RECIPNEU

International Theoretical and Practical Conference

"Contemporary Approaches to Rubber Goods and Tires Recycling"

Moscow, 1 - 2 June 2011

Title of the Presentation:

"Use of Rubber Powder cryogenically recovered from end-of-life tires in Asphalt Rubber for high performance road paving"

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RECIPNEU – Portugal

RECIPNEU
The European Leader in Cryogenic Rubber

- Plant Site: Sines Industrial Park, Portugal
- Land Area: 40,000 m2
- Plant Area: 3,000 m2
- Technology: Cryogenic process for tire recycling
  '*primary direct cryogenic system*'
- Products: Cryogenic rubber powders and granulates
- Capacity: 15.000 ton/yr
- Start-up : Early 2001 (innovative technology in Europe)
- Operation: Continuous in 3 shifts (24 h/d, 7 d/w)
- Certifications: EN ISO 9001, 14001, OSHAS 18001 (since 2004)
- Website: www.recipneu.com

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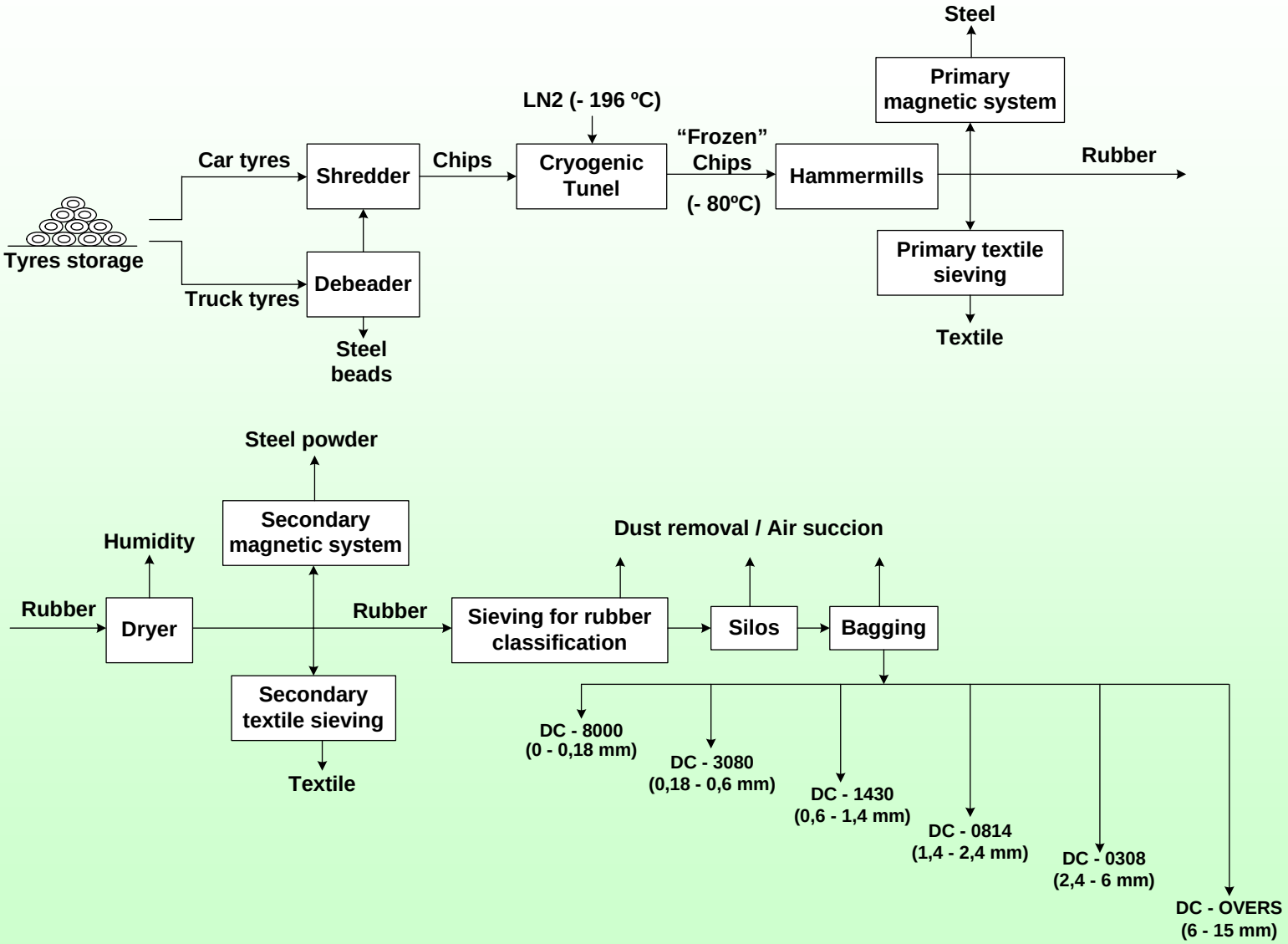
RECIPAV
The European Leader in Asphalt Rubber binder

- Site: Where the jobs are (Portugal, Europe)
- Equipment: 3 sets of mobile equipment
- Technology: "In-situ" wet process
- Product: Rubber modified bitumen for road paving with up to 25% of tire rubber powder
- Capacity: In each set of equipment, 20 ton/hour of binder (*equivalent to 250 ton/hour of Hot Mix*)
- Start-up : Mid 1999 (innovative technology in Europe)
- Operation: Continuous, follows contractor operation timings
- Certification: EN ISO 9001
- Website: www.recipav.pt

Cryogenic Process flow-sheet



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Cryogenic tunnel (*12m*) and rotating dryer

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Hammer mills bunker, dryer, and primary textile / magnetic separation

Rubber sieving and Silos

Inside: CRYOGENIC Cold

by Liquid Nitrogen (- 196ºC) at RECIPNEU

... to surpass the Glass Transition Point of all tire rubber polymers

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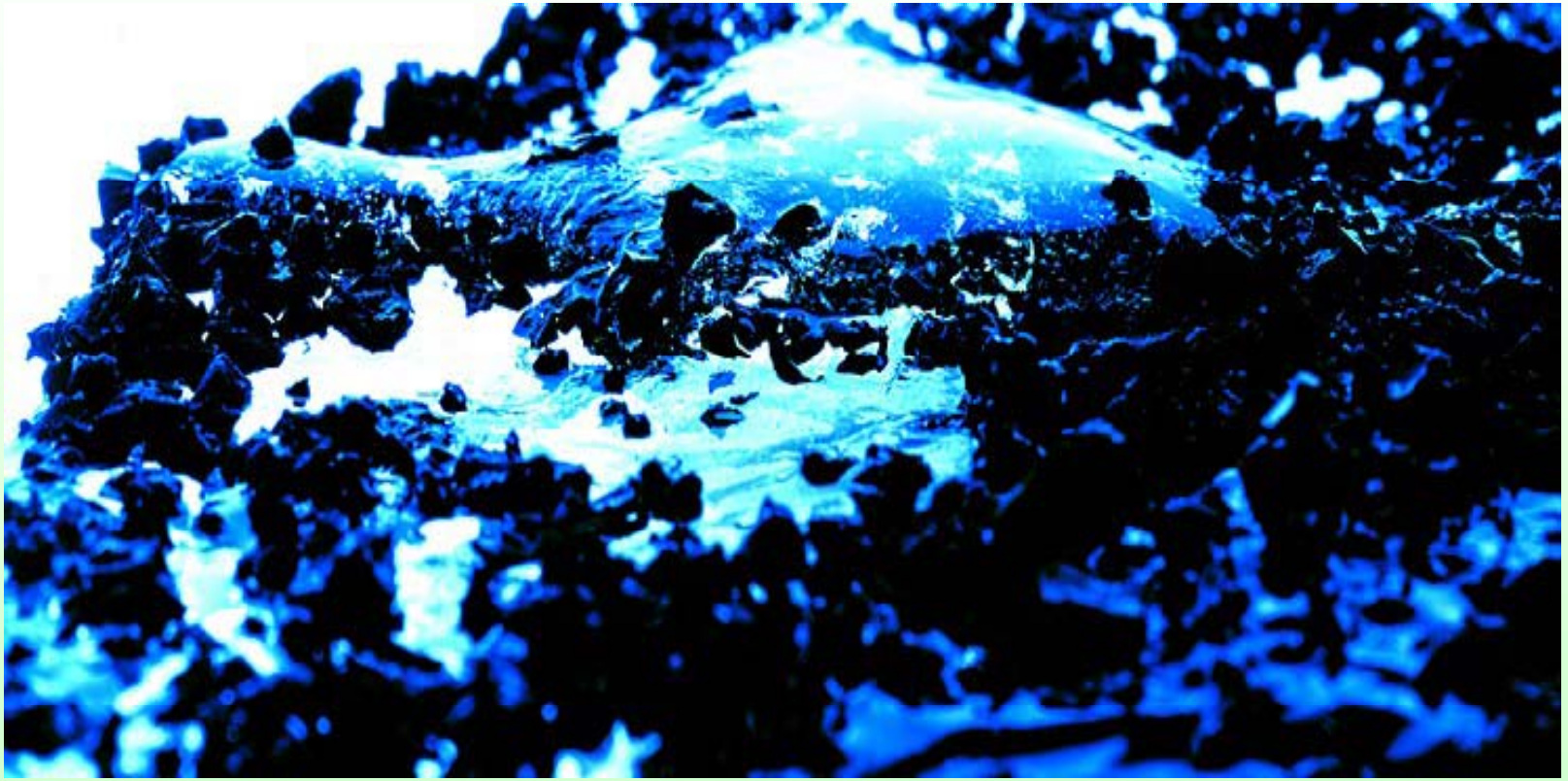
Clean Steel from tires

Cryogenic Rubber Particles



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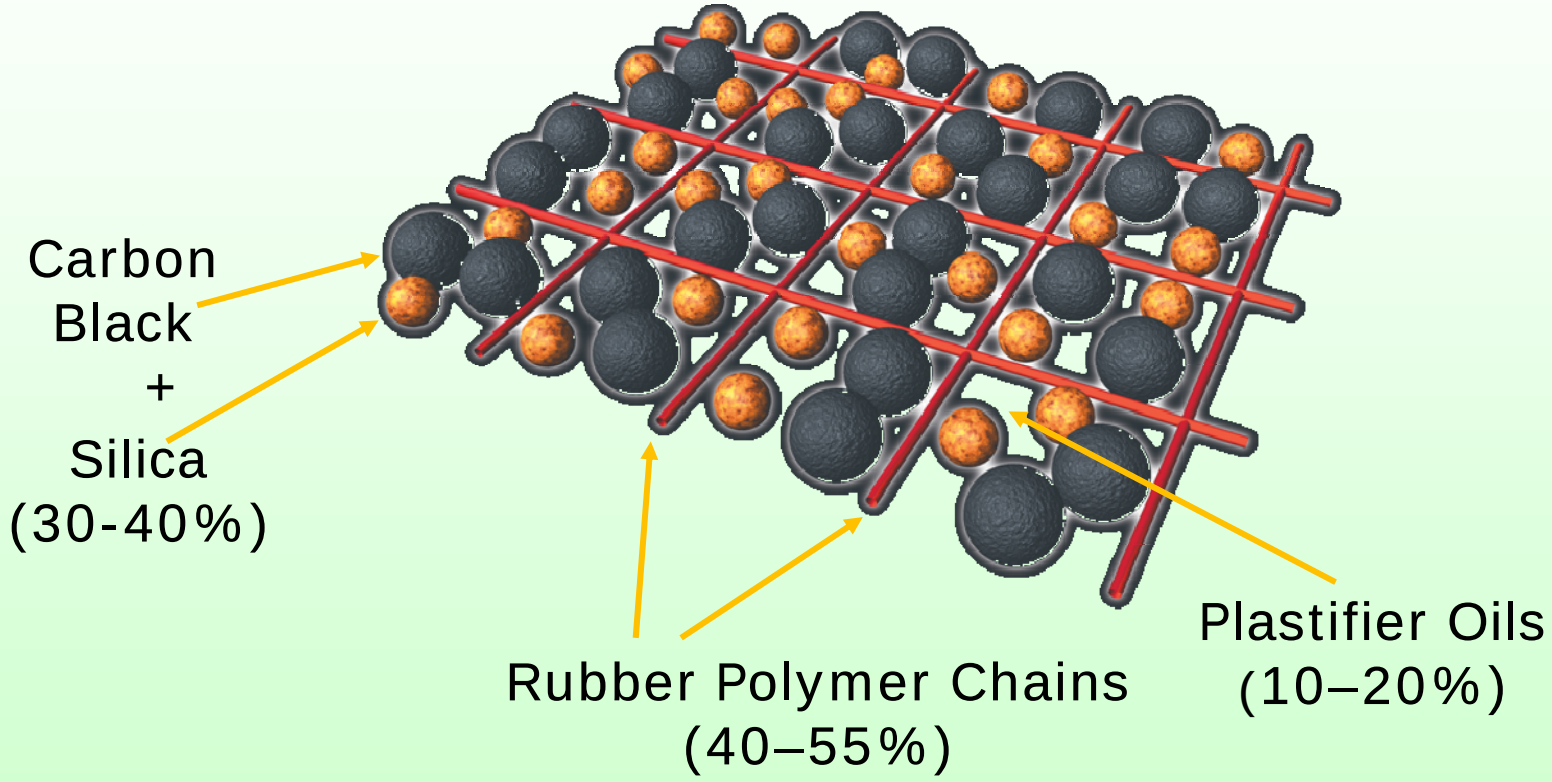
The typical tire rubber mix



+ Vulcanizers (sulfur, zinc oxide, sulfenamid, etc.)
+ Protective / anti-ageing ingredients (UV, O2, O3)

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Glass Transition Points

Rubber Polymers	Tg (°C)
NR Natural Rubber	- 58
IR Polyisoprene Rubber	- 58
SBR Rubber (various grades)	- 52 to - 48
BR Polybutadiene Rubber	- 73
IIR Butyl Rubber	- 58

Surface Morphologies of Rubber Particles (superficial area per unit mass)

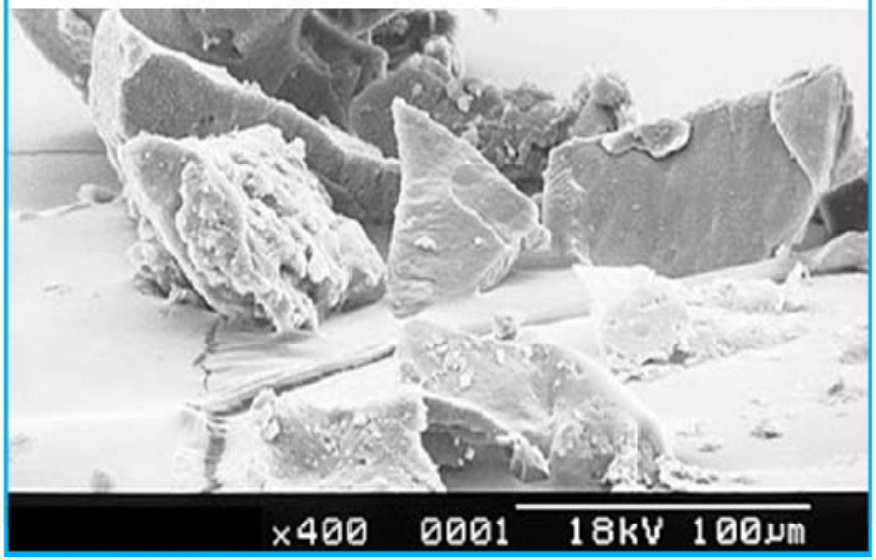
Mechanical Rubber Grinding

High specific surface particles

This characteristic morphology is due to the very intense mechanical forces applied continuously to the rubber (high shear, friction, cutting, abrasion, attrition) during the relatively long rubber grinding time, originating a very high temperature increase.

Cryogenic Rubber Grinding

Low specific surface particles



This characteristic morphology is due to an instantaneous impact under extreme cryogenic cold (below Tg's) causing the fracture of the rubber in small particles with flat surfaces. In this process there is no shear, friction, cutting, attrition or abrasion forces applied to the rubber.

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What main materials are obtained in the rubber recycled from tires?

In the rubber powders obtained in the recycling of end-of-life tires, we obtain basically a mixture of:

- **Rubber Polymers** (elasticity), being the more important:
  - Natural Rubber - **NR**
  - Synthetic Rubber - **SBR**
  - Polybutadiene - **BR**
- **Fine Chemicals,** specific functional ingredients for:
  - Compounding, Vulcanizing, and
  - Anti-ageing protection (**CB, UV, O_2 and O_3 ,…**)

There is not any thermal or chemical degradation in the rubber powders obtained by the cryogenic process, due to its operating conditions: very cold, very fast, no oxygen, no subject to applied intensive attrition forces to cause heat generation / degradation.

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Asphalt Rubber
- a comprehensive view ...?

Specifications – USA and Europe

ASTM D 6114: 2009

'Asphalt Rubber' is a rubber modified bitumen binder that contains 15% or more of tire recycled rubber.

It is manufactured in special reactors, in a **digestion reaction** between bitumen and rubber, with control of the **temperature**, **time**, **and stirring power**, resulting a thick and viscous fluid.

Asphalt Rubber was born in the USA many decades ago; at the time, the rubber gradation was specified in many Departments of Transportation accordingly with the usual sizes – rubber particles smaller than 1.2 mm - obtained by the (*only existing*) process for tire recycling: the mechanical process (also called '*ambient*' process).

EN 14023 : 2010

Polymer modified bitumens - Bitumen and bituminous binders – framework specification for polymer modified bitumens.

ASTM D 6114 : 2009
Asphalt Rubber Specifications

Apparent Viscosity, 175 ºC [cP] ***ASTM D 2196 method A***	**min 1500, Max 5000**
Penetration 25º C, 100 g, 5 sec [1/100 mm] ***ASTM D 5***	**min 25, Max 75**
Penetration 4º C, 200 g, 60 sec [1/100 mm] ***ASTM D 5***	**min 15**
Softening point [ºC] ***ASTM D 36***	**min 54**
Resilience 25 ºC [%] ***ASTM D 5329***	**min 20**
Flash Point [ºC] ***ASTM D 92***	**min 232**
Penetration Retention, 4ºC [% of original] ***ASTM D 5***	**min 75**

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EN 14023 : 2010
Polymer modified bitumens

Table 1 — Framework specifications for polymer modified bitumens – Properties applying to all polymer modified bitumens

PROPERTY		TEST METHOD	UNIT	Classes for all polymer modified bitumens									
				2	3	4	5	6	7	8	9	10	11
Penetration at 25 °C		EN 1426	0,1 mm	10-40	25-55	45-80	40-100	65-105	75-130	90-150	120-200	200-300	
Softening Point		EN 1427	°C	≥ 80	≥ 75	≥ 70	≥ 65	≥ 60	≥ 55	≥ 50	≥ 45	≥ 40	
Cohesion [a]	Force ductility [a] (50 mm/min traction) or	EN 13589 followed by EN 13703	J/cm^2	≥ 3 at 5 °C	≥ 2 at 5 °C	≥ 1 at 5 °C	≥ 2 at 0 °C	≥ 2 at 10 °C	≥ 3 at 10 °C	≥ 0,5 at 15 °C	≥ 2 at 15 °C	≥ 0,5 at 20 °C	≥ 0,5 at 25 °C
	Tensile test [a] (100 mm/min traction) or	EN 13587 followed by EN 13703	J/cm^2	≥ 3 at 5°C	≥ 2 at 5 °C	≥ 1 at 5 °C	≥ 3 at 0 °C	≥ 3 at 10 °C					
	Vialit pendulum [a] (Impact test)	EN 13588	J/cm^2	≥ 0,7									
Resistance to hardening [b]	Retained Penetration	EN 12607-1	%	≥ 35	≥ 40	≥ 45	≥ 50	≥ 55	≥ 60				
	Increase in Softening point		°C	≤ 8	≤ 10	≤ 12							
	Change of mass [c]		%	≤ 0,3	≤ 0,5	≤ 0,8	≤ 1,0						
Flash Point		EN ISO 2592	°C	≥ 250	≥ 235	≥ 220							

Table 2 — Framework specifications for polymer modified bitumens – Properties associated with regulatory or other regional requirements

PROPERTY		TEST METHOD	UNIT	Classes for regional requirements										
				0	1	2	3	4	5	6	7	8	9	10
Fraass Breaking Point		EN 12593	°C	NR [a]	TBR [b]	≤ 0	≤ - 5	≤ - 7	≤ - 10	≤ - 12	≤ - 15	≤ - 18	≤ - 20	≤ - 22
Elastic recovery	25 °C or [c]	EN 13398	%	NR [a]	TBR [b]	≥ 80	≥ 70	≥ 60	≥ 50					
	10 °C	EN 13398	%	NR [a]	TBR [b]	≥ 75	≥ 50							

What happens during the reaction?

In the high temperature (170 – 180 ºC) of the digestion reaction of the rubber in the bitumen, the main effects are:

- Transfer of substances between the tire rubber and the bitumen (*elasticity and anti-ageing properties);*
- Volume increase of the individual vulcanized rubber particles (*swelling*);
- Fixation of maltenes (*bitumen aromatic fraction*) "inside" the tri-dimensional molecular network of the vulcanized rubber particles, not been loss by evaporation;
- "Colloidal" rubber behavior in the bitumen;
- Huge increase of the viscosity of the mix.

Result: *a non brittle, elastic, and "fresh" binder, with a very high extended life durability.*

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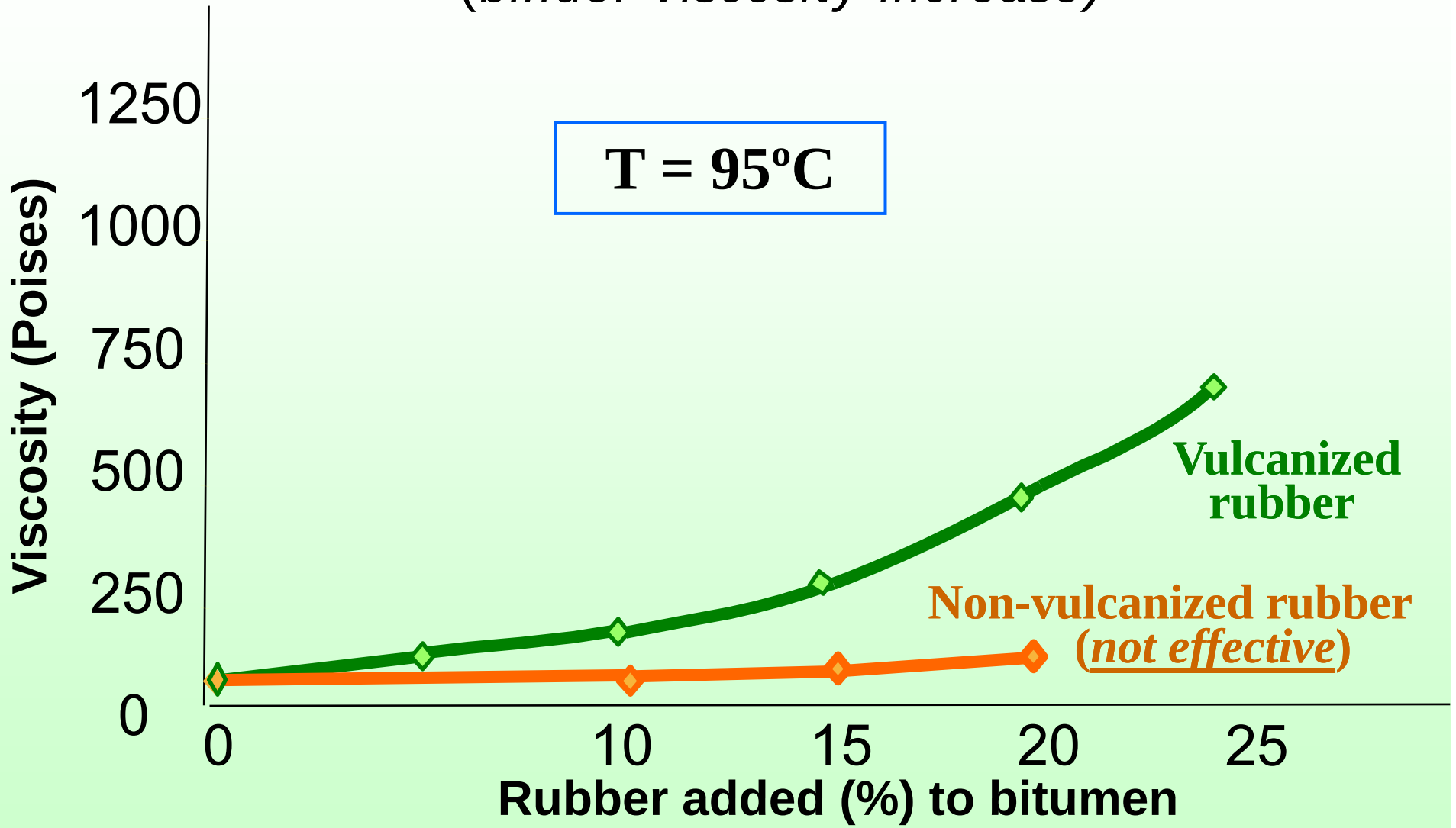
Swelling effect

(binder viscosity increase)



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Asphalt Rubber binder: properties and performances

Properties:

- ♦ Aromaticity
- ♦ Acidity
- ♦ Networking
- ♦ Dispersion
- ♦ Compatibility
- ♦ Stability
- ♦ Less degradability
- ♦ High elasticity
- ♦ Anti-ageing properties:
  - UV resistance
  - Oxygen/ozone resist.
  - Thermal resistance

Performances :

- ♦ Higher viscosity
- ♦ Resist. permanent deformation
- ♦ Resilience / elasticity
- ♦ Resistance to fissure propagation
- ♦ Water + Air impermeability
- ♦ Extended durability
- ♦ Safety increase (lower stop dist)
- ♦ Noise reduction (4 to 8 dB!!!)
- ♦ Thinner layers (50%!!!)
- ♦ Cost competitiveness
- ♦ Recyclability
- ♦ Environmental friendliness

- Performances are maximized with higher rubber content -

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Performances of roads paved with Asphalt Rubber

Excellent anti-ageing resistance:

- Reduction/elimination of pavement oxidation by air/radiation;
- Superior impermeability to water and air;
- Better behavior of the pavement structure to water infiltration.

Optimal road performances at high and low service Temp:

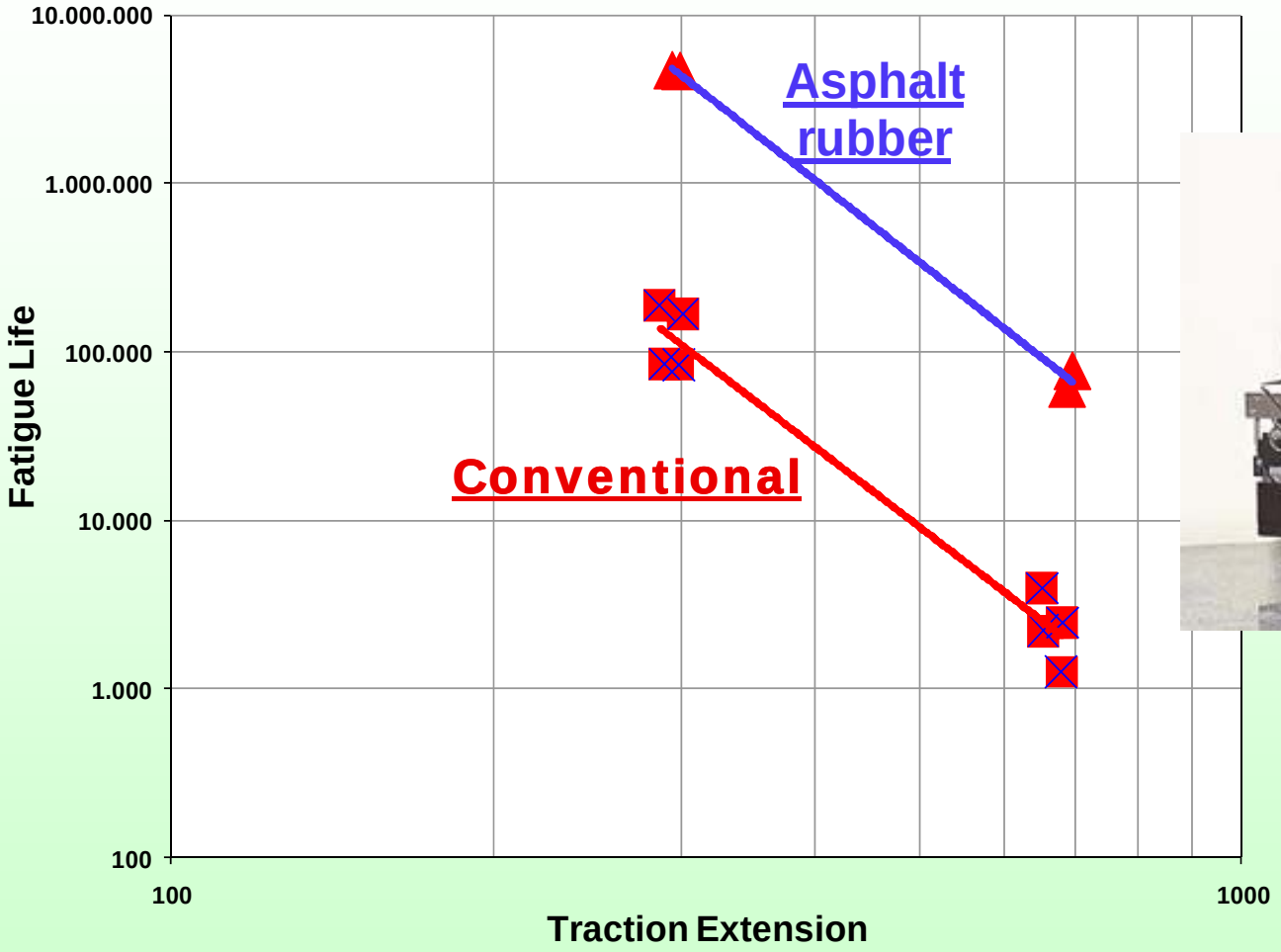
Excellent elastic properties at high and low T, showing:

- High viscosity at high temperatures (excellent resistance to the permanent deformation);
- Excellent flexibility/elasticity at low temperatures (resists to the propagation of fissures in the bitumen - crack resistance).

Lower investment cost (Reduced Hot Mix thickness up to 50%):

- Much less (*up to 50%*) mineral aggregates;
- Faster construction time, less manpower and equipment use.

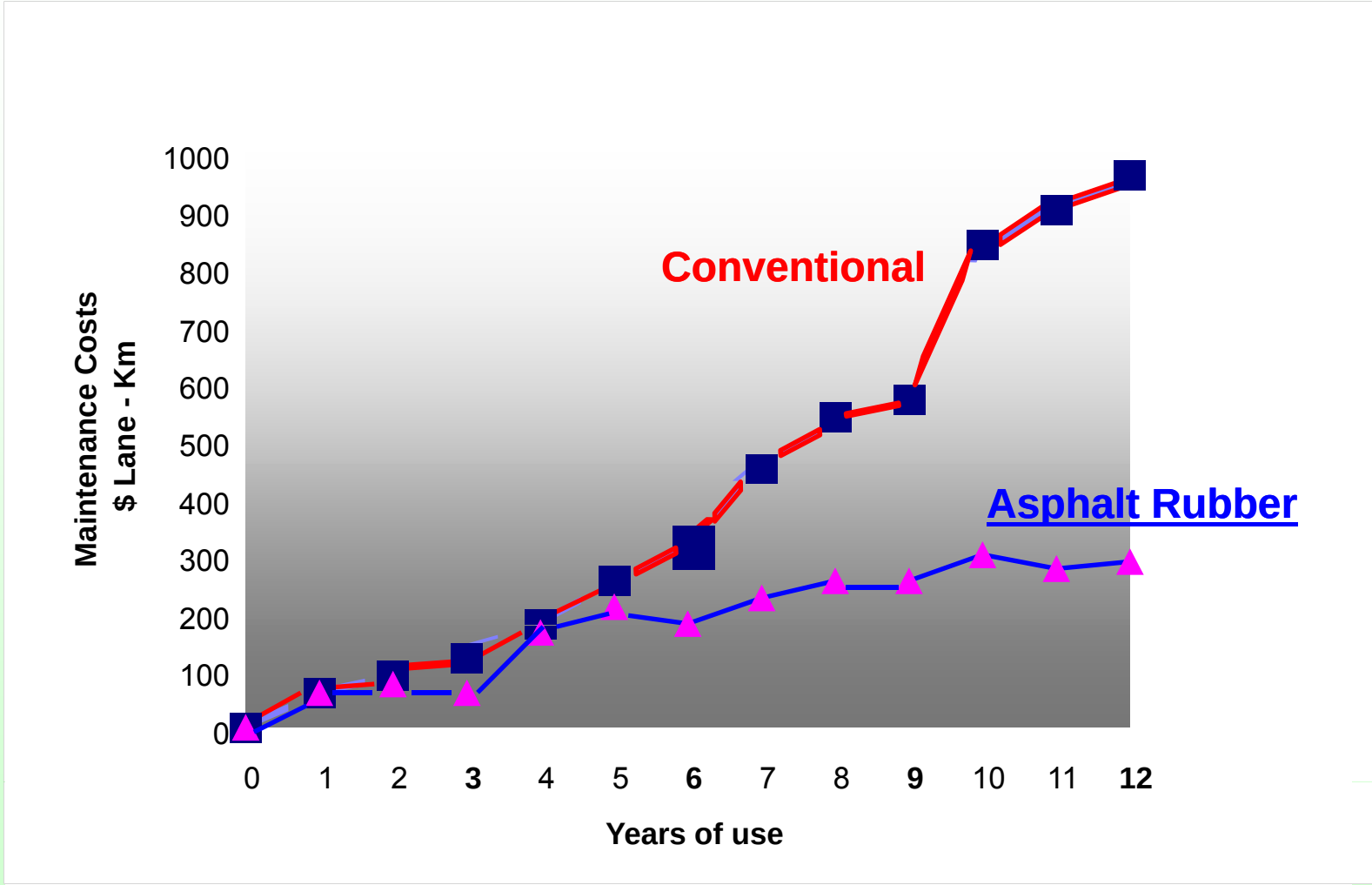
Fatigue Life (*durability*)



LAB EQUIPMENT
(AASHTO TP 8-94)

Fatigue Life: Comparing binder results in Hot Mixes
Conventional bitumen (red) vs. Asphalt Rubber (blue)

Maintenance Costs



Maintenance Costs time evolution $/Lane-Km (ADOT)
Asphalt Rubber(blue) vs. Conventional bitumen (red)

CALTRANS Design Technical Tables

Equivalence Table for Hot Mixes

Convencional (cm)	Asphalt Rubber [1] (cm)	Asphalt Rubber with SAMI (cm)
4,5	3,0 [2]	-
6,0	3,0	-
7,5	4,5	3,0
9,0	4,5	3,0
10,5	6,0	4,5
12,0	6,0	4,5
13,5	4,5 [3]	6,0
15,0	4,5 [4]	6,0
16,5	6,0 [3]	4,5 [3]
18,0	6,0 [4]	4,5 [4]

1 – Maximum allowed for thickness **equivalence** is **2:1** (Conventional / Asphalt Rubber)
2 – Minimum allowed for thickness of the Gap Graded Hot Mix is 3 cm
3 Over a layer of 4,5 cm conventional Hot Mix
4 – Over a layer of 6,0 cm conventional Hot Mix

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The "beauty" of Asphalt Rubber binder

An excellent **Engineering Material** for paving roads:

Elastic Properties + Extended Life (anti-ageing)
(good tire rubber polymers) *(protective tire fine chemicals)*

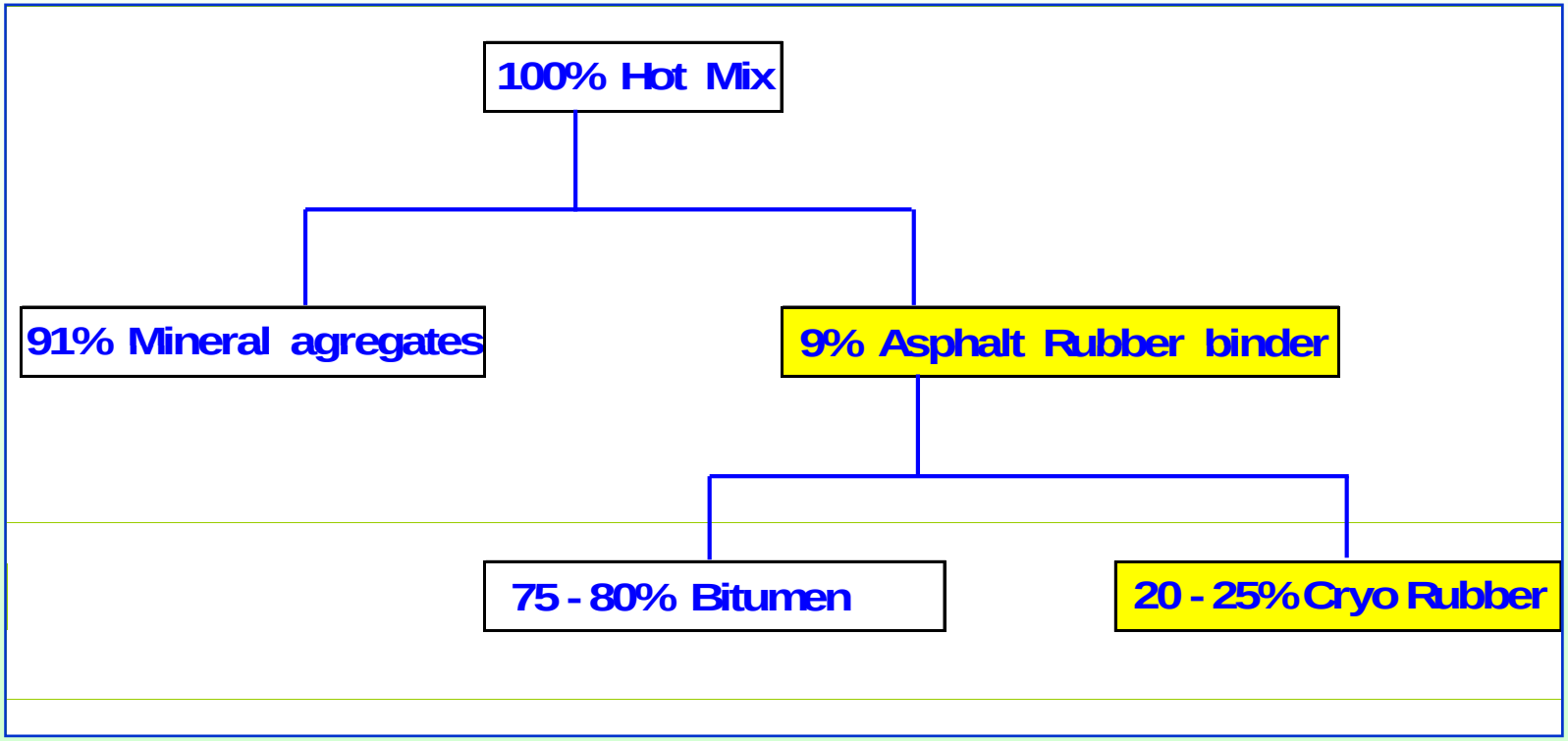
transmitted by the tire rubber to the rubber-bitumen system by the *wet process* (*"in-situ"* rubber-bitumen digestion reaction):

- reaction at T = 170ºC - 180ºC
- high rubber incorporation (*up to 25% with cryogenic rubber*)
- sufficient curing time - *not more and not less!*

EXCELLENT results for road paving:

MUCH BETTER ROADS with LESS MONEY
(lower initial cost + lower maintenance costs)

Typical Asphalt Rubber Hot Mix (with Cryogenic Rubber Powder)



Typical data from RECIPAV in Hot Mix paving jobs, using Cryogenic Rubber Powder from RECIPNEU

RECIPAV Technology

RECIPAV uses the 'Arizona Technology' *("in-situ" wet process)*, a "green" and proved technology in the USA since the 70's:

- No extender oils or solvents,
- No additives for terminal blending,
- ONLY TIRE RUBBER + BITUMEN.

In the USA, mechanical/*'ambient'* rubber is very common and traditional, since it was the only product available in the 70's/80's. This rubber with size < 1.2 mm is incorporated at 15% by weight.

In Europe, the 12 year experience of RECIPAV is based in the use of cryogenic rubber powder with fine size (< 0.6 mm), allowing the maximization of the rubber content in the Asphalt Rubber binder up to 25% by weight.

With Cryogenic Rubber Powder we can use MORE 50% OF RUBBER!

- Performances are maximized with higher rubber content -

RECIPAV paving solutions

RECIPAV produced and supplied Asphalt Rubber binder since August 1999 for many types of paving solutions in Portugal, and some in Europe as demonstration projects (*product and technology*), in a total about 1,000 Lane-Km in dozens of relevant paving jobs, for different road profile projects as highways, motorways, municipal roads, urban areas, etc.:

- Gap graded
- Open graded
- Dense graded
- SAMI
- Chip seal
- Silent asphalt

As well, RECIPAV can provide if necessary the paving job Project for rubber modified bitumen

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GAP GRADE SOLUTION - RECIPAV JOB, Portugal, August 2004

RECIPNEU

OPEN GRADE SOLUTION - RECIPAV JOB, Portugal - July 2002

RECIPAV JOB - AUSTRIA - July 2002

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RECIPAV JOB – GERMANY - July 2002

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RECIPAV JOB - SPAIN, AUMAR - November 2002

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RECIPAV JOB - SPAIN, AUMAR - November 2002

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RECIPAV JOB - PORTUGAL - July 2002

Safety and Comfort - road performances

Increase of Traffic Safety

In the road surface layer, the high amount of rubber in the Asphalt Rubber binder decreases significantly the stop distance of the vehicle: 25% LESS DISTANCE !

The reason is the very high adhesion between the two "rubber sisters" in contact: the tire rubber up (*in the vehicle tires*) and the road rubber down (*in the road paving binder*).

Noise Reduction

In recent studies done in USA and Portugal, in roads paved with Asphalt Rubber it was proved a rolling traffic noise reduction of 4 to 8 dB(A).

Performances Maximization

The "*in-situ*" *wet process* technology contributes for a good quality of Asphalt Rubber road paving, because the production equipment is placed in the contractor site, not very distant of the road paving job site: a short driving distance, and the Hot Mixes don't cool down significantly.

(the alternative *terminal blend* technology has one inconvenience: the great distance between the production plant and the road paving job site)

In the "*wet process*", the digestion reaction between the rubber particles and the bitumen is influenced by the conditions of Temperature, Time, and Agitation, being these variables set and controlled in the mobile production equipment during the "in-situ" operation.

However, there are other <u>important variables</u> to obtain a successful result, which are <u>not controlled by the equipment devices</u>:
- some are related with the **bitumen**: *aromaticity, acidity, viscosity*;
- some are related with the **tire rubber particles**: *size, morphology*.

We will analyse in more detail, in the next slides, the variables related with the rubber used to produce Asphalt Rubber by the "in-situ" wet process.

Performances Maximization – *Rubber size*

Smaller sized rubber particles contribute for a more homogeneous volume dispersion of the rubber particles in the bitumen – better Asphalt Rubber homogeneity and stability - and establish a good and uniform coverage of the hot mix mineral aggregates by a consistent and continuous viscous "liquid" film of Asphalt Rubber binder.

Also, the smaller the rubber particles, the better its stability inside the bitumen during transportation of the binder to the job site, avoiding gravity sedimentation/segregation.

Another advantage of the smaller sized rubber particles is in binder spray applications (SAMI's), to avoid clogging / collapsing of the spray nozzles.

It is well known the ability of cryogenic tire recycling technology to produce directly very high amounts of fine size rubber powders.

RECIPAV uses cryogenic rubber powder from RECIPNEU, with a particle size < 0.6 mm, having an average size < 0.4 mm (*Laser analysis*).

Smaller rubber particles is an advantage of Cryogenic Rubber Powder!

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Performances Maximization – *Rubber area*

The kinetics of the rubber-bitumen digestion reaction depends strongly of the rubber morphology, which is responsible for the total surface contact area of the rubber particles with the bitumen. The bigger the superficial area, the faster the reaction kinetics (*swelling, and transfer of substances between the rubber and the bitumen*), and the faster the viscosity increase of the Asphalt Rubber binder. Reciprocally, smaller surface area, slower kinetics in the digestion reaction, slower the viscosity increase.

Cryogenic Rubber particles have flat morphology surfaces (lower surface area), so for a given rubber mass they exhibit a total contact area much smaller than Mechanic Rubber Particles; because of that, Cryogenic Rubber Powder can be added in a much higher quantity - up to 25% weight, more 50%! - before exceeding the upper viscosity limit of the binder , where Asphalt Rubber binder cannot be pumped to flow out from the equipment!

But for a given rubber mass, there are many smaller sized rubber particles, so they exhibit a larger 'total contact area' comparing with bigger particles.

These two characteristics (*morphology* and *size*) of the Cryogenic Rubber Powder enable a good, controlled, sufficient, *but not too fast,* reaction time with the bitumen, to complete the rubber-bitumen digestion reaction.

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Performances Maximization – *Rubber added*

It will be an important advantage for road quality and durability if the rubber modified bitumen binder has the highest possible amount of rubber - this will maximize road anti-ageing and cracking resistance, along with the other benefits: lower stop distance, noise reduction, resistance to permanent deformation, water impermeability, etc.

In fact, the higher the rubber content in the Asphalt Rubber binder, the higher will be - proportionally – in the road the crack resistance and the ageing protections (UV radiation and O_2 / O_3 oxidation).

RECIPAV uses cryogenic rubber to get a technical win-win compromise, controlled by reaction kinetics, involving "*the highest possible rubber amount (up to 25%!)*" and the "*completion of the digestion reaction within the workable time (before reaching the upper viscosity limit of the binder)*".

This is only possible when using small sized cryogenic rubber particles, due to its "flat" surface morphology: Maximum rubber weight with minimum total superficial area!

Maximizing the rubber content in Asphalt Rubber binder, roads will have a maximum quality and durability, with less initial investment and less maintenance costs, optimizing cost/benefit project evaluation.

End of Presentation

Thank you for your attention!

I will be pleased to assist you in case you need any further information, feel free to contact me at

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