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MAIREPAV03 - Third International Symposium on Maintenance and Rehabilitation of Pavements and Technological Control

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Preface

MAIREPAV'03 is the sequel of the biennial symposiums on Maintenance and Rehabilitation of Pavements and Technological Control, firstly held in 2000, in São Paulo, Brazil, organised by the local Mackenzie University, followed by the second, held at Auburn University, USA, organised by Mississippi University, with the aim to exchange technological know-how and advancement among constructors, consulting engineers, academic and research communities and government, as well as public and private agencies, for the building and maintenance of longer lasting highways and airfields. The 3rd International Symposium, organised by University of Minho, is held in Guimarães.

Once a road is constructed according to standards established by the road administration, traffic and the environment wear down the pavements, making it necessary to apply maintenance and rehabilitation intervention. At this point, the answer is the classic definition of pavement preservation: applying the Right treatment to the Right road at the Right time.

It is known that in road administration, when it comes to budgeting, maintenance is always the weak point in the chain. Thus, to help the decision maker to establish sustainable investment in the preservation of the road network, it is imperative to substantiate the long-term savings that each proposed investment on preservation can provide. This has to be done through Information and Knowledge.

Information from the entire life-cycle of the road network is required, where the evaluation of the pavement performance takes on an important role, in order to produce accurate pavement performance models, which will be of fundamental assistance in the pavement maintenance management process.

Knowledge is required to help in the development of these models through the implementation of accelerated pavement tests, considered an important part of a valuable strategy, as well as new developments in the dynamic analysis of pavement data and in the nonlinear characterisation of unbound layers and subgrade. In addition, to apply the most cost-effective rehabilitation techniques from the information gathered from the road and from laboratorial research, it is necessary to invest in modern asphalt pavement materials as well as implement more efficient paving technologies. The intensive use of natural aggregates, as well as the need to establish sustainable environmental protection, is promoting the option for pavement recycling as a cost-effective alternative technique. However, regarding the panoply of existing pavements and the possible alternative techniques, in the forthcoming future recycling still constitutes a vast area of research in sustainable recycled materials and techniques.

The present book includes the contribution of more than 80 authors from all over the world, organized in eight topics: "Evaluation of Pavement Performance and Performance Models", "Full-Scale Trials / Accelerated Pavement Testing", "Modern Asphalt Pavement Materials and Paving Technologies", "Advanced Trends in Pavement Rehabilitation Design and Preservation", "Recycling and Use of Industrial by-Products", "Management Systems / Life Cycle Analysis", "Technological Control and Trends in Contracting", "Maintenance and Rehabilitation of Low Volume Roads".

In addition to the free presentations, this book also includes the lectures of four invited speakers: "Asset Management", "Good Technical Foundations are Essential for Successful Pavement Management", "Pavement Performance Evaluation and Rehabilitation Design", "Pavement Rehabilitation Techniques – Pavement Recycling".

It is expected that the large number of industry professionals, educators, transportation engineers, involved in education, research, building, and preserving transportation infrastructures, gathered at the Symposium, will exchange their experiences and find a precious guidance for their future activities in the valuable contribution of this book.

Guimarães, July 2003 — Paulo Pereira / Fernando Branco

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Feasibility of the Use of Crumb Rubber as Asphalt Pavement Material

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ABSTRACT: This paper presents the findings of a laboratory study that aimed to evaluate the effects of recycled tire rubber on the properties of dense asphalt mixtures. It was considered two ranges of rubber particle sizes, which substituted part of mineral aggregates in the mixture gradation. The rubber-modified asphalt mixtures ("dry process") were compared to a control mixture without rubber. For the evaluation of mechanical properties, the asphalt mixtures were submitted to three laboratory tests: dynamic indirect tension for the determination of the resilient modulus; tensile strength under indirect tension; and resistance to rutting in a wheel-tracking device. The results show that smaller rubber particles increase the resistance to rutting. The rubber-modified asphalt mixtures presented smaller values of resilient modulus and tensile strength than the control mixture. The tests results show that the size and percentage of rubber particles affect the mixture properties: the higher the rubber size and the rubber content, the smaller the resilient modulus; the higher the rubber content, the smaller the tensile strength. The performed test also show that the binder content and the digestion time significantly affect the results. The use of tire rubber in the asphalt paving industry can contribute to minimize the problems related to the disposal of used tires and, at the same time, improve some engineering properties of asphalt mixtures.

KEY WORDS: Asphalt mixtures, Tire rubber, Dry process, Mechanical properties.

1. INTRODUCTION

The tires play a very important role in our daily life. However, when they become useless they are a source of environmental and health problems (risk of fires, proliferation of mosquitoes, rodents and other vectors of diseases). At the same time, their disposition in sanitary landfills is very expensive because the tires present very low compressibility rate. Some unofficial estimates indicate that 44 million carcasses of tires are generated annually and that exist more than 100 million tires not correctly disposed in Brazil.

Researches have been developed to recycle tire rubber or to produce energy from used tires. In Brazil, the tendency is of an increase in the number of researches about this subject, since it was published, on December 02, 1999, a resolution of the National Council for the Environment (CONAMA) based on the concept of "producer and importer responsibility". Starting from January 2002, makers and importers of tires will be forced to collect and dispose them in an environmentally correct way. Initially, for each four tires produced or imported there will be one recycled or reused. The requirements increase until the year 2005 in according to time schedule and quantities presented in Table 1.

Table 1: Synthesis of the Resolution N. 258 of CONAMA

From:	New Tires		Used Tires	
	Brazilian and Imported	Recycling and/or Reuse	Imported	Recycling and/or Reuse
Jan/2002	4	1	-	-
Jan/2003	2	1	-	-
Jan/2004	1	1	4	5
Jan/2005	4	5	3	4

In the USA, country that disposes more than one used tire per habitant per year, there are laws that regulate the stocking and processing of tires, restrict the disposal in sanitary landfills, and incentive the development of new alternatives such as the utilization of used tires in pavement construction (FHWA, 1993).

The merits of using crumb rubber in asphalt mixtures consider environmental and engineering benefits. While the environmental benefits of recycling scrap tires are obvious, there is still no consensus whether the use of crumb rubber will bring significant engineering benefits such as improving fatigue life and rutting resistance.

There are two methods of tire rubber incorporation into asphalt mixtures. In the wet process, fine particles of rubber are mixed to hot asphalt cement, producing a new binder called "asphalt-rubber". In the dry process, bigger particles of rubber replace part of mineral aggregates and, with the addition of asphalt binder, form a product called "asphalt concrete modified with tire rubber".

This paper presents a laboratory evaluation of asphalt mixtures containing recycled tire rubber based on the dry process. It aimed at contributing to the solution of a very important environmental problem, since the large-scale utilization of used tires in Brazil has to be based on the clear understanding of technical and economical aspects related to the environmental and paving works.

It is still necessary a wide variety of studies and research projects concerning the feasibility, environmental suitability, and performance of the use of recycled tire rubber in highway construction. This study tries to match the need for safe and economic disposal of waste materials with the need for better and more cost-effective construction materials.

2. RUBBER MODIFIED ASPHALT CONCRETE (DRY PROCESS)

Two main systems currently use the dry process to incorporate used tire rubber into paving mixtures: the PlusRide system and the generic system.

The first method is based on a process that was developed in Sweden during the 60s and was patented with the name Rubit. In the USA it was patented with the name PlusRide. In this system, mixtures are prepared by a process that typically uses up to 3 percent, by weight of total mix, granulated coarse and fine rubber particles to replace some of the aggregates in the mixture. The mix requires 1.5 to 2 percent more asphalt than a conventional mix. The target air voids content is 2 to 4 percent. The tire rubber particles are added to a gap-graded aggregate and then mixed with hot asphalt cement. There is a partial reaction between the asphalt binder and the rubber particles finer than the mesh #20 (0.84 mm), which creates an interface bonding the two materials. Thus, the amount of fine rubber controls the degree of modification of the asphalt binder (FHWA, 1993; Epps, 1994). Laboratory tests have shown an increasing fatigue life of asphalt mixtures based on the PlusRide technology (Takallou et al., 1986; Takallou and Hicks, 1988).

The generic process is prepared by adding up to 3 percent by weight of fine and course rubber particles to a dense-graded aggregate mixture. Generally the generic dry technology system uses lower amounts of crumb rubber and smaller size as compared to PlusRide. It is a two-component system in which the fine crumb rubber interacts with asphalt cement, and the coarse crumb rubber performs as an elastic aggregate in the mixture. The combination of modifying the asphalt binder and increasing the elasticity of the mixture can increase the fatigue life, reduce thermal and reflective cracking, and increase the adhesion of the modified binder to the aggregate (FHWA, 1993).

Improved pavement performance with the addition of rubber using the dry process was also reported in Spanish (Gallego et al., 2000). The results of laboratory evaluation showed that modified mixtures resisted fatigue cracking and improved rutting resistance over conventional mixtures.

The results already obtained in the USA and Spanish are important as evidences of the potentiality of the use of tire rubber in the asphalt industry. But they do not exclude the necessity of additional researches in Brazil, since the climatic conditions and the available materials are different.

3. EXPERIMENTAL PROGRAM

The purpose of this paper is to evaluate the effect of the amount and gradation of rubber on the performance of rubber-modified asphalt mixture. It was considered two rubber contents (1 and 2 percent by weight of total mix) and two ranges of rubber particle sizes, which substituted part of mineral aggregates in the mixture gradation: coarse (C), between mesh 3/8" (9.5 mm) and mesh #30 (0.6 mm); and fine (F), between mesh #16 (1.18 mm) and mesh #100 (0.15 mm). The mixtures were compared to a control mixture without rubber.

Previously to the compaction process, the mixtures were submitted to aging in an oven, at 150°C, for 2 hours. This process simulated the short-term aging during the construction phase (mixing, transport and placing) in which occurs rubber-asphalt interactions. This period of time called "digestion time" has been identified as a parameter with major influence on the performance of the mix when the dry process is used (Gallego et al., 2000).

For the control mixture, the design void content was 4.0 percent. For all mixtures modified with tire rubber, samples were compacted with the same binder content of the control mixture.

In addition, it was performed an evaluation of the factors digestion time and asphalt content, considering the mixtures prepared with 2% of rubber for both coarse (C) and fine (F) gradations.

For the evaluation of mechanical properties, the asphalt mixtures were submitted to dynamic indirect tension for the determination of the resilient modulus, tensile strength under indirect tension, and resistance to rutting in a wheel-tracking device.

4. MATERIALS

4.1. Aggregate

The aggregate used in the specimen's preparation are basalt from Ribeirao Preto, SP, Brazil. The aggregate gradation is showed in Figure 1, which is in the middle of a gradation (C-mix - 12.5 mm nominal maximum size) specified by the Brazilian Department of Highways

(DNER, 1997). Results of stripping tests (AASHTO, 1989) showed no problems of bonding between the asphalt binder and the aggregate.

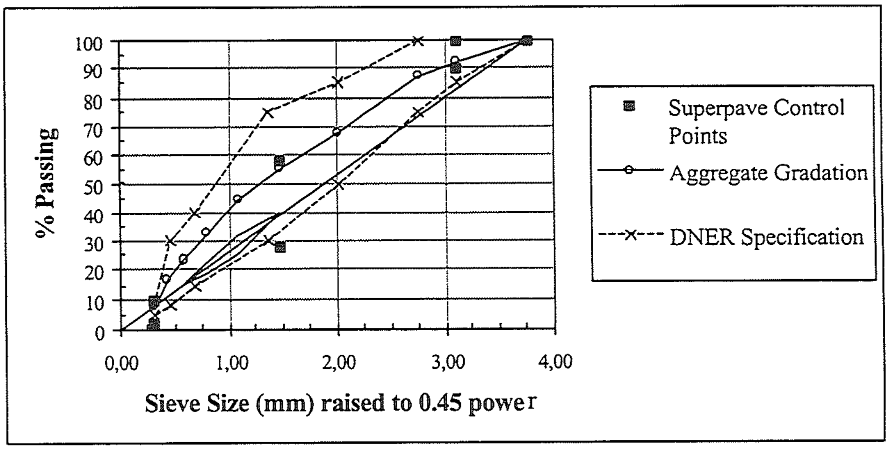

Figure 1: Gradation of the aggregates used in the asphalt mixtures

4.2. Asphalt cement

The asphalt cement used in this study was an AC-20 supplied by Ipiranga Asfaltos, Paulinia, SP, Brazil. Its properties are presented in Table 2.

Table 2: Asphalt Cement (AC-20) Properties

Test	Values	Specification DNC 01/92	Test Method
Absolute viscosity @ 60°C (poise)	3317	2000 - 3500	NBR 5847
Viscosity Saybolt Furol @ 135°C (s)	180	120 min.	MB-517
Viscosity Saybolt Furol @ 177°C (s)	30.3	30 - 150	MB-517
Effect of Heat and Air:			
Loss of weight (%)	0.044	1.0 max.	MB-425
Viscosity ratio	1.7	4.0 max.	-
Ductility, 25°C (cm)	> 100	20 min.	NBR 6293
Index of temperature susceptibility	-1.0	-1.5 - 1.0	-
Penetration, 25°C, 100g, 5s (0.1 mm)	59	50 min.	NBR 6576
Flash point (°C)	300	235 min.	NBR 11341

4.3. Rubber

Recycled rubber was supplied by BORCOL Rubber Industry Ltd., Sorocaba, SP, Brazil. The rubber was granulated under room temperature, and it is free of wire and fabric. It was considered two ranges of rubber particle sizes: coarse (C), between mesh 3/8" (9.5 mm) and mesh #30 (0.6 mm), and fine (F), between mesh #16 (1.18 mm) and mesh #100 (0.15 mm). In the grinding/granulating process, the particle reduction is accomplished by shearing actions that create particles with a rough surface.

Table 3 presents the properties of crumb rubber in different sizes fractions. The tests used to characterize the crumb rubber were: specific gravity, porosity, and thermogravimetric analysis (TGA). Thermogravimetric analysis (TGA) measures the amount and rate of weight change as a function of increasing temperature, in a controlled atmosphere. It can be used to analyze the weight change and to detect phase changes due to decomposition or oxidation.

Table 3: Rubber Properties

Property	Rubber			
	Coarse (C)		Fine (F)	
	3/8" - #4	#16 - #30	#16 - #30	#50 - #100
Specific gravity	1.1334 ± 0.0010	1.1547 ± 0.0007	1.1607 ± 0.0016	1.1934 ± 0.0012
Loss of weight at 170°C (%)	0.7410	0.7877	-	-
Porosity (%)	9.65	16.08	-	68.94

4.4. Mixtures

To provide enough room for the rubber particles, it was necessary to create a "gap" in the gradation curve from 9.5 mm to 0.6 mm (coarse particles) and from 1.18 mm to 0.15 mm (fine particles), as showed in Figure 2. The difference in specific gravity between rubber particles and aggregate required a weight adjustment factor of about 2.5.

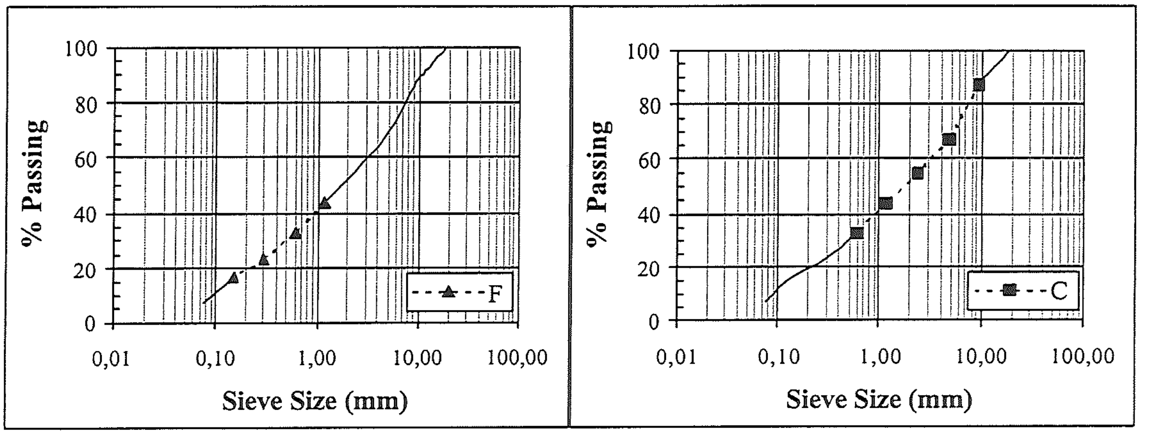

Figure 2: Ranges of rubber particle sizes: F (1.18 mm - 0.15 mm) and C (9.5 mm - 0.6 mm)

The Marshall mix design procedure was used in this study (ABNT, 1993). Laboratory mixing and compaction temperatures for all mixtures were selected in according to viscosity criteria. The rubber, at room temperature, was dry-mixed with aggregate at 175°C. The binder was heated to 160°C, and then added to the aggregate and rubber. The mix was wet-mixed for about 2 minutes to ensure that the aggregate/rubber particles were completely and uniformly coated by the binder. Upon mixing, the loose mixture was then placed in an oven for either 0, 2 and 4 hours at 150°C. This aging process simulated the short-term aging during mixing and placing conditions. After that, samples were compacted using an automatic Marshall hammer with 75 blows in each side.

The samples were allowed to cool overnight and were then extracted from the molds for testing. The bulk specific gravity and height of each compacted specimen were measured immediately after extrusion from the mold (AASHTO, 1993). Part of the specimens was immersed in a water bath maintained at 60°C. After 30 to 40 minutes, they were removed from the water bath and tested immediately using the Marshall apparatus. Stability and the flow values were recorded. Bulk density, specific gravity, air voids, voids in the mineral aggregate, voids filled with asphalt and the stability/flow values were calculated for each specimen.

5. DISCUSSION OF THE RESULTS

5.1. Effect of digestion time on volumetric properties

The interaction between asphalt binder and rubber, during the mixing and transportation times, is called rubber digestion. Aiming at evaluating the effects of the control mixture aging and of the rubber-modified mixtures digestion, the samples were kept in the oven, at 150°C, for 2 and 4 hours prior to the compaction.

Figure 3 shows the relationship between binder content and air voids for rubber-modified asphalt mixtures (2% of rubber). It can be observed that the aging time did not affect the air voids of the control mixture.

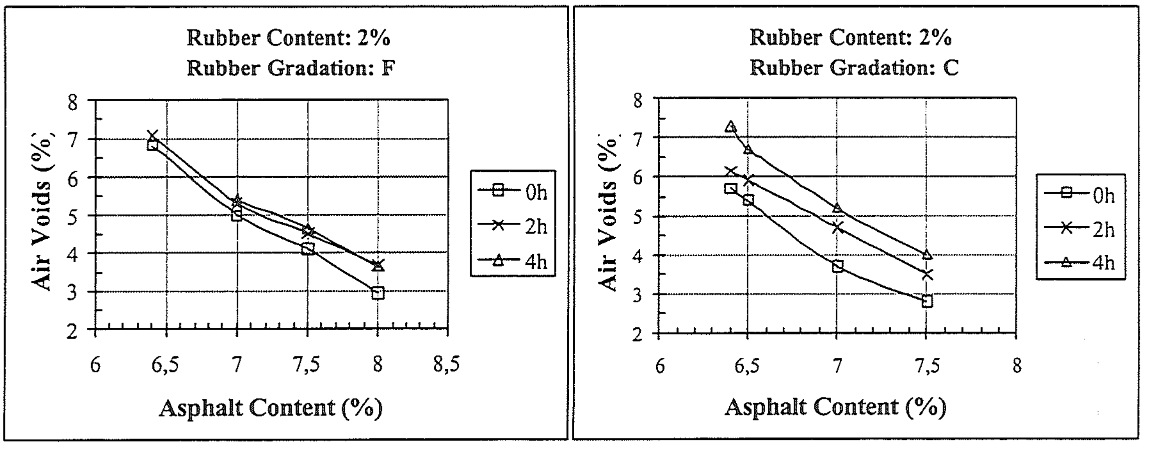

Figure 3: Effect of digestion time on volumetric properties

The digestion time has a significant effect on rubber-modified mixtures: the longer the digestion time, the higher the binder content to achieve an air voids of 4%. Probably, part of the required binder is being absorbed by the rubber, which presents high porosity. Although in the dry process the rubber is considered an aggregate, the particles passing # 20 (0.84 mm) reacts partially with the binder, and the degree of reaction depends on the particles size, i.e., the smaller the particles, the more efficient the reaction between rubber and asphalt binder, requiring less digestion time.

5.2. Mixture design

To evaluate the influence of the rubber gradation, rubber content and asphalt content on the mechanical properties of the mixtures aged in oven for 2 hours, it was considered two ranges of rubber particle sizes, coarse (C) and fine (F), and two rubber contents (1 and 2% by weight of total mix). For the control, 2C' and 2F'mixtures, the design binder content were selected to achieve air voids of 4.0 percent. The other mixture samples (2C, 2F, 1C, 1F) were carefully controlled to have the same binder content of the control mixture.

In Brazil, the conventional mixture design method used by highway agencies are still based on Marshall procedure. Table 4 presents the mixture composition, asphalt content, bulk density, air voids, voids filled with asphalt (VFA), Marshall stability and flow (average of three replicates).

Table 4: Results of Marshall Mix Design

Property	Mixture Type						
	2C'	2C	2F'	2F	1C	1F	Control
Composition:							
Stone (g)	1140	1140	1141.7	1141.7	1170	1170.8	1200
Rubber (g)	24	24	24	24	12	12	-
Asphalt (g)	91.7	79.3	98.6	79.3	79.3	79.3	79.3
Asphalt (%)	7.3	6.4	7.8	6.4	6.3	6.3	6.2
Bulk Spec. Gravity	2.365	2.344	2.356	2.325	2.399	2.387	2.469
Air Voids (%)	4	6.1	4	7.1	5.4	5.9	4
VFA (%)	80	69	83	67	73	71	79
Stability (kgf)	937	978	872	1059	1219	1013	1399
Flow (mm)	5.2	4.7	5.1	4.5	4.5	4.1	3.2

Table 4 show that mixtures modified with tire rubber had lower Marshall stability value than the control mixture and the flow increased with the rubber content. Only the control mixture presented all the values in according to the requirements of Brazilian Standards.

5.3. Mechanical properties

Resistance to Rutting

The French Pavement Rutting Tester (Laboratoires des Ponts et Chaussees - LCPC) was used to evaluate the mixture susceptibility to permanent deformation. The result obtained from laboratory simulation of the rutting phenomenon can provide one of the selection criteria for a mix design (Brosseaud et al., 1993).

Samples were compacted with a LCPC laboratory rubber-tired compactor (AFNOR, 1991b). The LCPC equipment tests two slabs simultaneously in an air chamber with 5000 N applied by a 400 mm diameter pneumatic tire inflated to 600 kPa. During the tests, the tire passes over the center of the sample for twice in a second. The machine used in this research tests asphalt concrete slabs (500 mm X 180 mm X 50 mm).

The laboratory compacted slabs were aged at room temperature for as long as seven days. Then they were placed in the LCPC rutting tester and conditioned with 1,000 cycles at room temperature. The thickness of each slab was calculated by averaging 15 thickness measurements taken at 15 standard positions using a gauge with a minimum accuracy of 0.1 mm. The measurements are taken in three points across the width of he specimen and in five locations along the length of the slab. This thickness is considered the initial thickness of the slab.

Prior to the wheel-tracking test, the samples were heated to 60°C (test temperature) for 12 hours. The average rut depth in each slab is measured at 100, 300, 1,000, 3,000, 10,000, and 30,000 cycles. The average percent rut depth is based on the initial thickness of the slab.

According to French specification, a mixture is acceptable if the average rut depth at 30,000 cycles is less than or equal to 10 percent (AFNOR, 1991a). Slopes for different mixtures taken from log rut depth vs. log cycle plots can also be compared. Rut-susceptible mixtures generally have higher slopes, but there is no French specification about the slope.

The results of the wheel tracking tests (an average of two replicates) are given in Figure 4 and Table 5. Based on the results, the mixture with best performance in terms of rutting resistance was 1F (1% of rubber, fine particles, and asphalt content equal to the control mixture). Mixture 2F (2% of rubber, fine particles, and asphalt content equal to the control mixture) and the control mixture presented both good performance. The mixture with the worst performance was 2C' (2% of rubber, coarse particles, and a binder content to achieve

4% air voids). Mixture 2F presented the lowest deformation rate, which means the least potential to develop rutting.

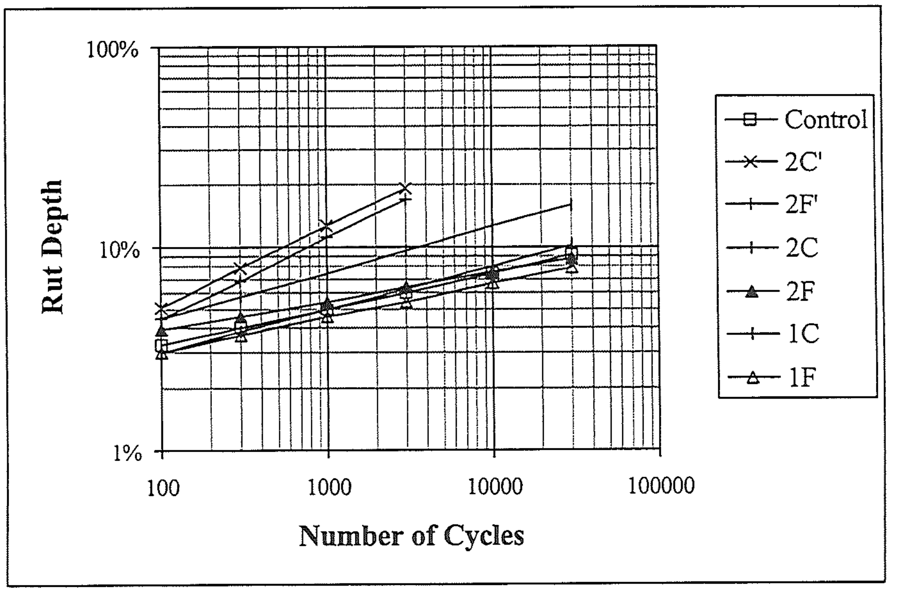

Figure 4: Evaluation of the resistance to permanent deformation using the LCPC wheel-tracking device

Indirect Tensile Strength and Resilient Modulus

The resilient modulus tests were performed in the indirect tensile mode at a temperature of 25°C. The displacements were measured using a linear variable displacement transducer (LVDT). The procedure for the test was similar to ASTM D-4123 with a loading time of 0.1 s and a resting period of 0.9 s (DNER, 1994a). The indirect tensile strength tests were conducted at 25°C according to DNER (1994b).

The results (an average of three replicates) of the resilient modulus (RM), indirect tensile strength (TS) and the RM/TS ratio are summarized in Table 5. The mixtures modified with rubber presented smaller values of resilient modulus and tensile strength than the control mixture. The resilient modulus drops significantly with a small increasing in rubber content, but not proportionally to the reduction of tensile strength, which suggests a larger flexibility and resistance to fatigue cracking.

Table 5: Summary of Mechanical Test Results

Property	Mixture Type						
	2C'	2C	2F'	2F	1C	1F	Control
RM (MPa, 25°C)	1942	1634	2687	2104	2165	2793	3637
TS (MPa, 25°C)	1.09	1.02	1.12	0.99	1.14	1.11	1.29
RM/TS	1782	1602	2399	2125	1899	2516	2819
Permanent Deformation:							
Rut Depth (30,000 cycles)	failure	16%	failure	9%	10%	8%	9%
Slope	0.3960	0.2234	0.3950	0.1451	0.2129	0.1681	0.1789

It aimed at evaluating the influence of the factors rubber particles size (coarse, C, and fine, F), rubber content, and digestion time on mechanical properties (resilient modulus and tensile strength) of rubber-modified asphalt mixtures. Table 6 shows the resilient modulus and tensile strength of aged (two hours at 150°C) and non-aged mixtures. The samples were prepared with 2% of rubber (coarse, C, and fine, F) and the same asphalt content of the control mixture, which was selected to achieve air voids of 4%.

Table 6: Summary of Short-Term Oven Aging Data

Mixture	Short-term oven aging at 150°C (hours)	Air Voids (%)	RM (MPa, 25°C)	TS (MPa, 25°C)
Control	0	3.9	3623	1.26
	2	4.0	3637	1.29
2C	0	5.7	1853	0.93
	2	6.1	1634	1.02
2F	0	6.8	2230	0.93
	2	7.1	2104	0.99

The analysis of the results was based on the Tukey test and analysis of variance - ANOVA (Gibra, 1973). According to the Tukey test, the digestion time did not significantly affect the resilient modulus, but mixture 2C after the digestion time presented a significant increase in tensile strength. This result emphasizes the importance of considering the digestion time when producing rubber-modified asphalt mixtures (dry process), mainly if bigger rubber particles are used. The digestion time is associated to the improvement of mechanical properties, since the resilient modulus is kept constant and the tensile strength increases, i.e., the lower the RM/TS ratio, the longer the fatigue life (or the possibility of using smaller layer thickness for the same fatigue life).

6. CONCLUSIONS

This paper presented the results of a laboratory study that evaluated the effects of rubber content and rubber particle size on the properties of a dense asphalt mixture. The main conclusions achieved so far are the following:

1. Rubber-modified asphalt mixtures are affected by the digestion time, which must be considered in the dry-process design. The beneficial effects of the digestion time (tensile strength increasing and MR/TS ratio decreasing) are higher for coarser rubber particles.
2. The mixtures modified with tire rubber designed to achieve 4.0 percent of air voids presented excessive permanent deformation. It is an indication that the asphalt content for those mixtures are high, which means that the 4.0 % air voids should not be used as a unique criterion in the determination of the optimum asphalt content.
3. Mixtures modified with rubber presented smaller values of resilient modulus and tensile strength than conventional mixture. The rubber gradation and the asphalt content had small influence on the tensile strength values.
4. The tests results showed that the size and percentage of rubber affected the mixture properties: the higher the rubber size and content, the smaller the resilient modulus; the smaller de rubber size and the rubber content, the higher the rutting resistance.
5. The obtained results show that the use of recycled tires in asphalt paving can contribute for the solution of serious environmental problems and, at the same time, increase some engineering properties of asphalt mixtures.
6. Since only conventional mix design procedures have been used for mixtures modified with crumb rubber, further research could be necessary prior to the proposal of new procedures for those mixes in Brazil.

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REFERENCES

AASHTO (1989). *T-283 - Resistance of Compacted Bituminous Mixture to Moisture Induced Damage*. American Association of State Highway Transportation Officials.

AASHTO (1993). *T-166 - Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens*. American Association of State Highway Transportation Officials.

ABNT, 1993. *NBR 12891/93 - Marshall Method of Mix Design*. Brazilian Association of Technical Standards, Rio de Janeiro. "In Portuguese"

AFNOR, 1991a. *Déformation Permanente des Mélanges Hydrocarbonés – Partie 1: Essai d'orniérage, NF P 98-253-1*. Association Française de Normalisation, Paris, France.

AFNOR, 1991b. *Préparation des Mélanges Hydrocarbonés – Partie 2: Compactage des plaques, NF P 98-250-2*. Association Française de Normalisation, Paris, France.

Brosseaud, Y., Delorme, J., and Hiernaux, R., 1993. Use of LPC Wheel-Tracking Rutting Tester to Select Asphalt Pavements Resistant to Rutting. In *Transportation Research Record 1384*, TRB, National Research Council, Washington, D.C., pp.59-68.

DNER, 1994a. *ME 133/94 – Bituminous Mixtures – Determination of the Resilient Modulus*. National Department of Highways, Rio de Janeiro. "In Portuguese"

DNER, 1994b. *ME 138/94 – Bituminous Mixtures – Determination of the Tensile Strength*. National Department of Highways, Rio de Janeiro. "In Portuguese"

DNER, 1997. *DNER-ES 313/97 - Procedures for Asphalt Concrete Construction*. National Department of Highways, Rio de Janeiro. "In Portuguese"

Epps, J. A., 1994. *NCHRP Synthesis of Highway Practice 108: Uses of Recycled Rubber Tires in Highways*. TRB, National Research Council, Washington, D.C.

FHWA, 1993. *Crumb Rubber Modifier – Design Procedures and Construction Practices*. Workshop Notes, Federal Highway Administration, U. S. Department of Transportation, FHWA-SA-93-011.

Gallego, J., del Val, M. A., and Tomás, R., 2000. A Spanish Experience with Asphalt Pavements Modified with Tire Rubber. In *Proceedings of the Asphalt Rubber 2000 Conference*, Portugal, pp.673-687.

Gibra, I. N., 1973. *Probability and Statistical Inference for Scientists and Engineers*. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 596p.

Takallou, H. B., and Hicks, R. G., 1988. Development of Improved Mix and Construction Guidelines for Rubber-Modified Asphalt Pavements. In *Transportation Research Record 1171*, TRB, National Research Council, Washington, D.C., pp.113-120.

Takallou, H. B., Hicks, R. G., and Esch, D. C., 1986. Effect of Mix Ingredients on the Behavior of Rubber-Modified Asphalt Mixtures. In *Transportation Research Record 1096*, TRB, National Research Council, Washington, D.C., pp.68-80.