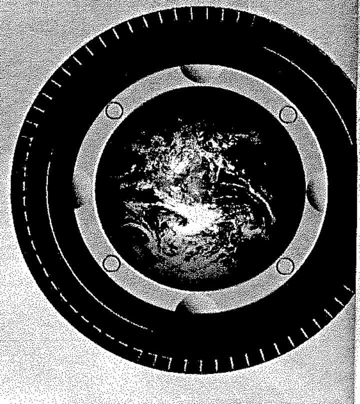
...ltrubber 2009 Conference

...rize close to half a century of experience in
...ber binders as defined by ASTM D6114-
...e functional and structural performance of
...es and binders is considered.

... of the Proceedings of AR2000 in
...03 in Brasilia,Brazil and AR2006 in Palm
... new developments took place in the
...al properties and performance of asphalt
...d in this AR2009 Proceedings from papers
...a.

...been supported by contributions and/or
...Rubber Pavements Association, Jiangsu
...s Department, Jiangsu Communication
...u Highway and Transportation Society,
...Research Institute, Consulpav, Jiangsu
...ngineering Construction Bureau,Jiangsu
... Communication Bureau,United States
...Agency, Recycled Tire Engineering and
...na State University



Jiangsu Highway Bureau

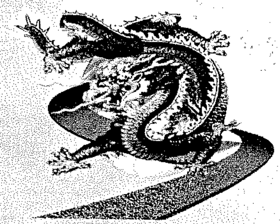
Nanjing Communication Bureau

JSTRI

consulpav

YGB

ASU Ira A. Fulton School of Engineering ARIZONA STATE UNIVERSITY

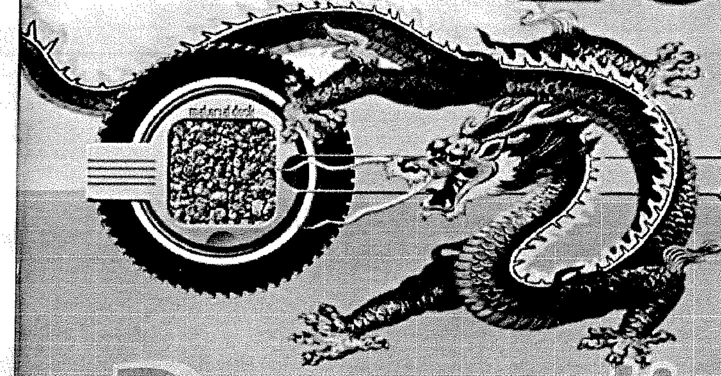


Proceedings Asphalt rubber 2009

Edited by
Dr. Jorge B. Sousa

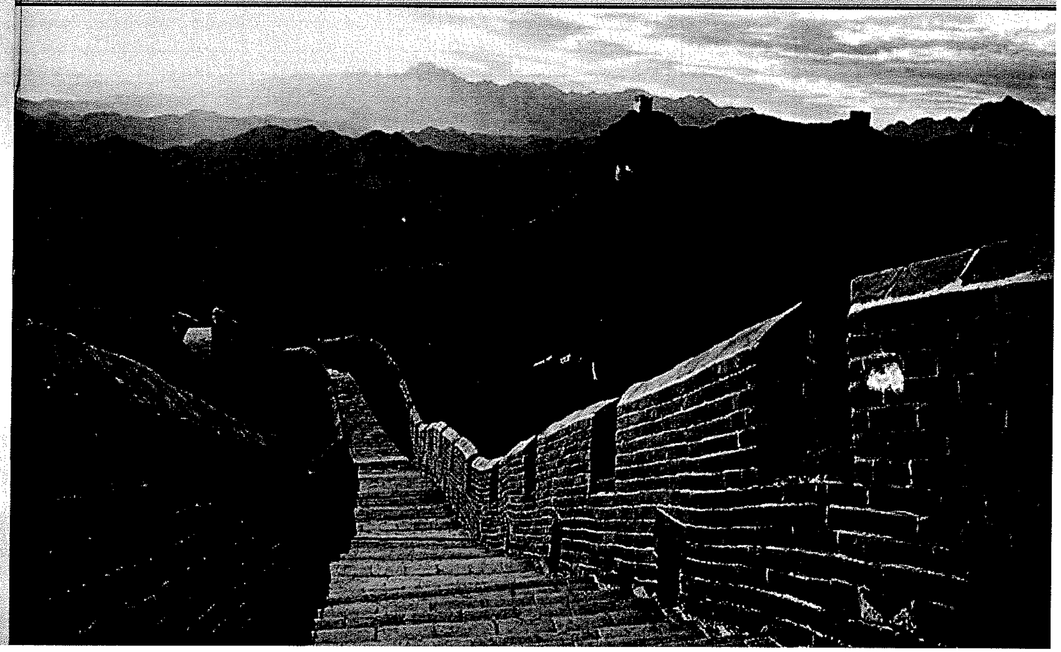
Asphalt rubber 2009

ROAD TO
SUSTAINABILITY



Nanjing - China
2th to 4th of November 2009

Proceedings



city as well. I sincerely wish every participant a happy stay in Nanjing's golden autumn and the **AR2009** Conference a complete and great success!

Dr. Qian Guochao,
Deputy Director
Jiangsu Provincial Communications Department

Index

Chapter 3 Binder Properties

Chapter 4 Case Studies

Chapter 5 Function, Environemental and other Aspects

Chapter 6 Evaluation and Design of Chip Seals

Chapter 7 Terminal Blend Binders

Chapter 8 Invited papers on related aspects

Evaluating Permanent Deformation in Asphalt Rubber Mixtures

Liseane P.T.L. Fontes* — Glicério Trichês*
— Jorge C. Pais — Paulo A.A. Pereira****

** University Federal of Santa Catarina*
Department of Civil Engineering
Florianópolis, SC, Brazil
lisefontes@matrix.com.br
ecv1gtri@ecv.ufsc.br

*** University of Minho*
Department of Civil Engineering, Campus of Azurém
4800-058 Guimarães, Portugal
jpais@civil.uminho.pt
ppereira@civil.uminho.pt

ABSTRACT. Permanent deformation or rutting, one of the most important distresses in flexible pavements, has long been a problem in asphalt mixtures. Throughout the years, researchers have used different test methods to estimate the performance of asphalt mixtures in relation to rutting. One of the alternatives to reduce permanent deformation in asphalt pavement layers is through the use of mixtures produced with asphalt rubber. This work aims at comparing the performance of a conventional dense graded mixture and that of asphalt rubber mixtures (dense and gap graded) in what respects to rutting. The asphalt rubber mixtures were produced by the wet process (continuous blend at laboratory and tire rubber-modified asphalt binder at an industrial plant). To study their performance, two laboratory tests, the Repeated Simple Shear Test at Constant Height (RSST-CH) and the Accelerated Pavement Testing Simulator test (wheel tracking) were carried out. The results from this study showed that asphalt rubber mixtures can be an alternative to minimize permanent deformation in asphalt pavement layers and that the resilience of asphalt rubber binders can be an indicator of that performance.

KEYWORDS: Permanent Deformation, Asphalt Rubber, RSST-CH, Wheel Tracking.

1. Introduction

Waste tires constitute a serious environmental problem that many countries have to face as they accumulate rapidly and they are not easily disposed of. The use of crumb rubber from waste tires in asphalt, what has given origin to the term asphalt rubber, has been an alternative to minimize their ecological impact and, simultaneously, to improve the mechanical properties of the asphalt mixtures.

Processing scrap tires into crumb rubber can be accomplished through two main types of technology: (i) ambient grinding; (ii) cryogenic grinding. In the ambient ground-rubber processing, scrap tire rubber is ground or processed at or above ordinary room temperature. Cryogenic processing uses liquid nitrogen to freeze tire chips or rubber particles prior to size reduction (-120℃). A very fine ground crumb rubber modifier is typically used in crumb rubber asphalt (Baker *et al.*, 2003).

There are two processes through which crumb rubber can be added into asphalt: a) through the dry process and b) through the wet process. In the dry process, the crumb rubber is mixed together with the aggregates prior to the addition of the asphalt. In this process, the crumb rubber is used as an aggregate.

The wet process includes any method by which crumb rubber is blended with conventional asphalt before incorporating the binder into the asphalt paving materials. Asphalt rubber binders result from the chemical reaction of a mix of liquid asphalt binder with 15 to 22% crumb rubber obtained from used tires and added to liquid asphalt. It reacts at high temperatures prior to being mixed with the aggregate. Potential benefits of asphalt rubber binders obtained through the wet process include: a) improvement of the fatigue life of a pavement; b) enhanced resistance to permanent deformation; c) reduction of crack propagation when compared to other binders (Caltrans, 2003).

This work intends to evaluate the performance of gap and dense graded mixtures, containing asphalt rubber binders, prepared through the wet processes (continuous blend and tire rubber-modified asphalt binder) and crumb rubber obtained from the cryogenic and ambient processes in relation to permanent deformation. The behaviour of asphalt rubber mixtures was compared to the performance of that of a conventional mixture. The tests were carried out through two rutting tests, such as the RSST-CH (Repeated Simple Shear Test at Constant Height) and the Accelerated Pavement Testing Simulator (wheel tracking).

2. Permanent deformation in asphalt pavements

The permanent deformation (rutting) of asphalt pavements has a major impact on the performance of a pavement. Rutting reduces not only the useful service life of pavements, but it may also affect basic vehicle handling manoeuvres, what can be hazardous to highway users. Rutting develops gradually as the number of load applications increases. Rutting appears as longitudinal depressions in the wheel paths and small upheavals to the sides. It is caused by a combination of densification and shear deformation. These depressions or ruts are important for at least two reasons: i) if the surface is impervious, the ruts trap water causing hydroplaning what is extremely dangerous, particularly for passenger cars; ii) as the ruts

progress in depth, steering becomes increasingly more difficult, posing some added safety concerns (Sousa *et al.*, 1991).

Zaniewski *et al.* (2003) asserted that densification is the further compaction of asphalt mixture pavements by traffic after construction. When compaction is poor, the channelized traffic provides a repeated kneading action in the wheel track areas and completes the consolidation. A substantial amount of rutting can occur if thick layers of asphalt are consolidated by traffic.

The lateral plastic flow of the asphalt mixtures due to wheel tracks results in rutting. The use of excessive asphalt cement in the mix causes the loss of internal friction between the aggregate particles, what provokes that traffic loads are supported by the asphalt cement rather than by the aggregate structure. Plastic flow can also occur due to a lack of angularity of the aggregates and to an insufficient surface texture that is needed for inter-particle friction. Plastic flow can be minimized by using large size aggregates, angular and rough textured coarse and fine aggregate and stiffer binders, as well as by providing suitable compaction during construction (Roberts *et al.*, 1996).

Additionally, for the assessment of the rut depth it is also necessary to recognize the evolution of the void content in a pavement asphalt layer. When the air-void content drops below 2-3%, the binder acts as a lubricant between the aggregates and reduces point-to-point contact pressures. Permanent deformation of asphalt aggregate mixes is strongly controlled by the plastic component due to the aggregate skeleton. This causes permanent deformation changes either in volume or in shear, what mostly occurs in hotter days or because of heavy loads (Sousa *et al.*, 1994).

Asphalt cements behave like viscous liquids and flow under hot conditions or under sustained loads. Viscous liquids, such as hot asphalts, are sometimes called plastic because, once they start flowing, they do not return to their original position. This is why, in hot weather, some asphalt pavements flow under repeated wheel loads and wheel path ruts appear. However, rutting in asphalt pavements during hot weather is also influenced by the properties of the aggregates and it is probably more correct to say that the asphalt mixture is behaving like a plastic mixture (FHWA, 1994).

According to Bennert *et al.* (2004), the addition of crumb rubber to asphalt mixtures and the proper design and field implementation of the asphalt rubber mixtures generally expand the working range of the conventional mixtures providing:

- Reduction of rutting at high temperatures;
- Reduction of fatigue cracking at intermediate temperatures;
- Reduction of thermal cracking;
- Minimization of the potential for age hardening.

At high temperatures, the asphalt binder tends to flow easier due to the natural decrease of viscosity associated with higher temperatures. This condition creates a "softer" asphalt mixture, which is prone to rutting. The addition of crumb rubber to the asphalt mixture provides extra viscosity, what contributes to the stiffening of the HMA at higher temperatures (Takallou *et al.*, 1997).

Asphalt rubber mixtures generally have a greater fatigue life due to the higher binder contents and higher rutting resistance caused by their higher binder viscosity. They are also generally more permeable than conventional mixes, what reduces the splash and spray during periods of rain (Hicks, 2002).

In the last years some laboratorial tests, like the Wheel Tracking, the Uniaxial Cyclic Compression, the Triaxial test and the Repeated Shear at Constant Height have been used to study permanent deformation in asphalt mixtures (Brown *et al.*, 2001).

3. Mixtures characterization

3.1. Materials characterized in laboratory

Two types of rubber, obtained through the ambient and the cryogenic processes, were used to produce the asphalt rubber binders for this work. In the ambient process the rubber from the tires are size reduced at an ambient temperature. In the cryogenic process liquid nitrogen is used to freeze (in general below 120℃) tire chips or rubber particles prior to size reduction.

Besides the size, the main difference between ambient and cryogenic rubber is the morphology of the particles. Rubber particles from the ambient process generally have a porous or fluffy appearance, whereas when produced by the cryogenic process, the surface of the particles is glasslike (Baker *et al.*, 2003).

The gradation analysis was carried out in accordance with the requirements of the ASTM C 136, amended by the Greenbook (2000) recommendations. The rubber gradations followed the Arizona Department of Transportation (ADOT) requirements type B (ADOT A-R Specifications, Section 1009, 2005), as presented in Table 1.

Table 1. *ADOT A-R specifications and rubber gradations*

Sieves (mm)	ADOT A-R (% passing)	Ambient (% passing)	Cryogenic (% passing)
2,00	100 – 100	100	100
1,18	65 – 100	99	99
0,60	20 – 100	96	90
0,30	0 – 45	44	20
0,075	0 – 5	4	3

Four asphalt rubbers were produced using ambient and cryogenic rubbers. 50/70 and 35/50 pen asphalts were used to produce the asphalt rubber binders. The asphalt rubber produced by the continuous process in laboratory had the following formulation: (i) mixing temperature: 180℃; (ii) digestion time: 90 minutes; (iii) rubber content: 21%. The tire rubber-modified asphalt binders were produced at an industrial plant, considering two different formulations: (i) rubber content: 20%; (ii) rubber content: 15%. Table 2 presents the designations and the summary of each asphalt rubber.

Table 2. *Asphalt rubber features*

Designation	Base asphalt	Rubber type	Rubber content (%)	Process
ARCB1	35/50 pen	cryogenic	21	tire rubber-modified
ARCB2	35/50 pen	ambient	21	tire rubber-modified
ARTB1	50/70 pen	ambient	20	tire rubber-modified
ARTB2	50/70 pen	ambient	15	tire rubber-modified

The asphalt rubber binders were characterized by the following tests: (i) penetration; (ii) softening point (ring and ball test); (iii) resilience; (iv) apparent viscosity. The hardening properties were also evaluated using the Rolling Thin-Film Oven Test (RTFOT). As a conventional asphalt 50/70 pen (ACO) was used to produce the conventional mixture, this binder was tested as well. The results of the asphalt characterization tests can be observed in Figure 1. Table 3 presents the results of RTFOT.

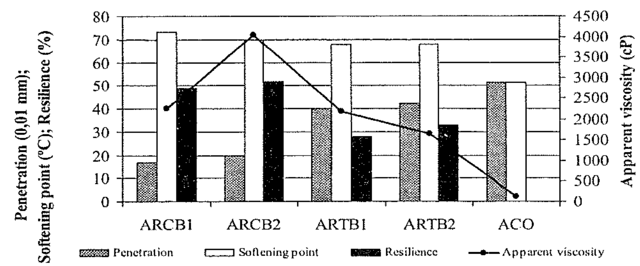


Figure 1. *Characterization tests of the asphalts*

Table 3. *Results of RTFOT (ASTM D2872)*

RTFOT 163℃, 85 minutes	ARTB1	ARTB2	ARCB1	ARCB2	ACO
Change of mass (%)	0,3	0,3	0,9	0,2	0,3
Softening point elevation (℃)	1,0	2,9	17,2	11,2	4,3
Penetration 25℃, 100g, 5s (0,1 mm)	28,8	25,3	15,5	19,5	22,3
Apparent viscosity* (cP), 175℃	5350	1962	3025	8813	95,8
Retained penetration (%)	72,0	60,2	92,2	99,0	43,3

* Brookfield viscometer, spindle number 27, 20 rpm.

The asphalt rubber binders produced by the continuous blend (ARCB1 and ARCB2) with 35/50 pen asphalt presented a higher softening point temperature than the tire rubber-modified asphalt binders (ARTB1 and ARTB2). The amount of crumb rubber did not influence these results. The same conclusion was drawn in relation to resilience. As expected, the conventional asphalt (ACO) presented a lower softening point and resilience, what indicates that this type of asphalt could produce mixtures with great thermal susceptibility at high temperatures and lesser elastic properties. The ARTB2 presented lower apparent viscosity, followed by ARCB1 and ARTB1. The ARCB2 showed the highest viscosity.

3.2. Mixtures and specimens

Asphalt rubber mixtures were produced using dense and gap gradations whereas the conventional mix was produced with a dense graded, as presented in Table 4. The binder content of the mixtures was evaluated according to the Marshall method. Figure 2 presents the gradation curves of the studied mixtures.

Table 4. *Binder and void content of the asphalt mixtures*

Name	Asphalt	Gradation	Binder content (%)	Void content (%)
MGTB1	ARTB1	gap	8,5	6,0
MDTB2	ARTB2	dense	7,0	5,0
MGCB1	ARCB1	gap	8,0	6,0
MDCB2	ARCB2	dense	7,0	5,0
MDCO	50/70 pen	dense	5,5	4,0

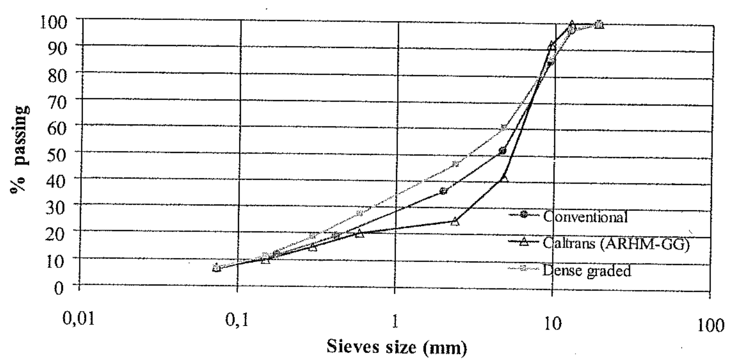


Figure 2. *Aggregate gradation of studied mixtures*

The dense asphalt rubber mixtures follow the aggregate gradation defined by the Asphalt Institute (mix type IV) in The Asphalt Handbook MS – 4, whereas the gap graded asphalt rubber mixtures follow that defined by the California Department of Transportation (Caltrans)

SSP39-400 - ARHM-GG mixture (Asphalt Rubber Hot Mix Gap Graded). The conventional mixture followed the DNIT gradation (Brazilian Road Department) specifications, which manage and establish the road technical specifications in Brazil.

After being designed, the mixtures were produced and compacted in slabs using a cylinder with up-vibration to achieve the apparent density of the mixtures defined in the design. The slabs of asphalt mixtures were sawed to produce eight cylindrical specimens for RSST-CH tests. In this type of test, the specimens are glued to aluminium caps, as depicted in Figure 3. For wheel tracking tests, specimens were extracted from slabs produced with two layers: the first layer was 3,0 cm in height with asphalt rubber mixture and the remaining 5,0 cm had a conventional mixture (MDCO), as illustrated in Figure 4.

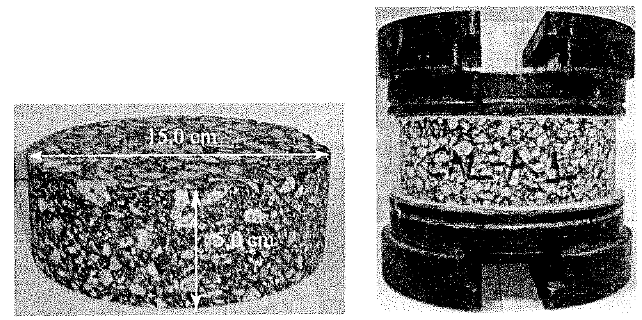


Figure 3. *RSST-CH specimen dimensions and glued to caps*

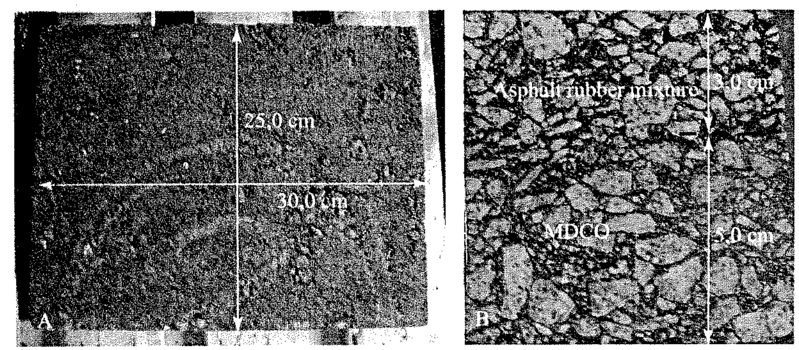


Figure 4. *Wheel tracking slab (A: dimensions in plan view; in B, cross section view showing the configuration adopted for asphalt rubber mixtures in the test)*

4. Permanent deformation tests

In this work the mechanical performance of the studied mixtures was evaluated through two tests: a) Repeated Simple Shear Test at Constant Height (RSST-CH); b) Accelerated Pavement Testing Simulator (wheel tracking).

4.1. Repeated simple shear test at constant height (RSST-CH)

Shear deformations in pavements that have been appropriately compacted, caused primarily by large shear stresses in the upper portions of the asphalt-aggregate layer(s), are frequent (Sousa *et al.*, 1991). Repetitive loading in the shear is required in order to accurately measure the influence of the mixture composition on permanent deformation resistance in laboratory. As the rate at which permanent deformation accumulates increases rapidly at higher temperatures, laboratory testing must be conducted at temperatures that simulate the highest levels expected in the paving mixture in service (Sousa *et al.*, 1994).

The RSST-CH test applies a repeated haversine shear stress of 1218 N to test cylindrical specimens. The applied load has a duration of 0,1 seconds, with an unload time of 0,6 seconds. The test follows the AASHTO TP7-01 Test Procedure C. The results of the RSCH-CH test are expressed in terms of number of passes of the equivalent standard axle load of 80 kN (ESAL 80 kN) as a function of the number of applied load cycles in the RSST-CH. The RSST-CH equipment is presented in Figure 5 (left side).

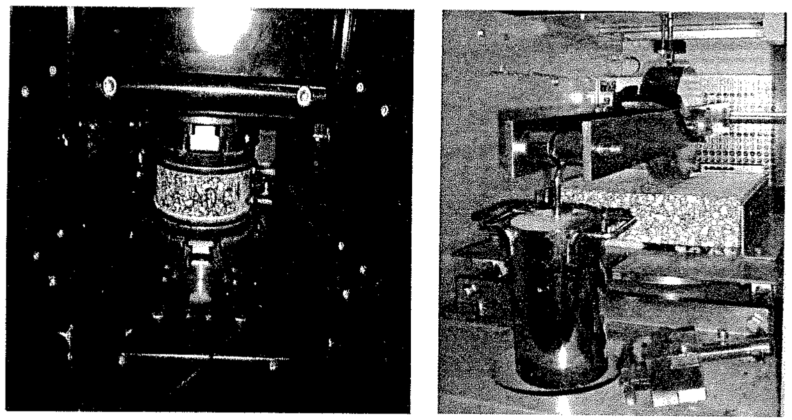


Figure 5. *RSST-CH and Wheel tracking equipments*

4.2. Accelerated pavement testing simulator (wheel tracking)

Wheel tracking is used to assess the permanent deformation resistance of asphalt mixtures under conditions which simulate the effect of traffic. A loaded wheel tracks a specimen under specified conditions of load, speed and temperature, while the development of the rut profile is monitored and continuously measured during the test.

The equipment used in this work is presented in Figure 5 (right side) and consists of a wheel that moves forward and backward (frequency of 1 Hz) and of a device that monitors the rate at which a rut develops on the surface of the test specimen. The deformation is measured in established intervals of time, until 120 minutes.

A steel mould has been used to provide confinement to the 30×25×8 cm specimens. The specimens were subjected to a 500 kPa pressure. The rut depth (permanent deformation) is recorded as a function of the number of wheel passes in the following intervals of time: 1, 3, 5, 10, 15, 20, 25, 30, 35, 40, 45, 60, 75, 90, 105 and 120 minutes. Testing was finished after 120 minutes.

The tests results, given by the following expression, are expressed in terms of the rate of deformation (v):

$$v_{t_2/t_1} = \frac{d_{t2} - d_{t1}}{t_2 - t_1} \qquad [1]$$

where: $v_{t2/t1}$ = rate of deformation between time 1 and 2; d_{t1} and d_{t2} = deformation or rut depth in time 1 and 2; t_1 and t_2 = time 1 and 2, respectively.

The results presented in this work correspond to the deformation verified between the 105 and 120 ($v_{105/120}$) minutes. The limit acceptable depends on the intensity of the traffic and on the climatic area where the pavement is located. For the most unfavourable conditions, the limit for $v_{105/120}$ is $1{,}5\text{x}10^{-2}$ mm/min.

5. Tests results

Both permanent deformation tests (RSST-CH and Wheel Tracking) were conducted at a temperature of 60°C. Eight specimens were tested for each mixture using the RSST-CH tests and three slabs using the wheel tracking device. Figure 6 presents the development of the plastic shear strain deformation in the RSST-CH tests, while Figure 7 represents the evolution of the vertical deformation in the wheel tracking tests.

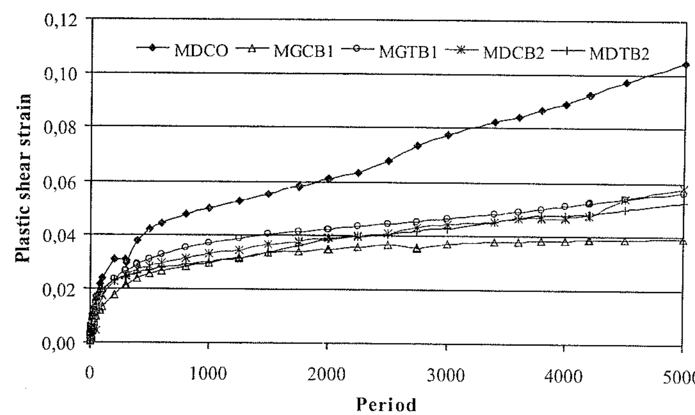


Figure 6. *Development of the plastic shear strain in the RSST-CH tests*

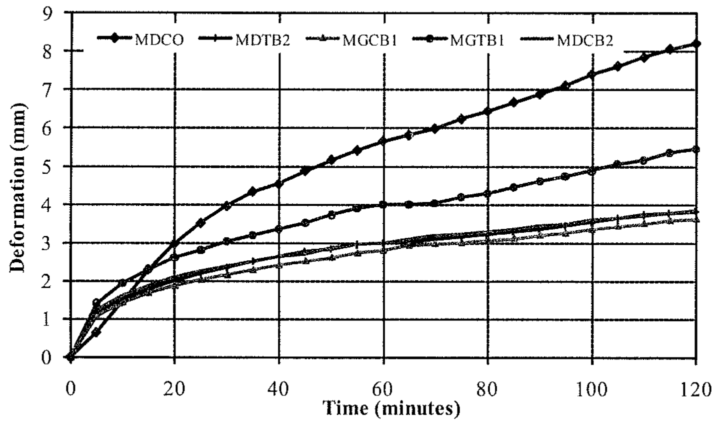


Figure 7. *Evaluation of the deformation in the wheel tracking test*

In both tests, the results showed that the conventional mixture (MDCO) presents the highest deformation and, therefore, the lowest resistance to permanent deformation, whereas asphalt rubber mixtures show more permanent deformation resistance. Most of the permanent deformation occurs at the first loading cycles during which the permanent deformation develops exponentially. After the first phase of tests, the permanent deformation increases gradually, as it can be observed in Figures 6 and 7.

The RSST-CH results, expressed in terms of number of cycles of the equivalent standard axle (ESAL 80 kN), are presented in Figure 8. The wheel tracking test results, expressed in terms of rate of deformation ($v_{105/120}$) of the slabs, are presented in Figure 9.

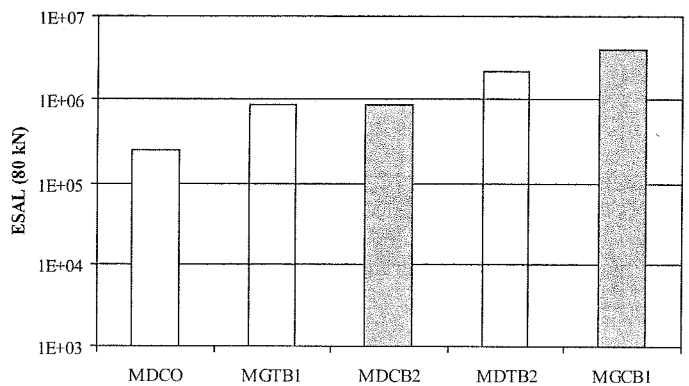


Figure 8. *RSST-CH test results*

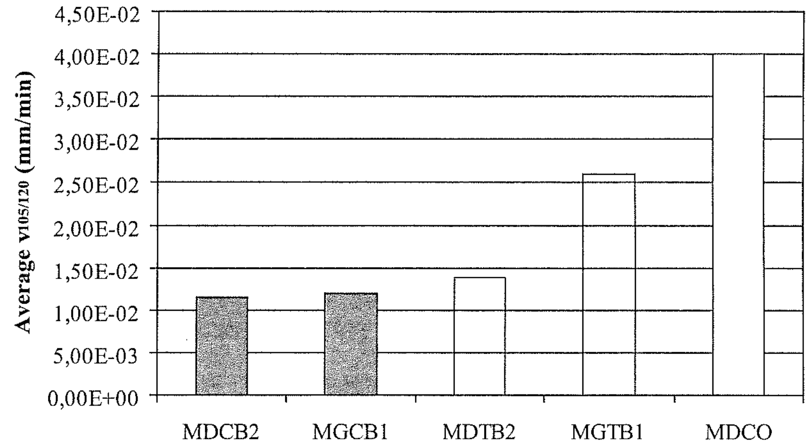


Figure 9. *Wheel tracking test results*

The results obtained from the RSST-CH allow to draw the following conclusions: i) an asphalt rubber binder improves the resistance to permanent deformation in comparison to the conventional one; ii) the MGCB1 (gap graded with continuous blend binder) presented the better performance; iii) the best tire rubber-modified asphalt binder mixture (MDTB2) is the one with the dense aggregate gradation curve; iv) the conventional mixture MDCO exhibited poor rutting performance; v) the mixtures prepared with continuous blend asphalt rubber performed very well independently of the type of rubber (MGCB1 and MDCB2); vi) the gap graded gradation provides rutting resistance, in spite of the fact that the MGCB1 had higher binder and void content.

The results of the wheel tracking tests confirmed that the conventional mixture MDCO presented a lower resistance to permanent deformation. The asphalt rubber binder improved significantly the resistance to rutting. , Except for the MGTB1 (tire rubber-modified asphalt binder and gap graded gradation) asphalt rubber mixtures exhibit identical performance. Mixtures with continuous blend binders (MGCB1 and MDCB2) presented the highest resistance.

The comparison between both tests is illustrated in Figure 10, from which it can be concluded that a linear trend, in log-log scale, exists between both tests. Mixtures with low resistance to permanent deformation in the RSST-CH test exhibit high deformation in the wheel tracking test. Mixtures with low deformation in the wheel tracking test exhibit high permanent deformation resistance in the RSST-CH test. The trend line presented in this case perfectly follows four of the five mixtures tested.

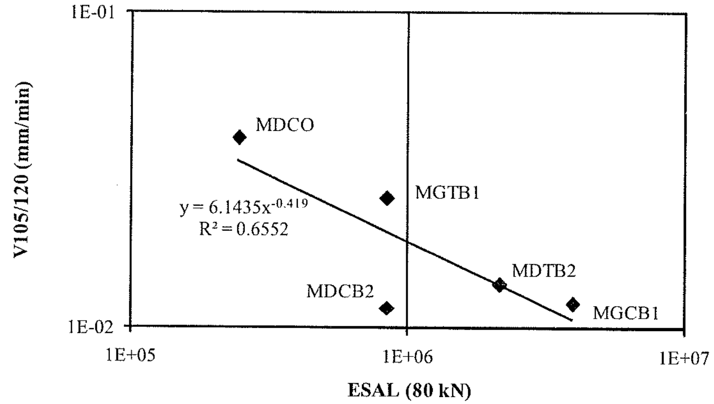


Figure 10. *Comparison between RSST-CH and wheel tracking tests*

To evaluate the influence of the properties of the asphalt binder in relation to permanent deformation resistance, a series of graphics is presented, in which the permanent deformation, expressed in terms of ESALs, and rate of deformation (v105/120), are related to the asphalt binder penetration (Figure 11), softening point (Figure 12), resilience (Figure 13) and apparent viscosity (Figure 14). These asphalt characteristics can be used to predict/estimate the permanent deformation resistance once they can be correlated with the asphalt stiffness.

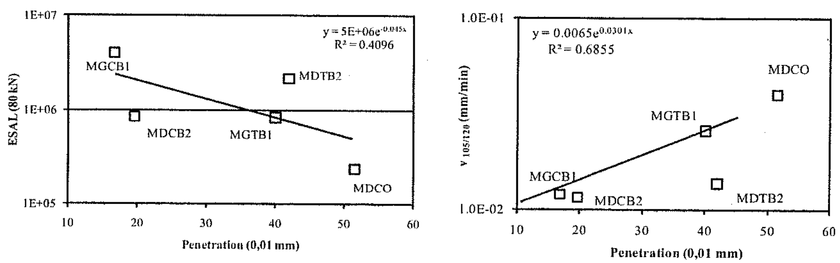


Figure 11. *Relationship between penetration and ESAL (80 kN) and rate of deformation*

The relationship between the permanent deformation resistance, in both tests, and the penetration (Figure 11) shows that an increase of the penetration (softer binders) will decrease the resistance to permanent deformation (decrease the ESALs and increase the rate of deformation). Despite a reduced correlation, mainly because the resistance to permanent deformation is influenced by the properties of mixtures (the most important are: a) aggregate gradation; b) binder content and c) void content) it is evident the influence of penetration on the resistance to permanent deformation.

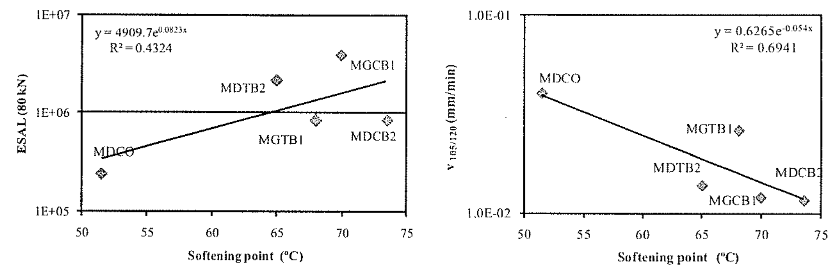


Figure 12. *Relationship between the softening point and ESAL (80 kN) and the rate of deformation*

The analysis of Figure 12 allows concluding that the softening point can be an indicator of the permanent deformation behaviour. It is noticeable that asphalts with a high softening point make mixtures with better resistance to permanent deformation, expressed in terms of low rate of deformation and high resistance to plastic deformation in the RSST-CH test. In general, a high softening point conducts to an enhanced resistance to permanent deformation.

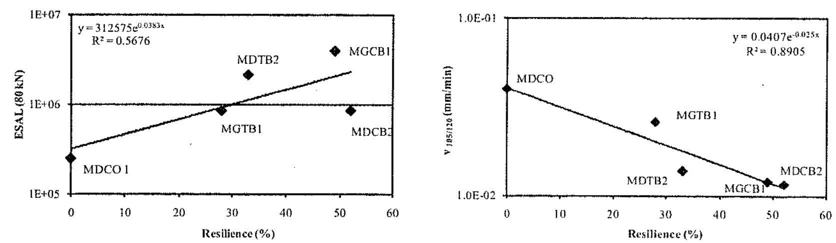


Figure 13. *Relationship between resilience and ESAL (80 kN) and rate of deformation*

The relationship between the resilience and the permanent deformation expressed in terms of ESALs and the rate of deformation allows concluding that the increase of the resilience enhances the resistance to permanent deformation.

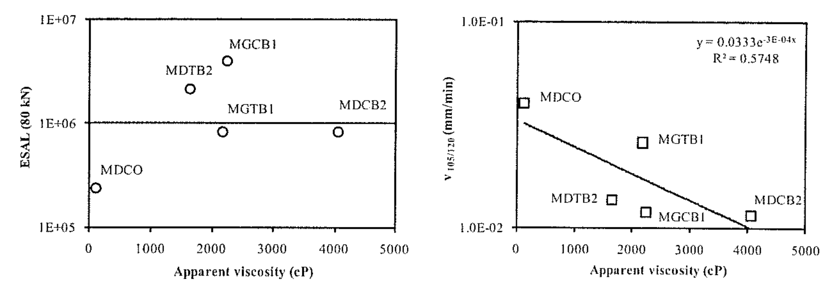


Figure 14. *Relationship between apparent viscosity and ESAL (80 kN) and rate of deformation*

The analysis of the results presented in Figure 14 indicates that the apparent viscosity of the binder cannot be used as an indicator of resistance to permanent deformation.

The best correlation between the asphalt characteristics and the resistance to permanent deformation was obtained by the penetration and the resilience in the wheel tracking test. An adequate correlation was also obtained between the resistance to permanent deformation in the RSST-CH test and resilience, allowing to define the resilience as the best indicator for the resistance to permanent deformation of the asphalt mixtures.

6. Conclusions

The incorporation of crumb rubber recycled from waste tires to conventional asphalt, known as asphalt rubber binder, produces asphalt rubber mixtures which have proven to be a great alternative to minimize permanent deformation in asphalt pavement layers.

In this work, the performance in relation to permanent deformation of four asphalt rubber mixtures and that of a conventional mixture were evaluated. The mixtures were tested by using: i) The repeated Simple Shear Test at Constant Height (RSST-CH); ii) the Accelerated Pavement Testing Simulator (wheel tracking). The tests were conducted at a temperature of 60°C to simulate the worst climate conditions to which the mixtures are subjected when applied in pavement rehabilitation in the South of Brazil.

The RSST-CH results showed that asphalt rubber mixtures improved their resistance to permanent deformation in relation to that of a conventional mixture, independently from the type of asphalt rubber or gradation adopted. The conventional mixture presented a poor rutting performance.

The results of the wheel tracking tests confirmed that the conventional mixture presented low resistance to permanent deformation, what made it inadequate to be applied in pavement layers. It was observed that the asphalt with the highest softening point resulted in a mixture with better resistance to permanent deformation.

The permanent deformation of asphalt rubber mixtures can be associated with the characteristics of the asphalt rubber binder (penetration, resilience and apparent viscosity). The results of this study allow concluding that: i) the higher the resilience of the asphalt, the better rutting resistance; ii) mixtures produced with a lower penetration asphalt showed more resistance; iii) the high apparent viscosity obtained by asphalt rubbers through the incorporation of rubber into the conventional asphalt contributed to improve their resistance to permanent deformation.

A good correlation was obtained between the resilience and the permanent deformation resistance in both tests allowing the use of the resilience to predict the resistance of asphalt mixtures to permanent deformation.

Acknowledgements

The authors would like to thank the companies that supplied the materials used in this study: Greca Asfaltos, Cepsa Portuguesa – Petróleos, Bezerras Ltda. The first author was supported by the Programme Alban, the European Union Programme of High Level Scholarships for Latin America, scholarship nº E04D040507BR from 2004 to 2006. Currently, the first author is supported by CNPQ (Conselho Nacional de Desenvolvimento Científico e Tecnológico).

7. Bibliography

Baker, T.E., Allen, T.M., Jenkins, D.V., Mooney, T., Pierce, L.M., Christie, R.A.; Weston, J.T. "Evaluation of the use of scrap tires in transportation related applications in the State of Washington", Washington State Department of Transportation, Washington, D.C., 2003.

Brown, E.R.; Kandhal, P.S.; Zhang, J., "Performance testing for hot mix asphalt (executive summary)", National Center of Asphalt Technology, Report nº 2001-05A, NCAT Auburn University, Alabama, 2001.

Dirección General de Carreteras, "Pliego de prescripciones técnicas generales para obras de carreteras y puentes", Ano vigente 2004, nº 543 – mezclas bituminosas discontinuas en caliente para capas de rodadura. Madrid, Espana, 2004.

FHWA, "Background of Superpave asphalt mixture design and analysis", Federal Highway Administration, FHWA-SA-95-003. Lexington, KY, 1994.

Greenbook, "Standard specifications for public works construction", 2000 Edition, Anaheim, 2000.

NLT-173, "Resistência a la deformación plástica de las mezclas bituminosas mediante la pista de ensayo de laboratório". Centro de Estudios de Carreteras. España, 1984.

Roberts F.L.; Kandhal, P.S.; Brown, E.R.; Lee, D.; Kennedy, T.W., "Hot mix asphalt materials, mixture design and construction", NAPA Education Foundation, Lanham, MD, 1996.

Sousa, J. B., Craus, J., Monismith, C.L., "Summary report on permanent deformation in asphalt concrete," Strategic Highway Research Program, Report nº SHRP-A/IR- 91-104, Washington, D.C., 1991.

Sousa, J.B., Solaimanian, M., Weissman, S.L., "Development and use of the repeated shear test (constant heigh): an optional Superpave mix design tool", Strategic Highway Research Program, Report nº SHRP-A-698, Washington, DC, 1994.

Takallou, H.B., Bahia, H.U., Perdomo, D., Schwartz, R., "Use of Superpave technology and construction of rubberized asphalt mixtures", Transportation Research Record 1583, TRB, National Research Council, Washington D.C., 1997, p. 71-81.

Zaniewski, J.P., Sri Harsha, N., "Asphalt technology program evaluation of binder grades on rutting performance", Department of Civil and Environmental Engineering, Morgantown, West Virginia, 2003.

Improvement of Moisture Damage of CRM-modified Asphalt Concretes in Korea

Minyong Ryu[1], Jin. C. Kim[1], Hyun. H. Kim[1], Young S. Doh[2] and Kwang W. Kim[3+]

[1] *Graduate student, Department of Regional Infrastructures, Kangwon National University, Chun Cheon, 200-701, Korea*

[2] *Research Professor, Institute for Advanced Construction Material, Kangwon National University, Chun Cheon, 200-701, Korea youngsdoh@hanmail.net*

[3] *Professor, Department of Regional Infrastructures, Kangwon National University, Chun Cheon, 200-701, Korea*
[+]*corresponding author, asphaltech@hanmail.net*

ABSTRACT. This study was initiated to suggest possible solution for preventing moisture damage of the CRM-modified asphalt pavement mixtures. Among many candidates, the hydrated lime (HL) was selected as the best additive for improving aggregate-bitumen adhesion from previous studies. Asphalt concrete specimens were prepared using various contents of the additive for estimating tensile strength retaining ratio by additive dosage under severe moisture condition. A cycle of freezing at -18oC and thawing at 25oC in 24 hours, and submerging at 60oC water for another 24 hours were applied for each specimen. The indirect tensile strength (ITS) before and after freezing and thawing cycle was measured and the retained tensile strength ratio (TSR) was calculated from the ITS test results. The TSR ratio improving levels were different for additive contents and a significant strength improvement was observed from 0.8% - 1.0% of HL contents.

KEYWORDS: CRM-modified asphalt pavement mixtures, hydrated lime, indirect tensile strength, tensile strength retaining ratio, freezing and thawing cycle