interaction with aggregates. In this case the hybrid process has practically the same result of a wet process.

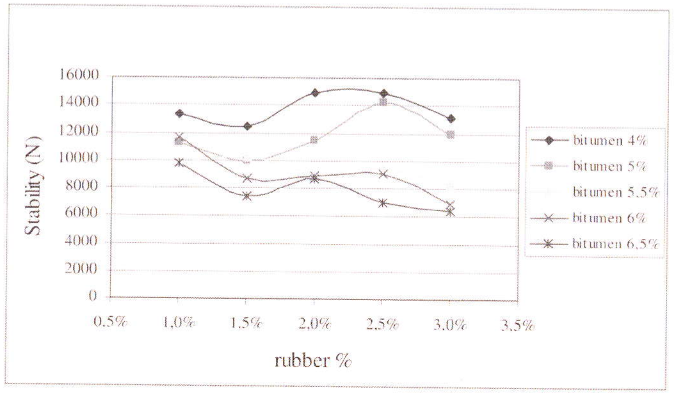

Figure 8. *diagram %rubber-stability*

Figure 8 reports the stability values as a function of rubber content. In the defined range of practical interest (bitumen content between 5,5 and 6), the rubber content affected slightly the behaviour of each mixture inducing small variation.

Table 9a,b reports also flow values resulted generally higher for RAMs , however found values are admissible for practical purposes and they tend to reach almost same values. As a result quotients are almost constant, so that the mixture can be selected with the only aim to maximize the recycling of waste tire rubber.

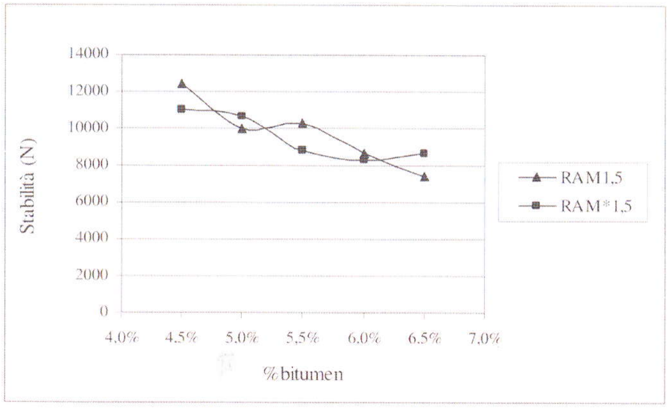

Figure 9. *diagram stability -%bitumen for mixture with low rubber content*

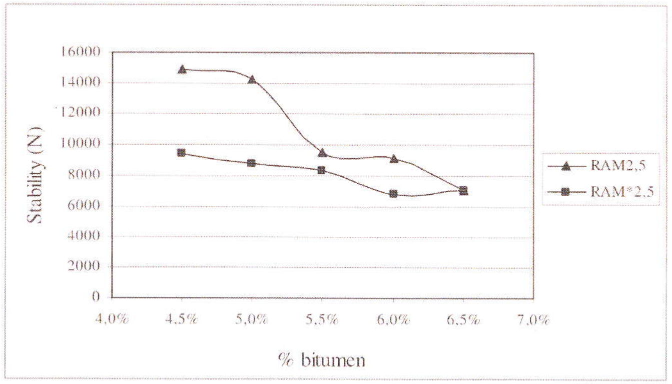

Figure 10. *diagram stability -%bitumen for mixture with high rubber content*

Concerning to the second procedure (wet-dry process) two mixes, RAM*1,5 and RAM*2,5 were produced in order to represent two classes of mixes with, respectively, high and low rubber content. The behaviours of these mixes were compared with the analogous mixtures produced with dry process, RAM1,5 e RAM 2,5. The figure 9 and 10 reports the comparison of stability as a function of % bitumen for the mixture with 1,5 and 2,5% of rubber content.

The figures clearly show that the stability values are comparable or higher for mixture by dry process.

Flow and quotient values, here not reported, confirmed that the hybrid dry process gives to mixtures better mechanical properties than the wet-dry process.

Table 10. *Indirect tensile strength of mixture for base course*

Mixture	5,5% bitumen	6% bitumen
	Indirect tensile strength (MPa)	
AM	1,03	
AM*	1,46	
RAM1	1,72	1,45
RAM1,5	1,43	1,28
RAM2	1,24	1,18
RAM2,5	1,27	1,18
RAM3	1,04	0,98

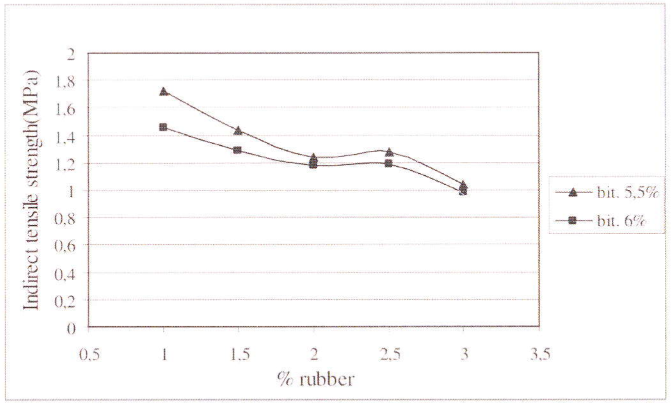

Figure 11. *diagram %rubber- Indirect tensile strength of mixture for base course*

Indirect tensile strength was performed on RAMs and AMs with a significative bitumen content (5,5 and 6%). The results are reported in table 10 . Higher values were found for RAMs rather than AMs.

In figure 11, where the Indirect tensile strength as a function of %rubber is reported, the values for the two bitumen contents appear to be not very different; a light influence of bitumen content on Indirect tensile strength is showed.

The rubber content within the range between 1,5 and 2,5% don't influence remarkably the mechanical performances of mixtures, so that the choice of these particular mixtures can be made on basis of economical and environmental criteria.

4. Conclusion

Experimental investigation showed that RAMs, for their mechanical properties comparable to AMs' properties, are suitable for technical application, reaching also environmental purposes. The results encourage to continue the research performing a wider number of tests in order to evaluate other mixtures properties.

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PERFORMANCE OF ASPHALT-RUBBER HOT MIX OVERLAYS AT BRAZILIAN HIGHWAY

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ABSTRACT: This work presents a research program that aims at evaluating the performance of hot asphalt mix used in highway pavement rehabilitation with the addition of recycled rubber of tires. The objective of this study is to quantify the performance of asphalt mix when recycled rubber is added. This study will be based upon field tests to evaluate whether a relatively thin overlay with Asphalt Rubber (AR) could reduce reflective cracking. In 2001, the private agency Univias designed and carried out a large scale AR test project in Rio Grande do Sul, Brazil on the very heavily trafficked Interstate BR116. AR is a mixture of 88% hot paving grade asphalt and 12% ground tire rubber. This mixture is also commonly referred to as the asphalt rubber wet process. The overlay project was built on top of a very badly cracked concrete asphalt pavement. The performance of the asphalt rubber overlay surpassed the original expectation. This paper presents a brief history of asphalt rubber use and comparative results to evaluate the performance for hot-mix structural overlays, containing conventional or polymer-modified binders with similar applications containing asphalt rubber binder. After two years of service the overlay is still virtually crack free, with good ride, virtually no rutting or maintenance and good skid resistance. The findings indicate that asphalt rubber is cost effective.

KEY WORDS: Asphalt- rubber, field performance, bituminous mixtures, prediction models.