

# Crumb Rubber in Asphalt Pavements and Recycling

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## Outline

- Waste Tyres
- History and Technology
- Crumb Rubber in Bitumen and Asphalt Mixes
- Crumb Rubber Pavement – Sweden
- Recycling and HSE Aspects
- Conclusions



# Waste Tyres



## Waste Tyres

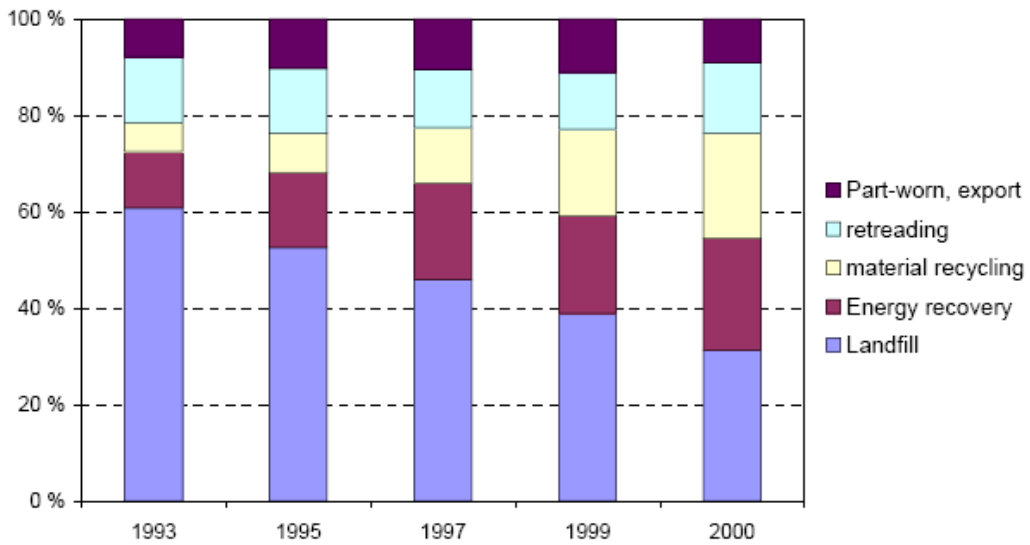
### Waste Tyres Arising 1996 – 2003

(Source: European Tyre Recycling Association, ETRA, Unit: 1000 tonnes)

	1996	1998	2000	2002	2003
Austria	40	41	50	50	50
Belgium	65	70	70	70	72
Denmark	38	38.5	37.5	39.5	41
Finland	30	30	30	32	42
France	480	380	370	401	390
Germany	650	650	650	640	600
Greece	58	58.5	58.5	58.5	50
Ireland	7.6	7.6	32	32	32
Italy	360	360	350	350	388
Luxembourg	2	2	2.8	3	5.5
Netherlands	65	65	67	67.5	67.5
Portugal	20	45	52	52	50
Spain	115	330	244	280	301
Sweden	65	65	60	60	64
UK	400	380	435	435	450
<b>Total</b>	<b>2400</b>	<b>2520</b>	<b>2510</b>	<b>2570</b>	<b>2600</b>

## Treatment of Waste Tyres in EU

(Source: European Environment Agency)



EU Landfill Directive: 2003 Ban on landfilling whole tyres  
2006 Ban on landfilling shredded tyres

EU Incineration of Wastes Directive: 2008 Due to lower emission requirement, the use of waste tyres as a secondary fuel may be challenged

## Treatment of Waste Tyres in Sweden

(Source: Swedish Environmental Protection Agency, Rapport 5599, July 2006)

	2003	2004	2005
	76,700 tonnes	75,725 tonnes	68,800 tonnes
Retreading	4 %	3 %	2 %
Export, whole tyre	10 %	3 %	7 %
Export, cutted	4 %	10 %	0
Re-use	2 %	0.2 %	0.3 %
Sprängmattor	6 %	6 %	9 %
As alternative materials...	22 %	26 %	19 %
Recycling	7 %	7 %	13 %
Energy, heating	15 %	14 %	21 %
Energy, cement industry	29 %	30 %	29 %
Landfilling	-	0	0

## Treatment of Waste Tyres in USA (Source: US Environmental Protection Agency)

Approximately 290 million waste tyres in 2003

- 80% consumed by markets
  - 45% used as fuel
  - 19% used in civil engineering projects
  - 6% recycled into products
  - 4% used in rubber-asphalt
  - 3% exported
  - 3% miscellaneous uses
- 6% retreaded
- 9% landfilled



## The range of tyre materials

- Whole tyres
- Shred and chips      Fragmented irregular tyre pieces by a mechanical process. Shred 75 – 300 mm, Chips 15 – 75 mm
- Granules      Finely dispersed particles (1 – 10 mm) produced by ambient or cryogenic method
- Powders      Fine granules (< 2 mm) through ambient or cryogenic processing

**Crumb rubber for asphalt paving: 74 µm (200 mesh) – 10 mm**

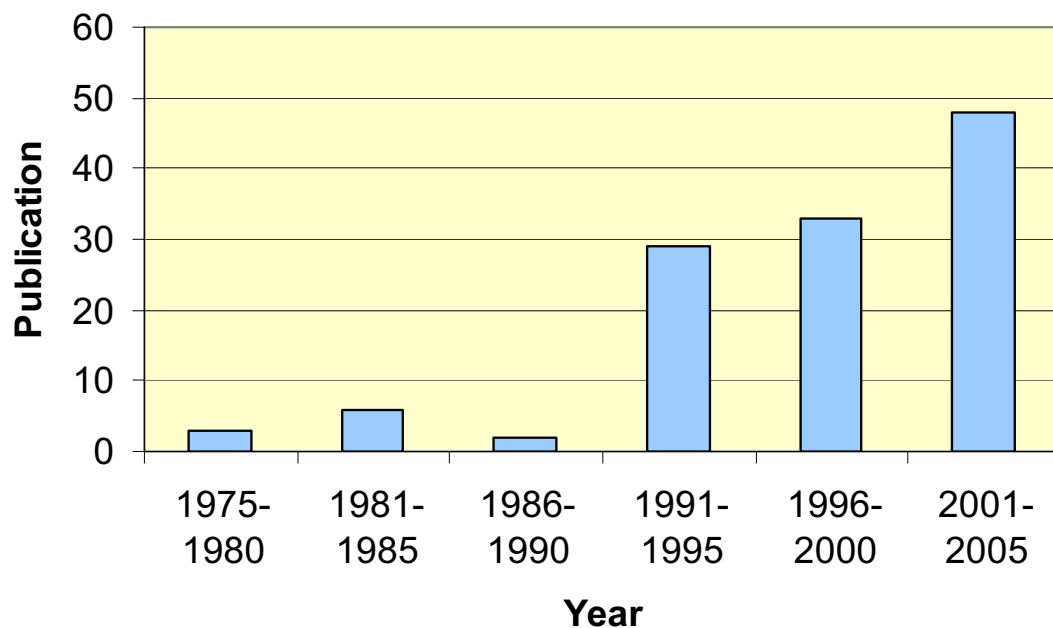


# History and Technology



## History and Technology

### Publications on Crumb Rubber Asphalt (Based on Compendex 1975-2005)



# Incorporation of Crumb Rubber into Asphalt

## The wet process

- The first successful development was made by Charles McDonald in the 1960's;
- Crumb rubber is used as a bitumen modifier;
- A high temperature blending unit is required;
- Crumb rubber content is usually high;
- Rubber particles are small (< 2.38 mm according to ASTM D 6114).

## The dry process

- Ramflex (recycled rubber particle) was marked in the US in the 1940's;
- Rubit was developed in Sweden in the 1960's, and patented in the US as PlusRide in the late 1970's;
- Crumb rubber is used to replace part of aggregate fraction (1 to 3% );
- The gradation of crumb rubber may range from *mm* to *μm*;
- No special equipment is required;
- Product quality control is more difficult than the wet process.



# Examples of US Patents on Crumb Rubber Asphalt Materials

Patent No	Patent Title	Issue Date
<a href="#">6894092</a>	<a href="#">Aqueous asphalt emulsions containing liquefied or devulcanized...</a>	2005-05-17
<a href="#">6790897</a>	<a href="#">Aqueous crumb rubber composition</a>	2004-09-14
<a href="#">6478951</a>	<a href="#">Compatibilizer for crumb rubber modified asphalt</a>	2002-11-12
<a href="#">5959007</a>	<a href="#">Bituminous compositions prepared with process treated vulcanized rubbers</a>	1999-09-28
<a href="#">5938832</a>	<a href="#">Crumb rubber modified asphalt with enhanced settling characteristics</a>	1999-08-17
<a href="#">5936015</a>	<a href="#">Rubber-modified asphalt paving binder</a>	1999-08-10
<a href="#">5927620</a>	<a href="#">Activated method for treating crumb rubber particles</a>	1999-07-27
<a href="#">5827568</a>	<a href="#">Rubber base asphalt emulsion additive</a>	1998-10-27
<a href="#">5704971</a>	<a href="#">Homogeneous crumb rubber modified asphalt</a>	1998-01-06
<a href="#">5683498</a>	<a href="#">Process for preparing rubber-modified asphalt compositions</a>	1997-11-04
<a href="#">5558704</a>	<a href="#">Paving asphalt concrete composition</a>	1996-09-24
<a href="#">5525653</a>	<a href="#">Rubber asphalt mix</a>	1996-06-11
<a href="#">5460649</a>	<a href="#">Fiber-reinforced rubber asphalt composition</a>	1995-10-24
<a href="#">5385401</a>	<a href="#">Process for adding recycled tire particle to asphalt</a>	1995-01-31

## Examples of European Patents on Crumb Rubber Asphalt Materials

Patent No	Patent Title	Pub. Data
EP1357155	<a href="#"><u>Modified asphalt</u></a>	2003-10-29
EP0994161	<a href="#"><u>Rubber-modified asphalt paving binder</u></a>	2000-04-19
EP0866837	<a href="#"><u>Rubber base asphalt emulsion additive and method</u></a>	1998-09-30
EP0677086	<a href="#"><u>Treatment of rubber to form bituminous compositions</u></a>	1995-10-18
EP0587816	<a href="#"><u>Recycled rubber in a polymer modified asphalt and a method of making same</u></a>	1994-03-23
EP0439232	<a href="#"><u>A method of preparing rubber bitumen and asphalt and a device for carrying out such a method</u></a>	1991-07-31

## Crumb Rubber in Bitumen and Asphalt Mixes



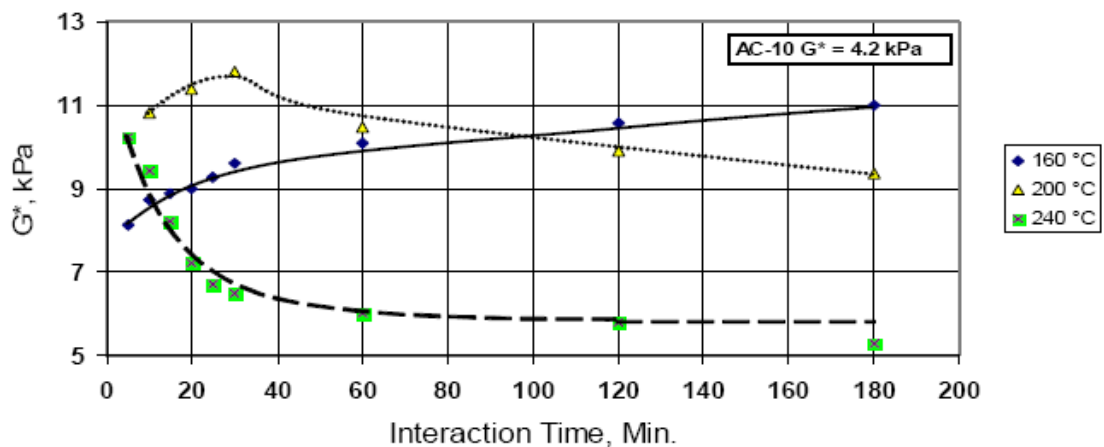
# Crumb Rubber and Bitumen Interactions

- **Rubber particles swelling**

- The swelling of rubber particles increases bitumen viscosity and stiffness.
- The extent and rate of swelling is dependent on bitumen composition, crumb rubber characteristics, reaction conditions, and additives.

- **Rubber degradation**

- Rubber can be degraded if temperature is too high and interaction time is too long.
- Rubber degradation decreases viscosity /stiffness of rubber-bitumen.



**At 160°C - Continuous swelling over the entire time period**

**At 200°C - Swelling + degradation**

**At 240°C - High degree of degradation**



Source: M. Abdelrahman, TRB Annual Meeting 2006



## Crumb Rubber Asphalt Applications


- Crack and joint sealing
- Chip seals
- Interlayer
- Hot mix asphalt



### Field Performance of Crumb Rubber Asphalt – Examples in USA and Canada

State	Projects	Field Performance
Alaska	HMA	Similar to conventional HMA
Arizona	SAMS, SAMIs 18 overlay projects	Performing satisfactorily Performing extremely well
Arkansas	HMA	Uncertain
Florida	3 HMA projects	The wet process: improved crack resistance The dry process: similar to conventional HMA
California	210 projects (HMA, surface treatment)	Generally good performance
Georgia	HMA (the wet process)	Binder became very brittle over time; No improvement in cracking resistance
Louisiana	8 sections + control sections	Improved performance
Minnesota	HMA	Performing well after two winters
Mississippi	HMA	No cracking but significant rutting
New Jersey	Resurfacing (the dry process)	Ravelling soon after construction
New York		No improvement in performance
Oregon	13 projects	The dry process: poorly performing The wet process: better or similar to control sections
Virginia	4 test sections (the wet process)	Performing as well as the conventional mixes
Texas	SAM, SAMI, and OGPF	Good performance
Washington	The dry process and the wet process	Poor or average performance; high cost
Ontario, Canada	11 projects	The wet process: enhanced durability The dry process: unfavorable life-cycle cost

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### Crumb Rubber in Bitumen and Asphalt Mixes

## Varied performance of crumb rubber asphalts are attributed to, for example

- Compositional differences in the materials
- Differences in binder formulations and mix design procedures
- Experience of contractors with highly modified paving materials
- Production, handling, and construction procedures
- Quality of construction
- ....



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## Crumb Rubber Asphalt Used for Noise Reduction

Country	Year	Mixture	Noise Level Reduction
Belgium	1981	Drainasphalt	8-10 dB
Germany	1980	Drainasphalt	3 dB
France	1984	Drainasphalt	2-3 dB/3-5 dB
Austria	1988	Flüsterasphalt	> 3 dB
Netherlands	1988	Open-graded	2.5 dB
USA	2002- *	ARFC	3-5 dB

\* *The Arizona Department of Transportation (ADOT) Quiet Pavement Pilot Program: rubberized asphalt resurface*



## Crumb Rubber Pavement - Sweden

- Early activities on the dry process
- Poroelastic road surface
- Crumb rubber bitumen in HMA



**In the west region Sweden, 17 objects (15 on bridge surfacing) were constructed in 1979-1992 by the dry process:**

- Rubit 13 objects
- Kondinor 4 objects

**Observations in 1995:**

- Permanent deformation non
- Wear 3 objects
- Cracks 5 objects
- Stone loss 15 objects



Tjörn bridge surfaced with Rubit

Source: M. Juthage & F. Thunström, Rubber-Bitumen Asphalt Concrete Rubit & Kondinor, Chalmers, May 1995

## Poroelastic Road Surface

- Invented by Nilsson in the 1970's
- Description:
  - A wearing course with a very high content of interconnecting voids ( $\geq 20\%$  by volume)
  - A highly elastic surface due to the use of rubber or other elastic materials as main aggregate (rubber content  $\geq 20\%$  by weight)
  - Binder: epoxy resin, polyurethane, or bitumen
- Field trials
  - Japan, Norway, Sweden, ...

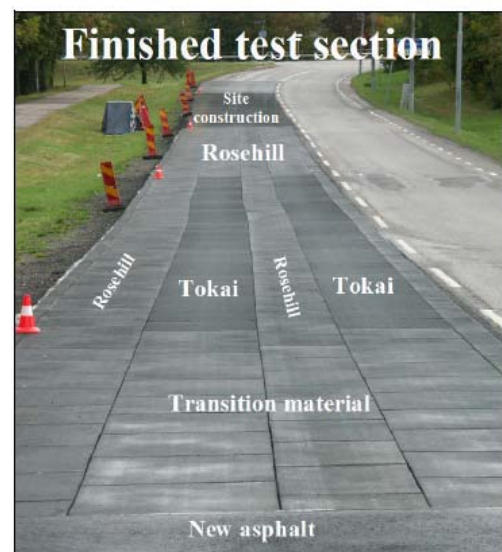


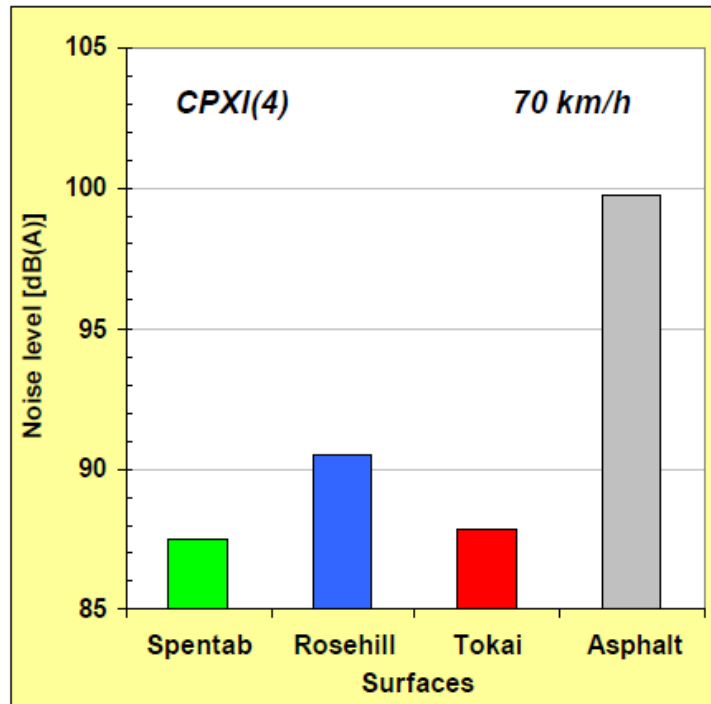
## Poroelastic Road Surface – A Field Trial in Stockholm

Rubber particles bound with polyurethane to form 30 mm thick porous structure with 30 - 35 % interconnecting air voids

<b>Spentab</b>	Site-constructed rubber-based mix, VTI design, and produced by Spentab AB (Sweden)
<b>Tokai</b>	Prefabricated rubber panels 1x1 m <sup>2</sup> , produced by Tokai Rubber Industries Ltd. (Japan)
<b>Rosehill</b>	Prefabricated rubber panels 1x1 m <sup>2</sup> , produced by Rosehill Polymers Ltd.(UK)

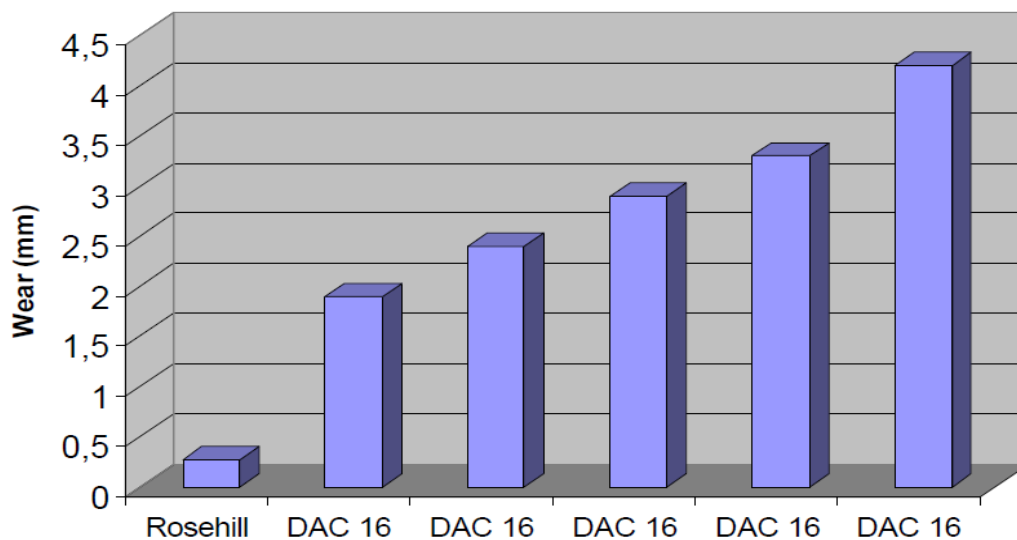
Sources: U. Sandberg & B. Kalman, *Forum Acusticum 2005, Budapes*  
U. Sandberg, B. Kalman & R. Nilsson, *SILVIA-VTI-005-02-WP4-141005*





## Noise levels at a test speed of 70 km/h

Track Depth @ 105 000 rev.



## Wear Caused by Studded Tyres in the VTI Pavement Testing Machine



Disintegrated asphalt  
base course

Asphalt layer adhered to  
rubber panels



## Poroelastic Road Surface – A Field Trial in Gothenburg

- A part of EU Project QCITY (Quite City Transport, Feb 2005 – Jan 2009)
- A single poroelastic asphalt layer producing using conventional asphalt mixing plant and conventional paving machines
  - Wetting/pre-treating crumb rubber with hot bitumen before the plant mixing
- At 70 km/h, 6 dB(A) lower noise compared to SMA11, and 7 dB(A) lower compared to SMA16

Source: N. Å Nilsson, N. Ulmgren & A. Sandin, *Acoustics 2008, Paris*



## VV Development Project 2007-2009 on Crumb Rubber Asphalts

- Technical Formulations
- Performance
  - Cracking, Permanent deformation, Wear resistance, Water sensitivity, etc.
- Environmental Impact
  - Noise reduction, Emission, Particles
- Traffic Safety
  - Skid resistance, Spray in wet weather



Source: Thorsten Nordgren, MET08, Göteborg  
Lars Preinfalk, Swedish Road Administration, Transportforum 2009



## Producing crumb rubber bitumen by the wet process

- *Crumb rubber:*                    *0 – 1 mm*  
    *up to 20 wt% of bitumen*
- *Mixing conditions:*            *1h at 160 – 175 °C*

8 – 9 % crumb rubber bitumen used in the asphalt mix





# Recycling

## EPA Asphalt Figures 2006 – Recycling

Country	Available reclaimed asphalt (tonnes)	% actually used in hot recycling	% used in cold recycling	% of the new hot mix production that contains reclaimed material
Austria	600 000	10	10	5,0
Belgium	1 300 000	50		36
Czech Republic	604 400	30	50	10
Denmark	240 000	> 80		53
France	6 500 000	13	< 2	< 10
Germany	14 000 000	82	18	60,0
Great Britain	5 000 000			
Hungary		15	0	0,6
Ireland	48 000	38	0	2,1
Italy	14 000 000	18	2	
Luxembourg	200 000	90	10	60
Netherlands	3 400 000	80	20	65
Norway	590 000	7	26	8
Poland	1 000 000	4	55	0,2
Slovakia	1 250			
Slovenia	22 000	50	10	15
Spain	690 000	30	15	5,0
Sweden	650 000	50	50	40
Switzerland	945 000	50	50	

# Recycling



## FEASIBILITY OF RECYCLING RUBBER-MODIFIED PAVING MATERIALS



State of California Department of Transportation  
 Materials Engineering and Testing Services  
 Office of Flexible Pavement Materials  
 5900 Folsom Blvd  
 Sacramento, California 95819

February 2, 2005

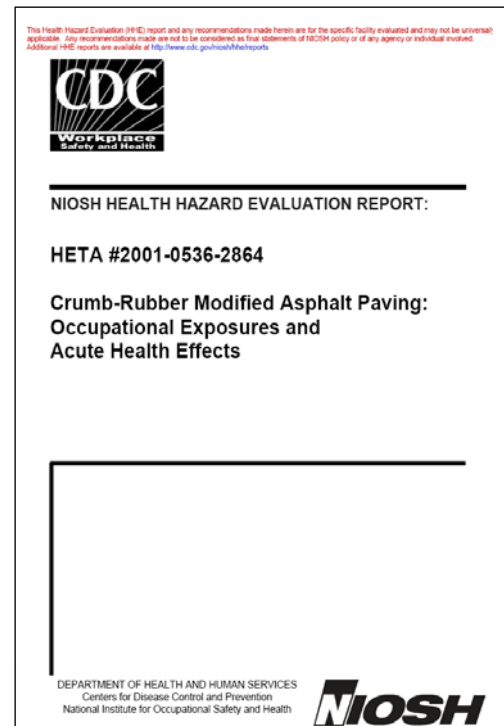
The majority of the limited number of studies indicate that crumb rubber modified paving materials can be recycled to provide serviceable pavements.

*The resulting recycled pavements typically appeared to perform at least as well as conventional mixes that included conventional RAP.*

Emissions during the production of recycled mixes were typically similar to those for conventional mixes and rarely exceeded EPA limits.

## HSE Aspects

*“Overall, although no definitive results were obtained indicating that CRM exposures are more hazardous than CONV exposures, the trends are suggestive that CRM exposures are potentially more hazardous....”*



## Concluding Remarks

- The technologies of incorporating crumb rubber into asphalts are generally classified as wet process or dry process.
  - *The wet process has been more common and more successful than the dry process.*
  - *Crumb rubber asphalts are most frequently used / reported in the US.*
- Laboratory tests generally show improved properties for crumb rubber asphalts; BUT, field performance varied widely. There is still a lack of long-term performance data, particularly for the HMA application.

## Concluding Remarks, cont.

- Final product quality is influenced by a lot of parameters, including crumb rubber characteristics, bitumen composition, and reaction conditions.
- Crumb rubber asphalt exposures may be potentially more hazardous than the conventional asphalt.
- Experience on the recycling of crumb rubber asphalts is still limited.

