Crumb Rubber 101: Background, History, Usage

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Rubber Pavement Association

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Baton Rouge, Louisiana

RAF
Rubberized Asphalt Foundation

www.rubberpavements.org
www.RA-Foundation.org

Historical Overview of Crumb Rubber in Asphalt

1960s Charles McDonald Experiments w/AR

1970s AR Field City of Phoenix and ADOT Chip Seal Coat(SAM)

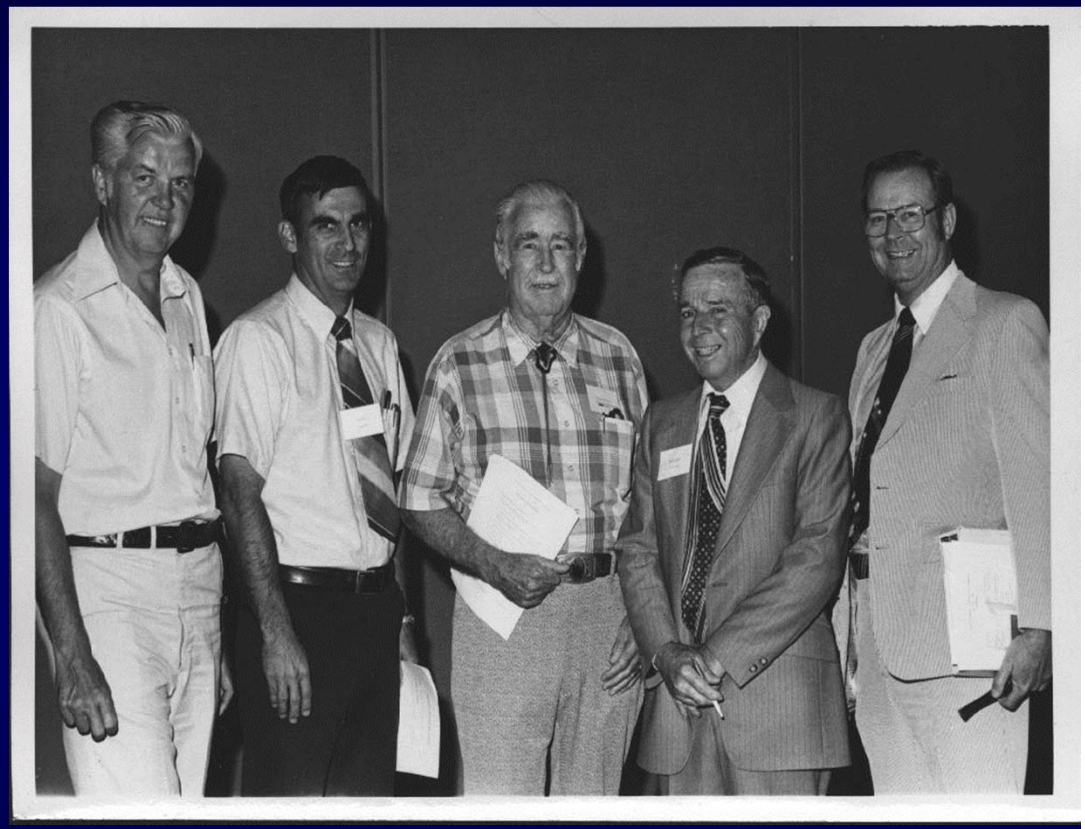
1978 Several AR patents

1985-88 AR Gap Graded & Open Graded Mixes

1993 ISTEA controversy
1994 ASTM Specification
1995 Patents expire

1997 RPA Formed

2000-2009 Three International AR Conf.



Charlie (center) at First National A-R Conf. 1980

Others: Dr. J. Love FHWA, Dr. J. Epps Tex A&M, Dr. B. Galloway TTI, Gene Morris ATRC

History of Crumb Rubber-Asphalt

1920-1950's Pre-Rubber Asphalt
1960's Early Development
1970's Chip Seal Coats
1980's Gap Graded & Open Graded Mixes
1990's Politics & Starting Over
2000's Performance, Research, Environment, Costs
2010+ Market Changes, International Asphalt-Rubber PG Binder Grading, WMA

1920-1950's Need
For All Weather Pavements

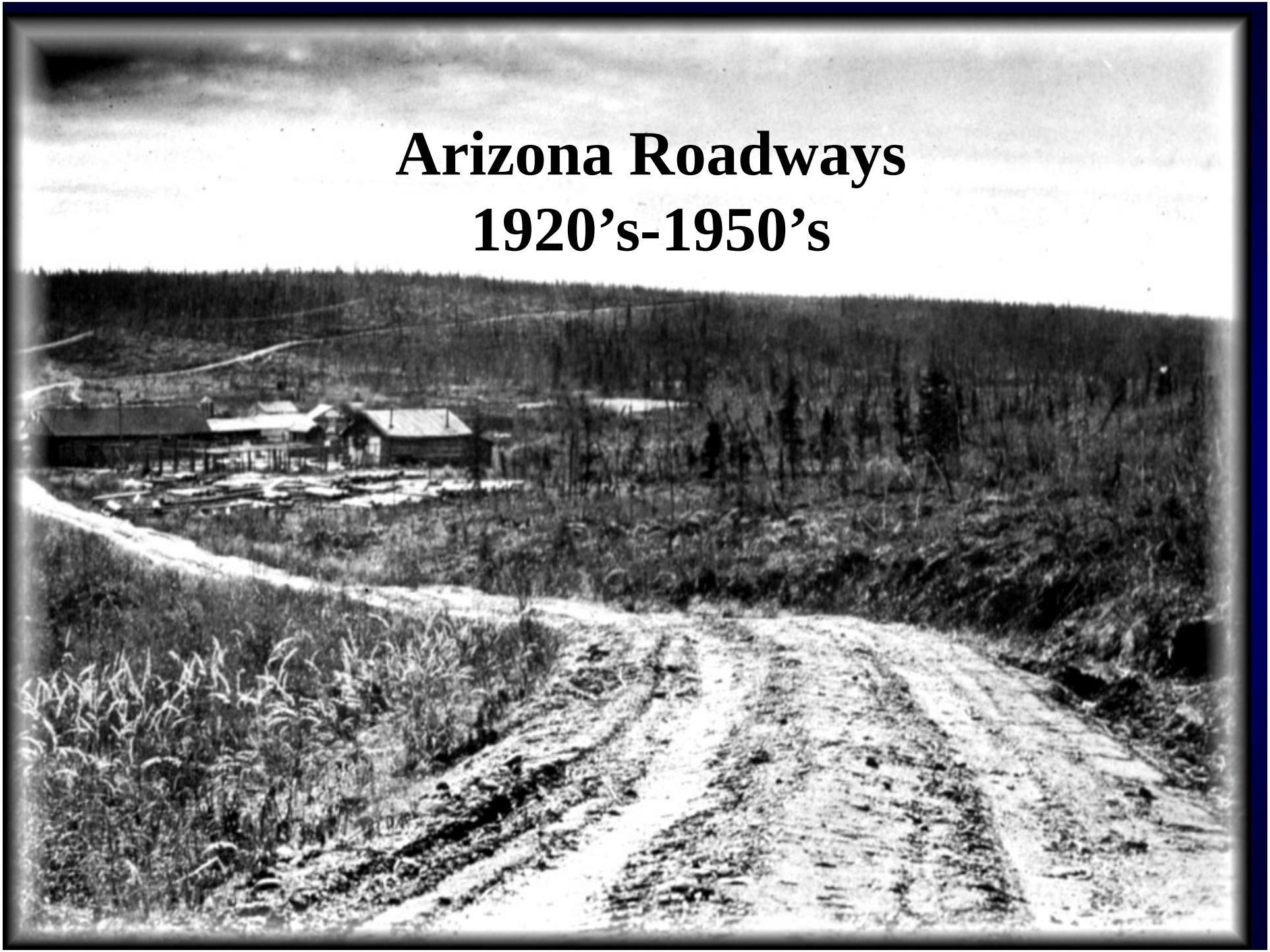
Get the Roadway
Out of the mud

Weather proof and
Water proof the roadway

Develop a pavement surface
That is weather proof and
Water proof

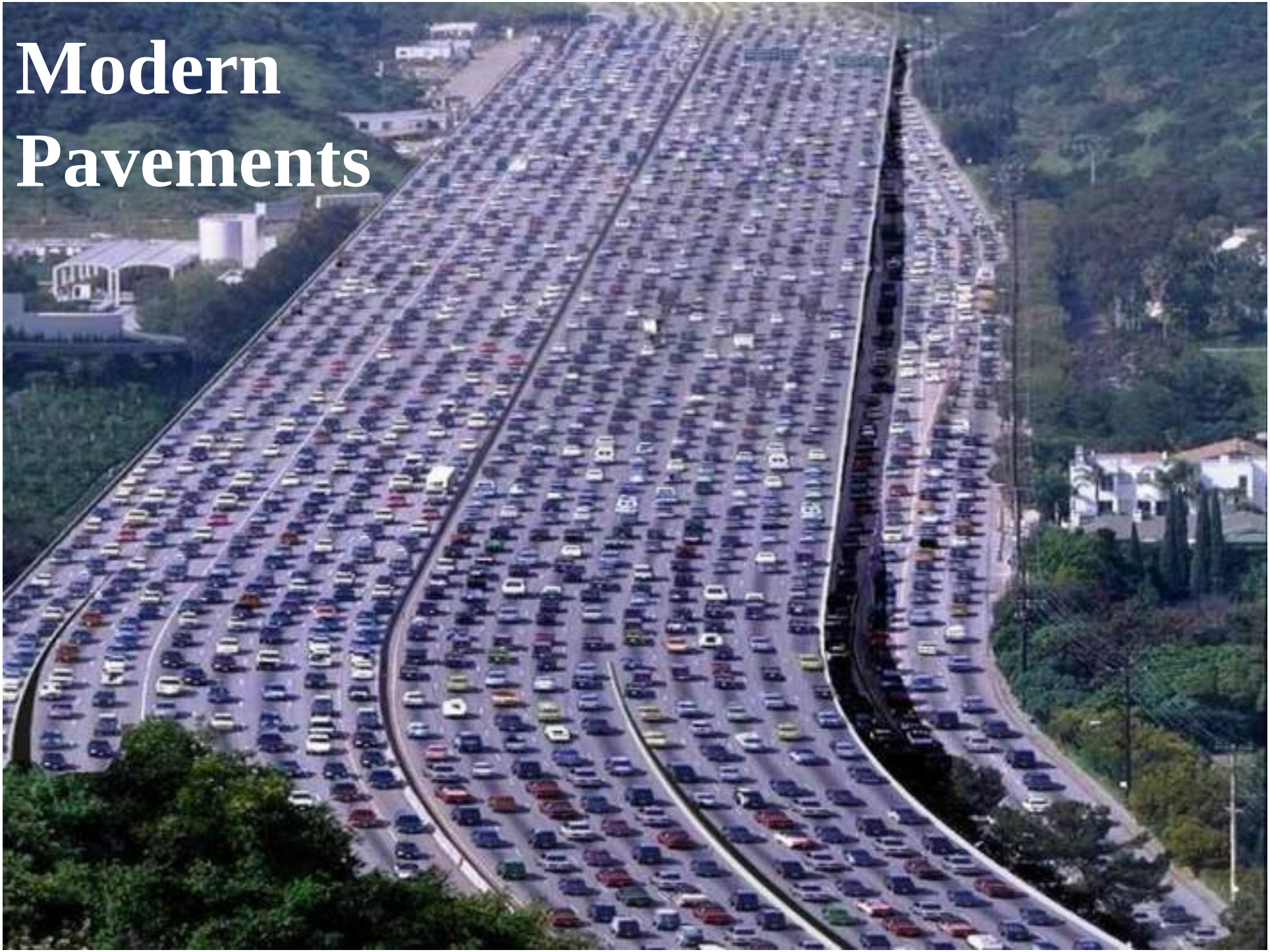
Pavement stand up to wet
Weather, poor soil mud,
And heavy truck traffic

Washington-Richmond road, 1919
NMAH, Archives Center, API Collection

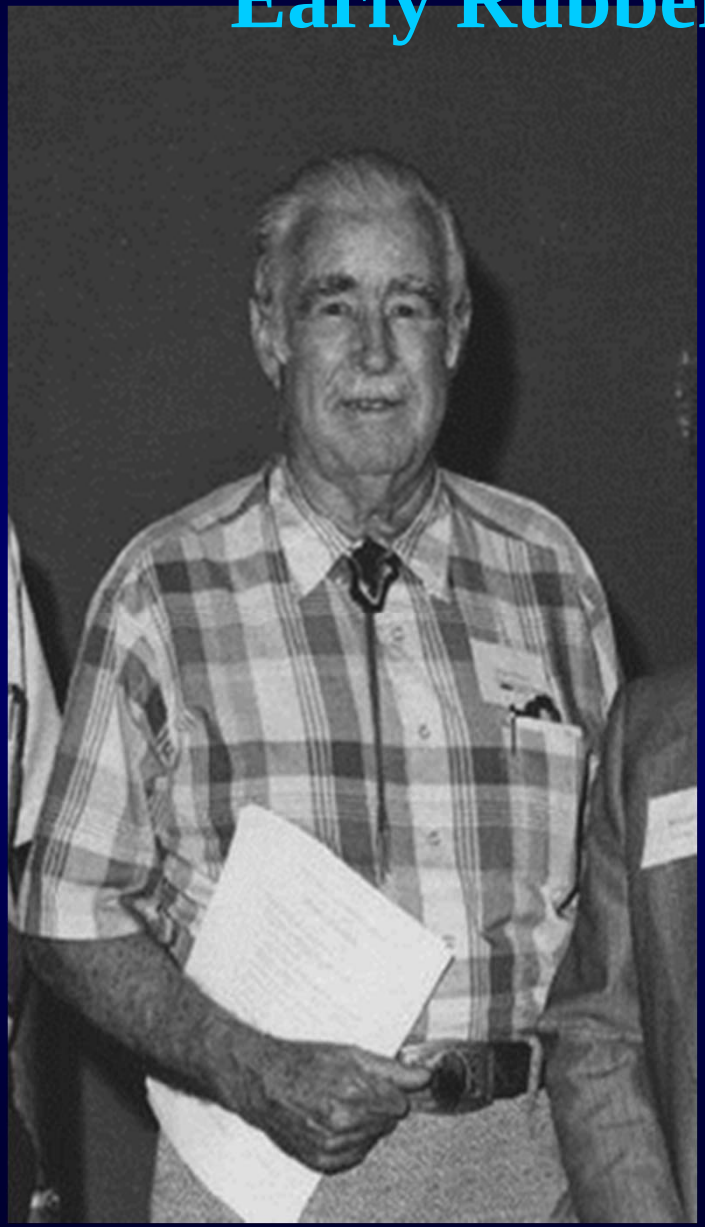

Arizona Roadways
1920's-1950's

Arizona

Modern Pavements



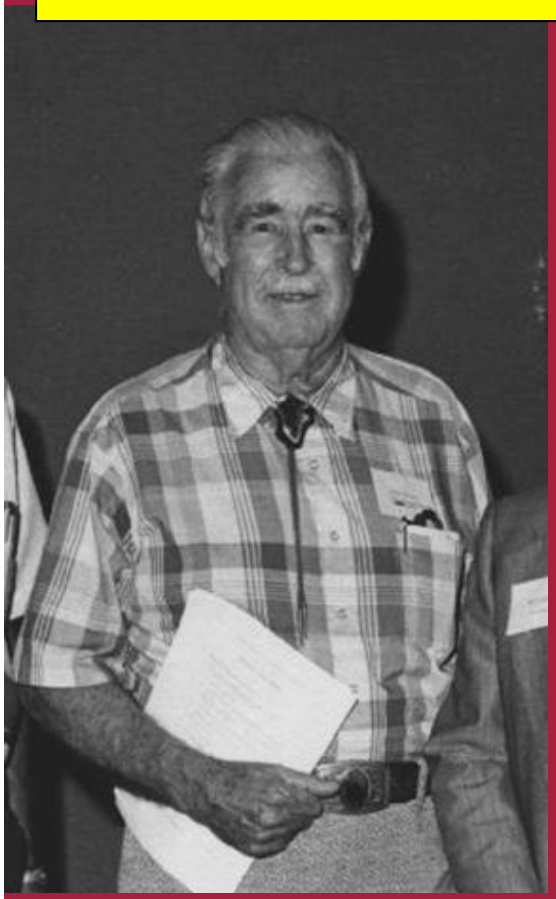
1960's Charles H. McDonald
Early Rubber in Asphalt Development



- 1950's Used asphalt to patch cracked roof of trailer when travelling with US Bureau of Public Roads (now FHWA).
- Mixed in ground tire rubber while heated to increase flexibility.
- Created pot-hole "band aid" for City of Phoenix 1960s

Phoenix, Arizona failed streets in the 1960’s.
McDonalds goal to maintain failed streets until reconstruction.

Charles McDonald
Inventor of
Asphalt Rubber

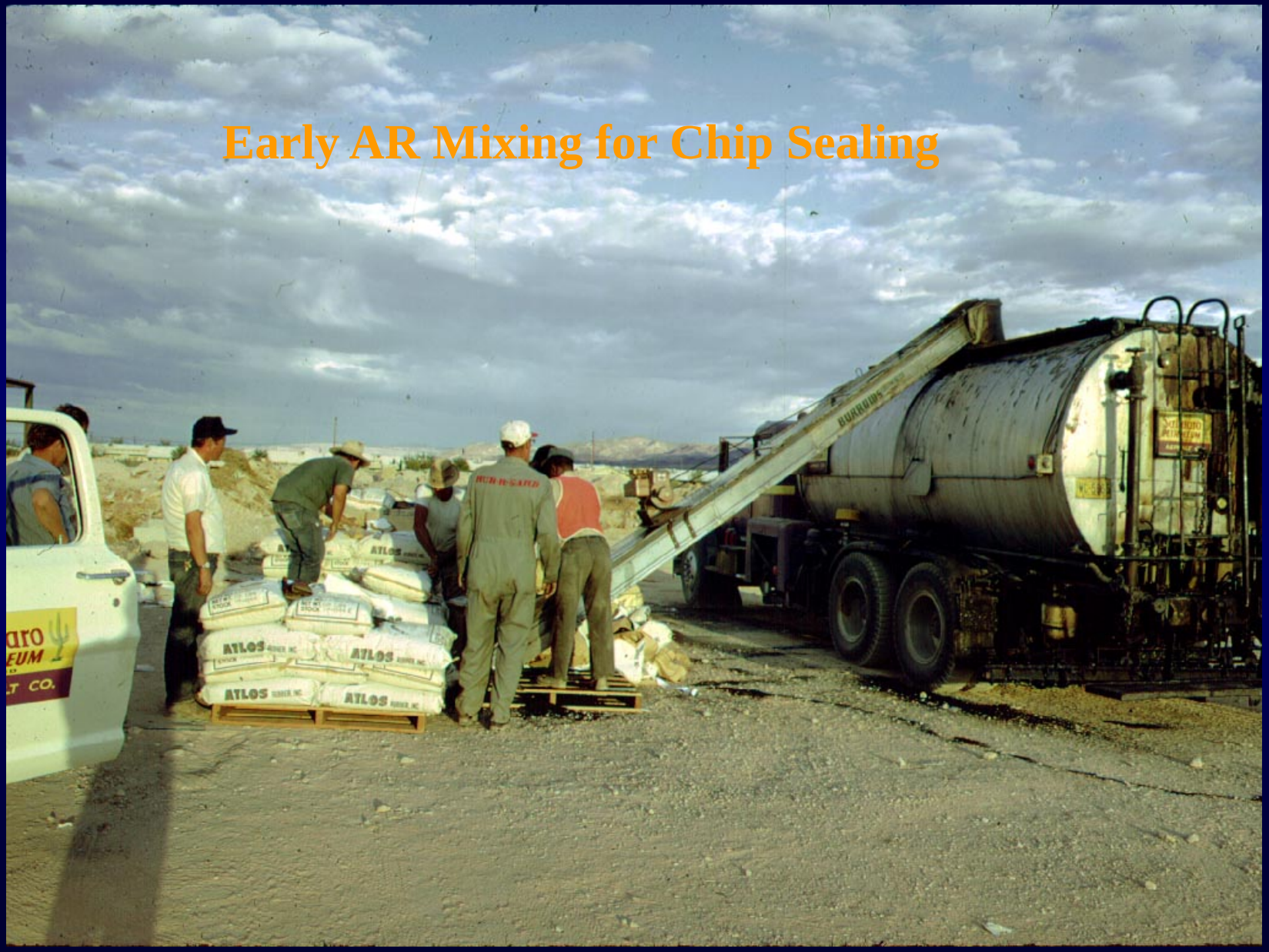


McDonald
Applying
AR Band Aid
Patch
Circa 1966

Asphalt
Rubber
Band Aid
Patch
Circa 1966

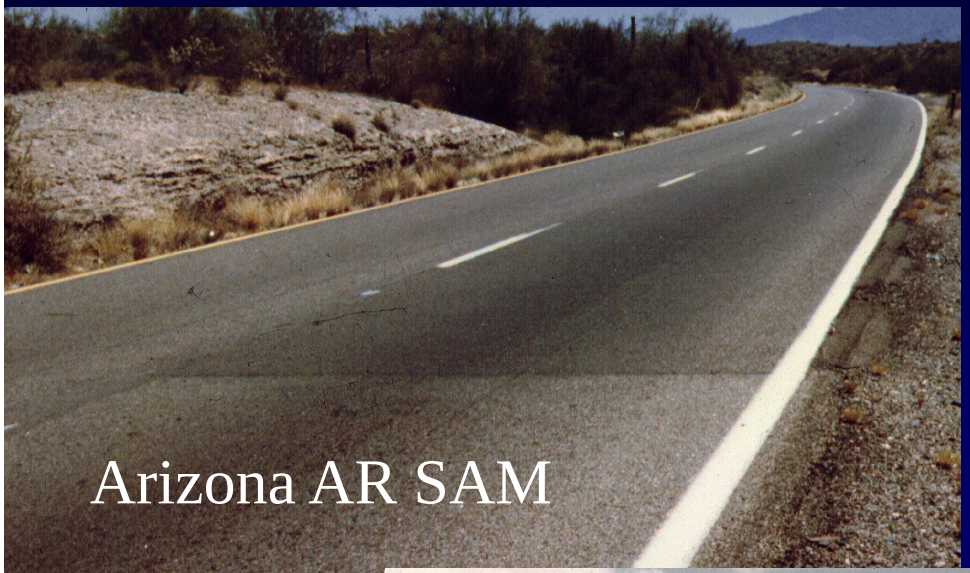
Asphalt rubber 2006 Conference

1970's AR Chip Sealing

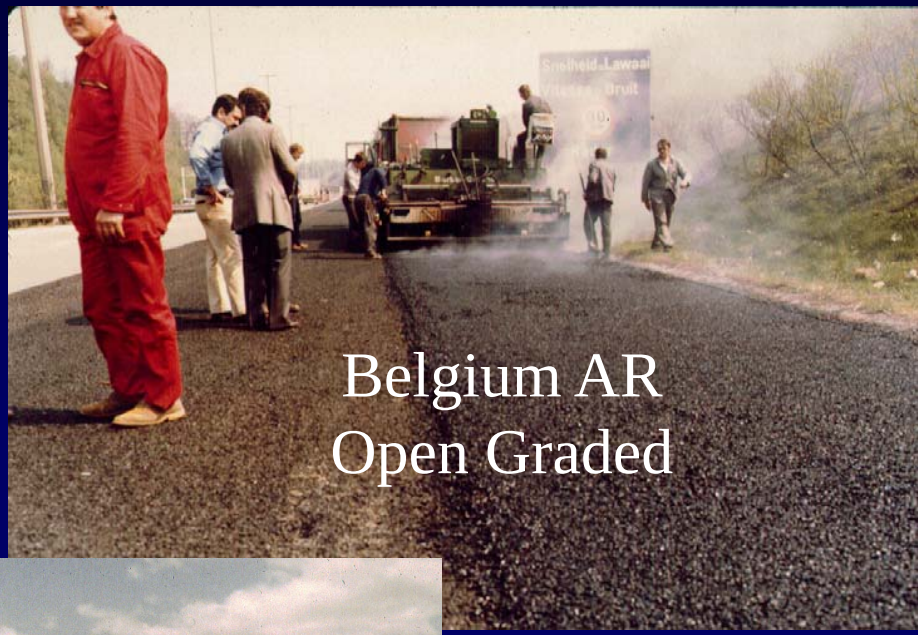


Early Chip Seal Spreader Truck Technology Mid 1970s

Early Hot Mix Application Placed 1975 Through Mid 1980's

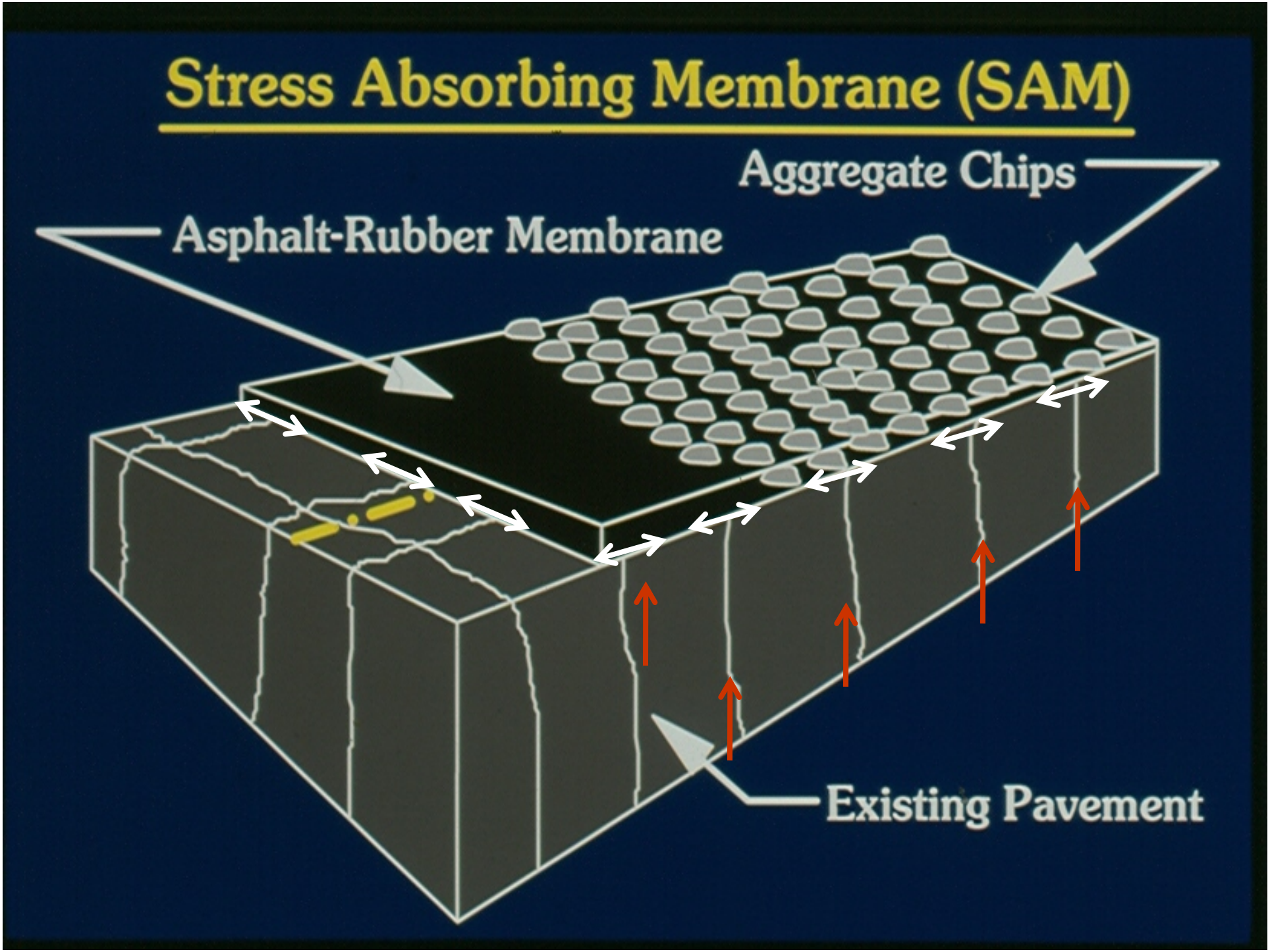


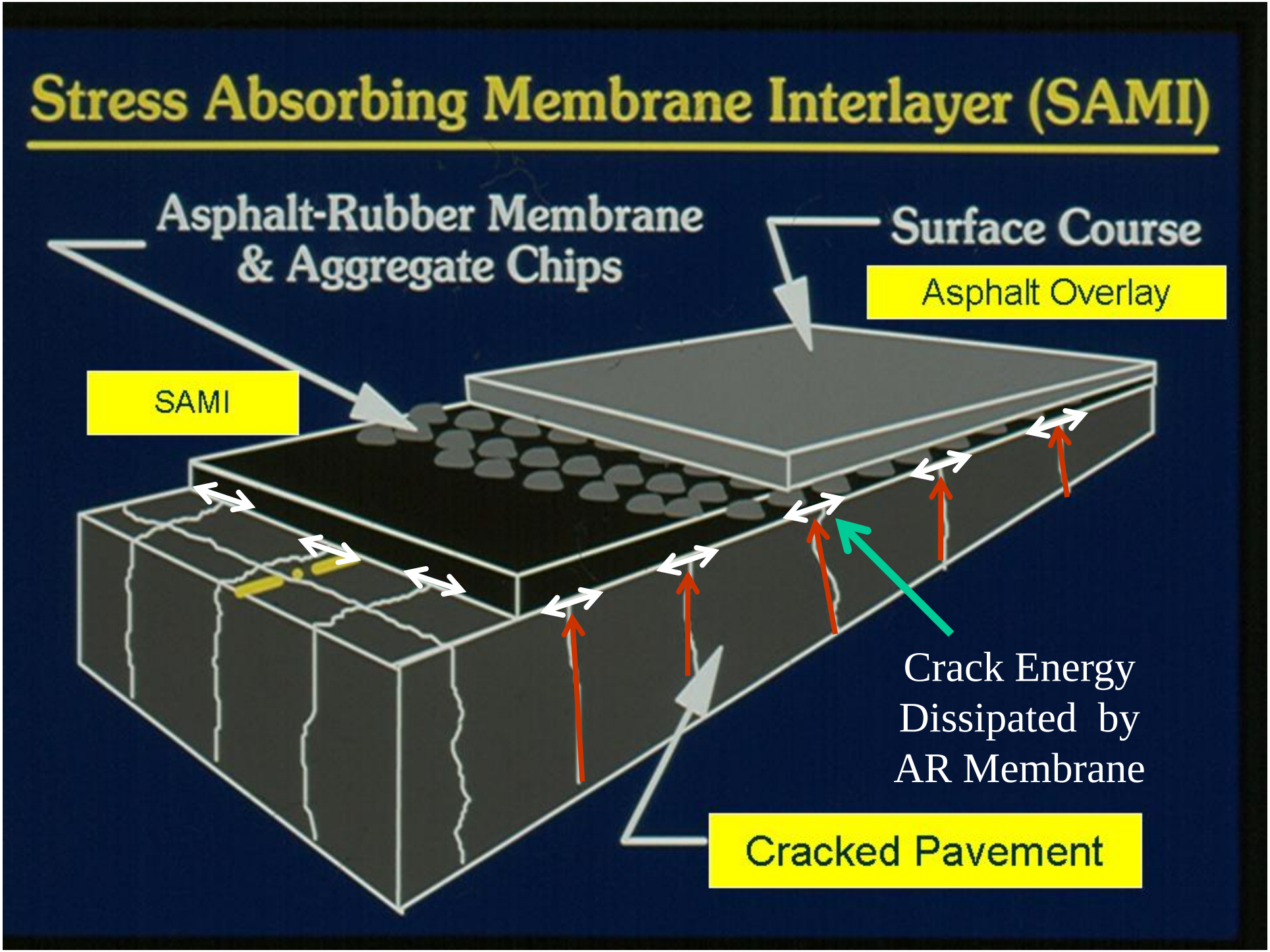
Arizona AR SAM



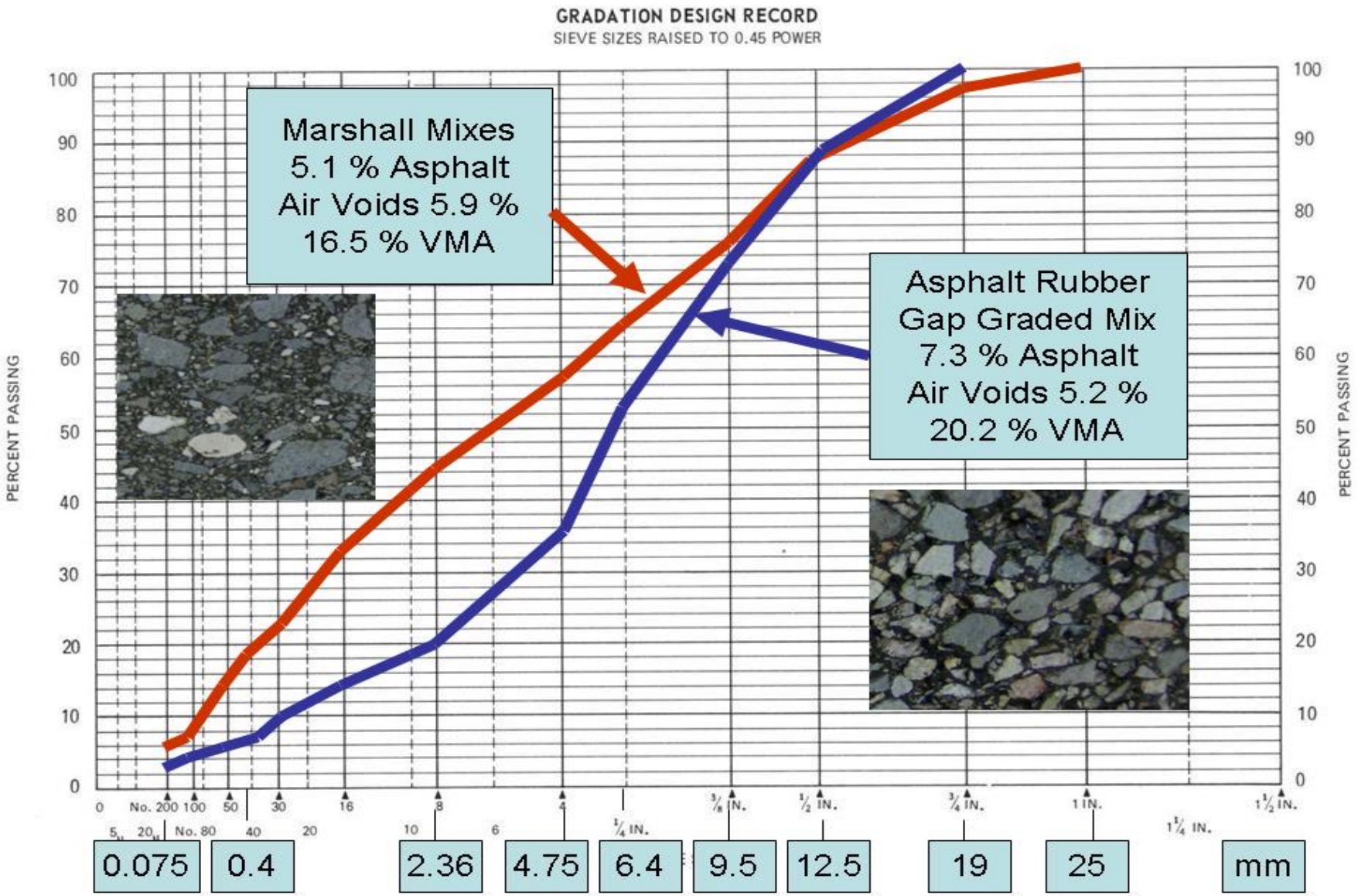
Belgium AR
Open Graded

South Africa AR SAM

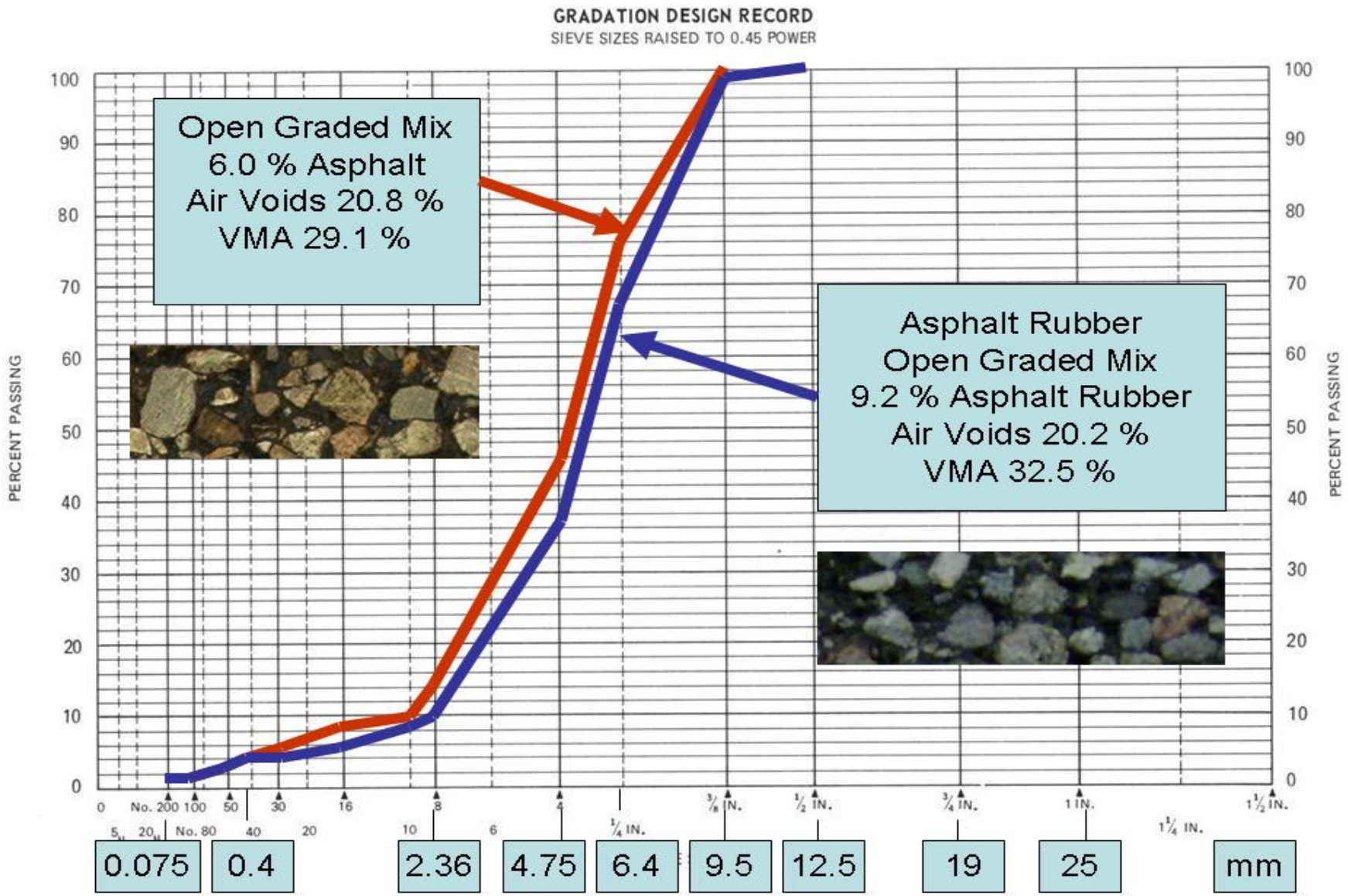

Stress Absorbing Membrane (SAM)
Aggregate Chips
Asphalt-Rubber Membrane
Existing Pavement


Stress Absorbing Membrane Interlayer (SAMI)
Asphalt-Rubber Membrane & Aggregate Chips
Surface Course
Asphalt Overlay
SAMI
Crack Energy Dissipated by AR Membrane
Cracked Pavement

Asphalt-Rubber Binder Application SAM/SAMI

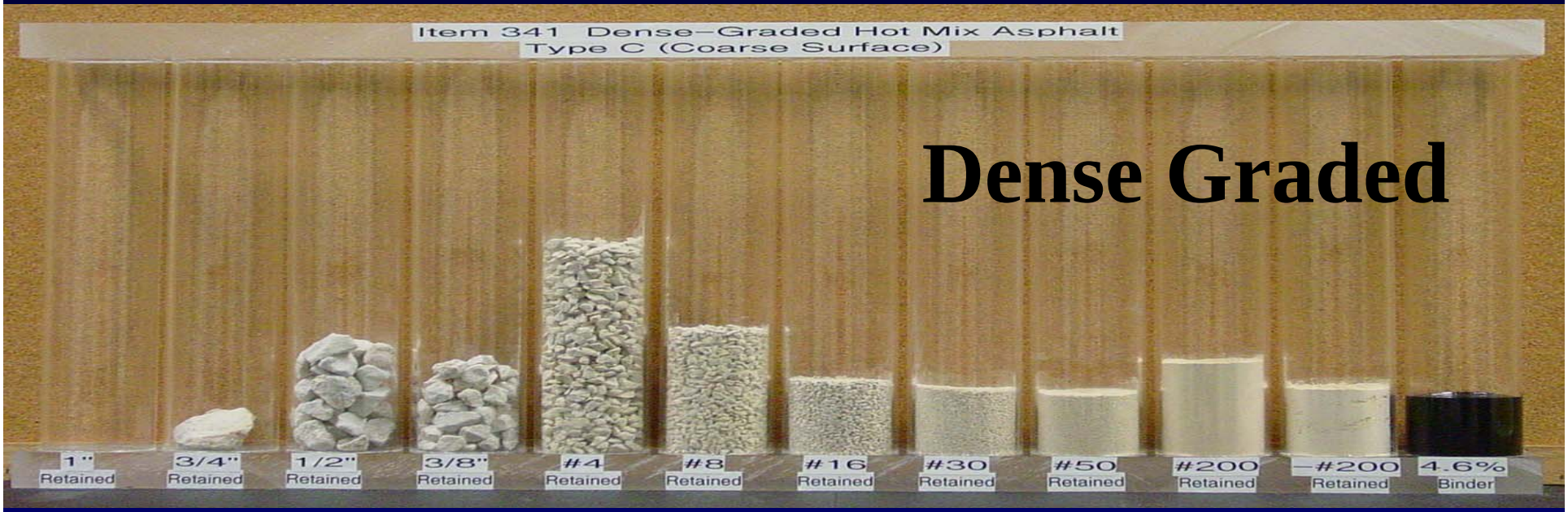


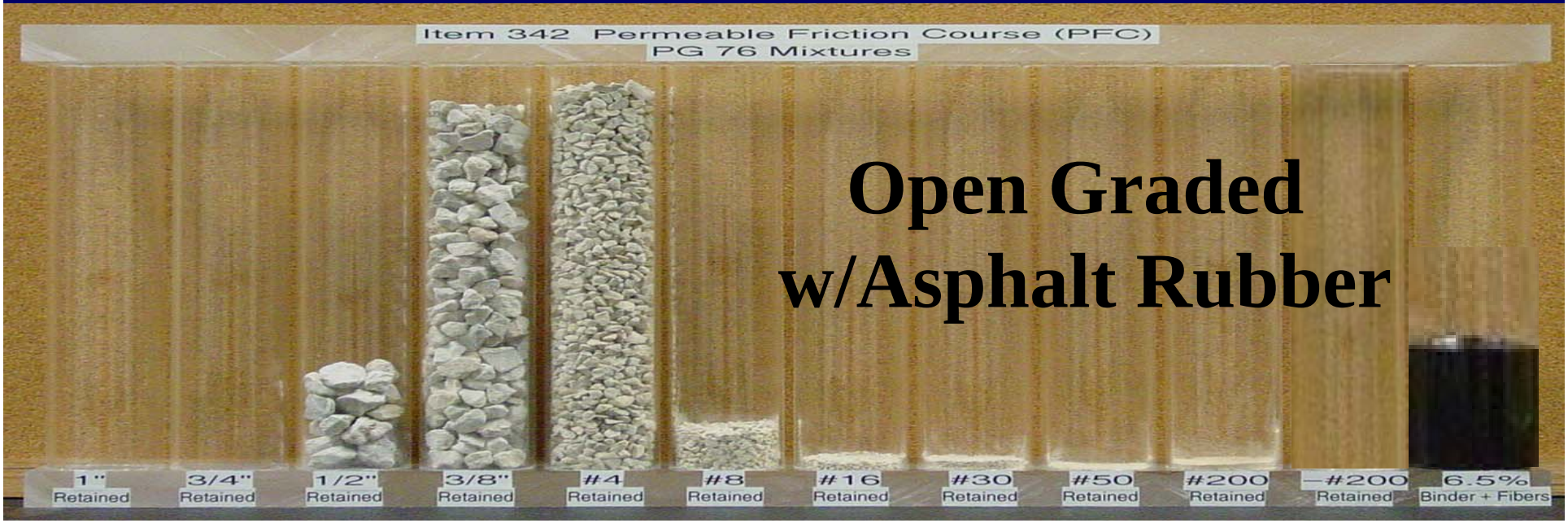
1980's Marshall Mix Gradation for HMA And Gap Graded Asphalt Rubber Mixes

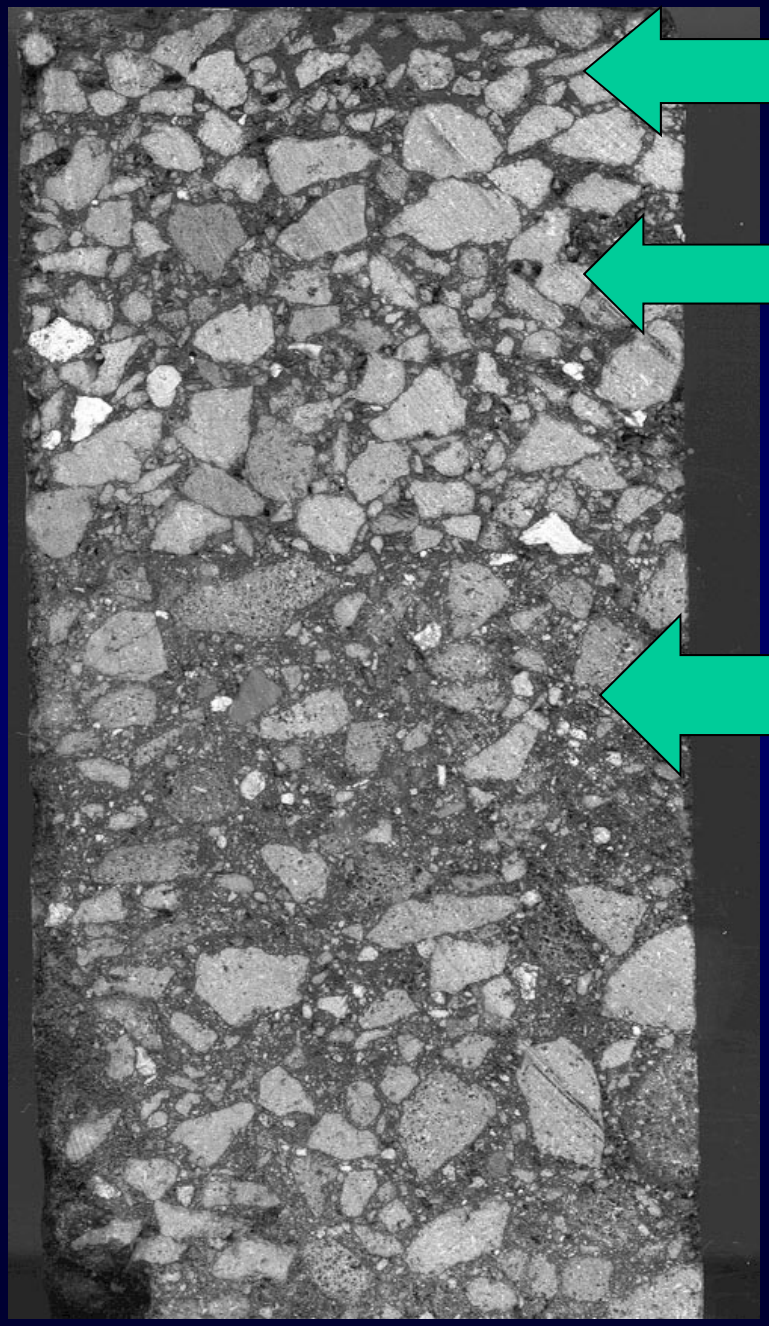


1980's Open Graded Mix Gradations

Example Dense-Graded HMA vs. AR Open Graded







AR-OGFC

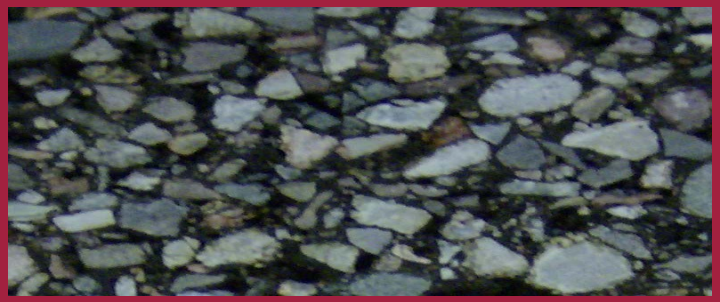
AR-AC

HMA
Base
Mix

Asphalt-Rubber Mixes

HMA Dense Graded Average
Overlay Thickness
140 mm – 5.5 Inches

Asphalt Rubber
Hot Mixes
Average Overlay
Thickness
45 mm – 1.7 Inches



HMA % of Miles
With Fatigue Cracking
20 %

Asphalt Rubber % Of Miles
With Fatigue Cracking
2 %

1990's Politics and Starting Over

1993 ISTEA controversy/ARPG

1994 ASTM Specification

1995 Patents expire

1997 RPA Formed to replace ARPG

RPA Dedicated to research and technology transfer

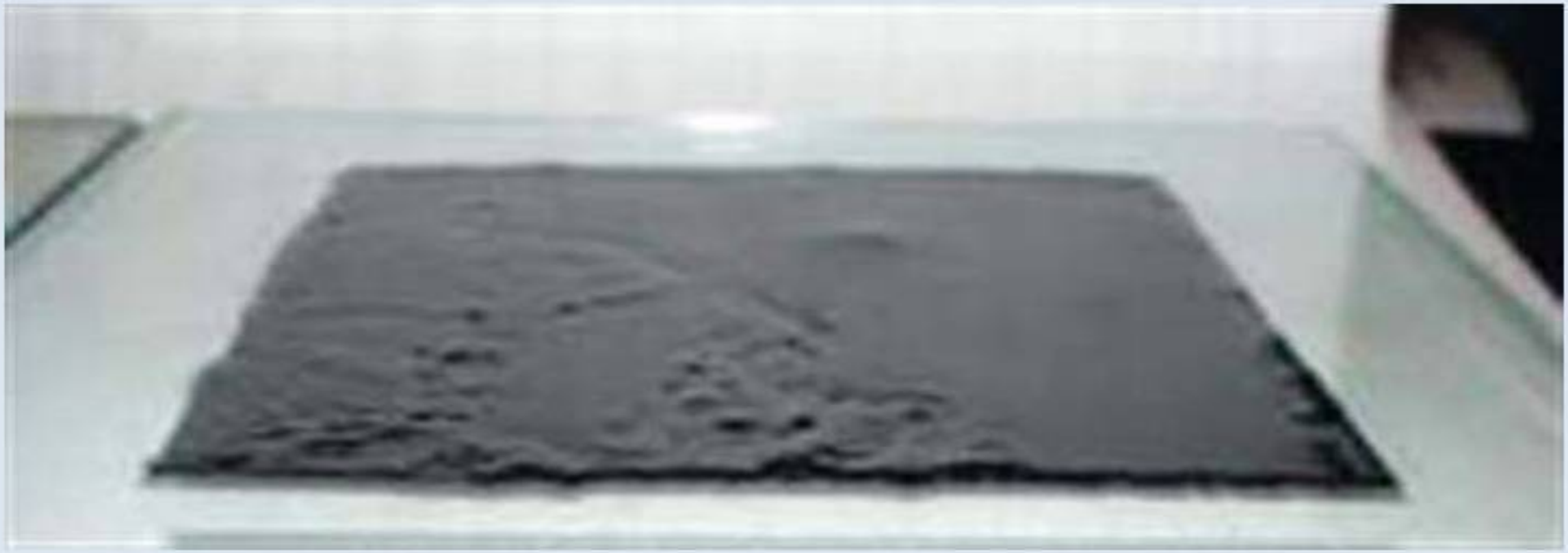
1994 ASTM AR Definition & Specification

Asphalt-Rubber as defined by ASTM D8, Spec. ASTM D6114

"Asphalt-Rubber is a blend of asphalt cement, reclaimed tire rubber and certain additives, in which the rubber component is at least 15% by weight of the total blend and has reacted in the hot asphalt cement sufficiently to cause swelling of the rubber particles."

Asphalt-Rubber Binder with Rubber Particles

Asphalt Binder, Neat asphalt, Polymer Asphalt, Terminal Blend

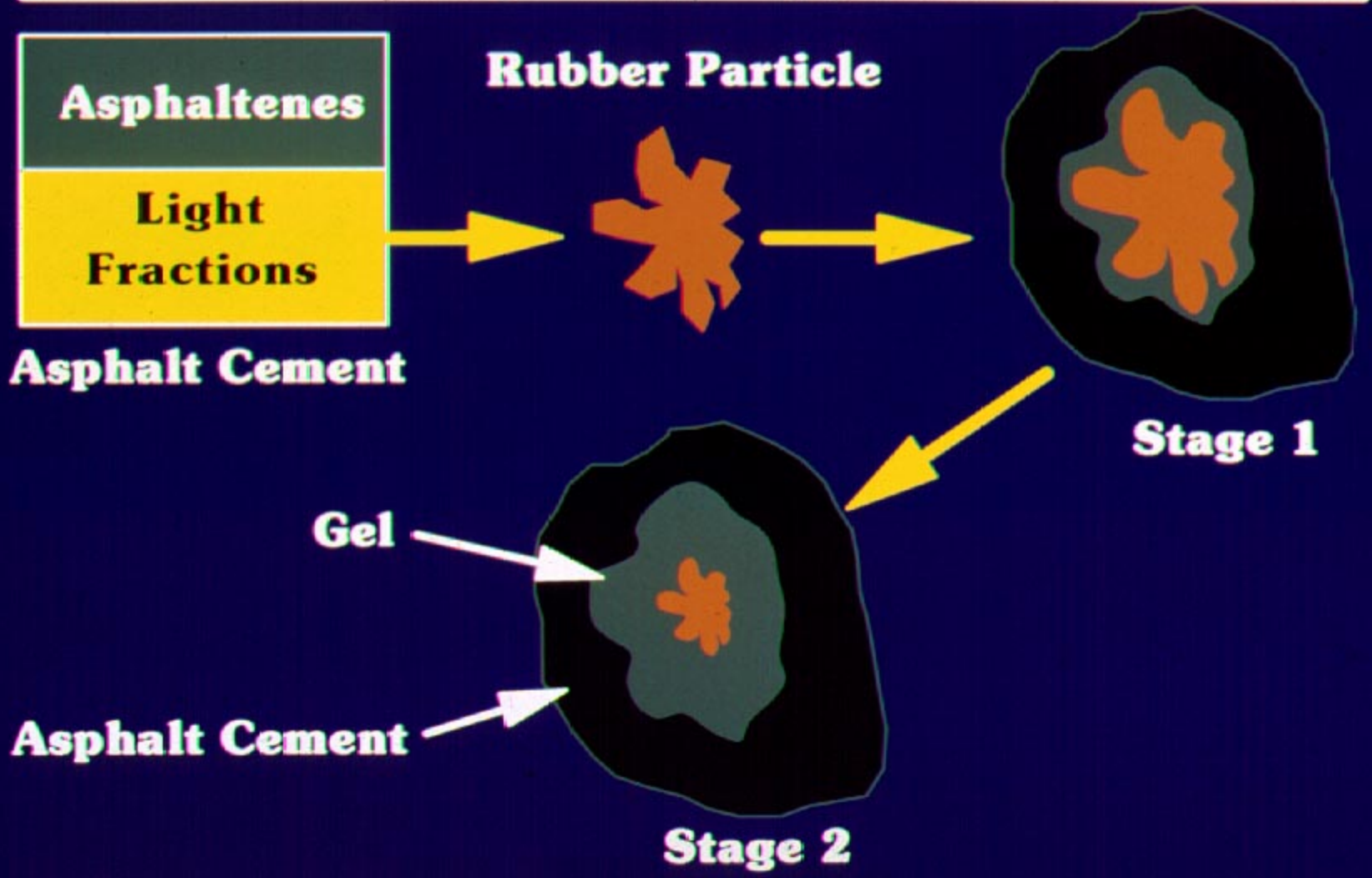


Crumb Rubber related terms

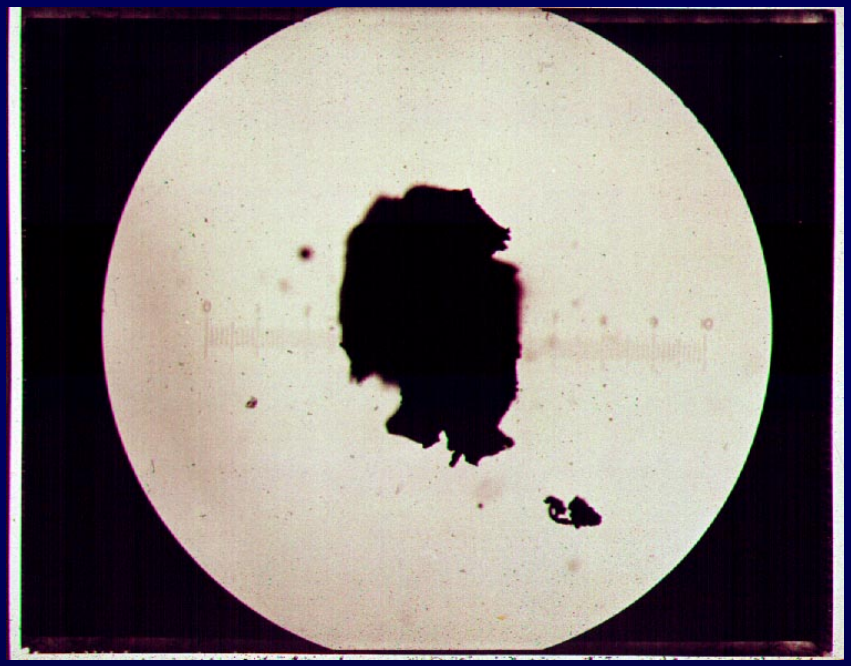
CRM – Crumb Rubber Modified Asphalt
GTR – Ground Tire Rubber
RTR – Recycled Tire Rubber

- No. 10 mesh and smaller is used (less than 2 mm)
- Free of wire and other contaminants
- 0.5% fiber or less.

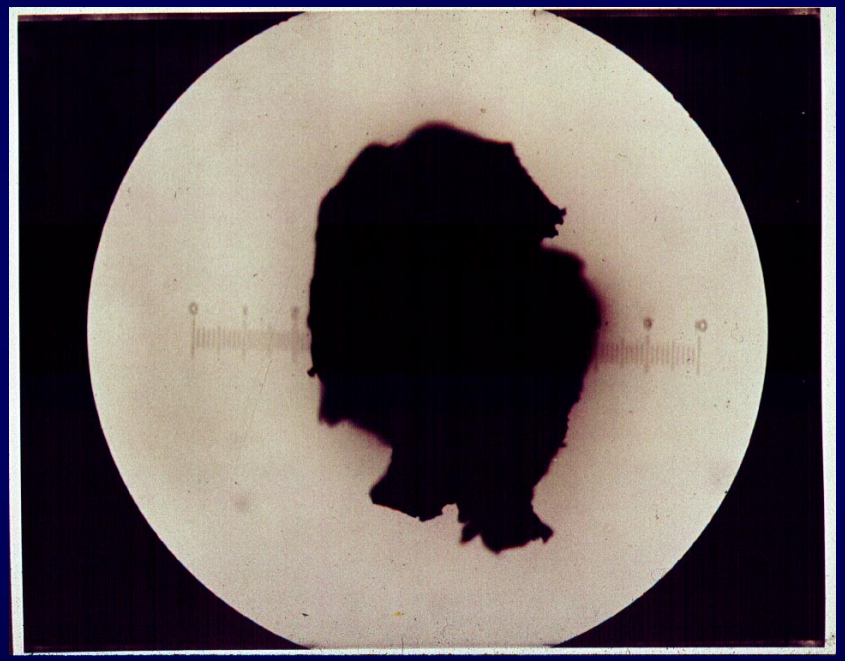
Reaction Stages of Asphalt & Rubber



Rubber Particle Interaction

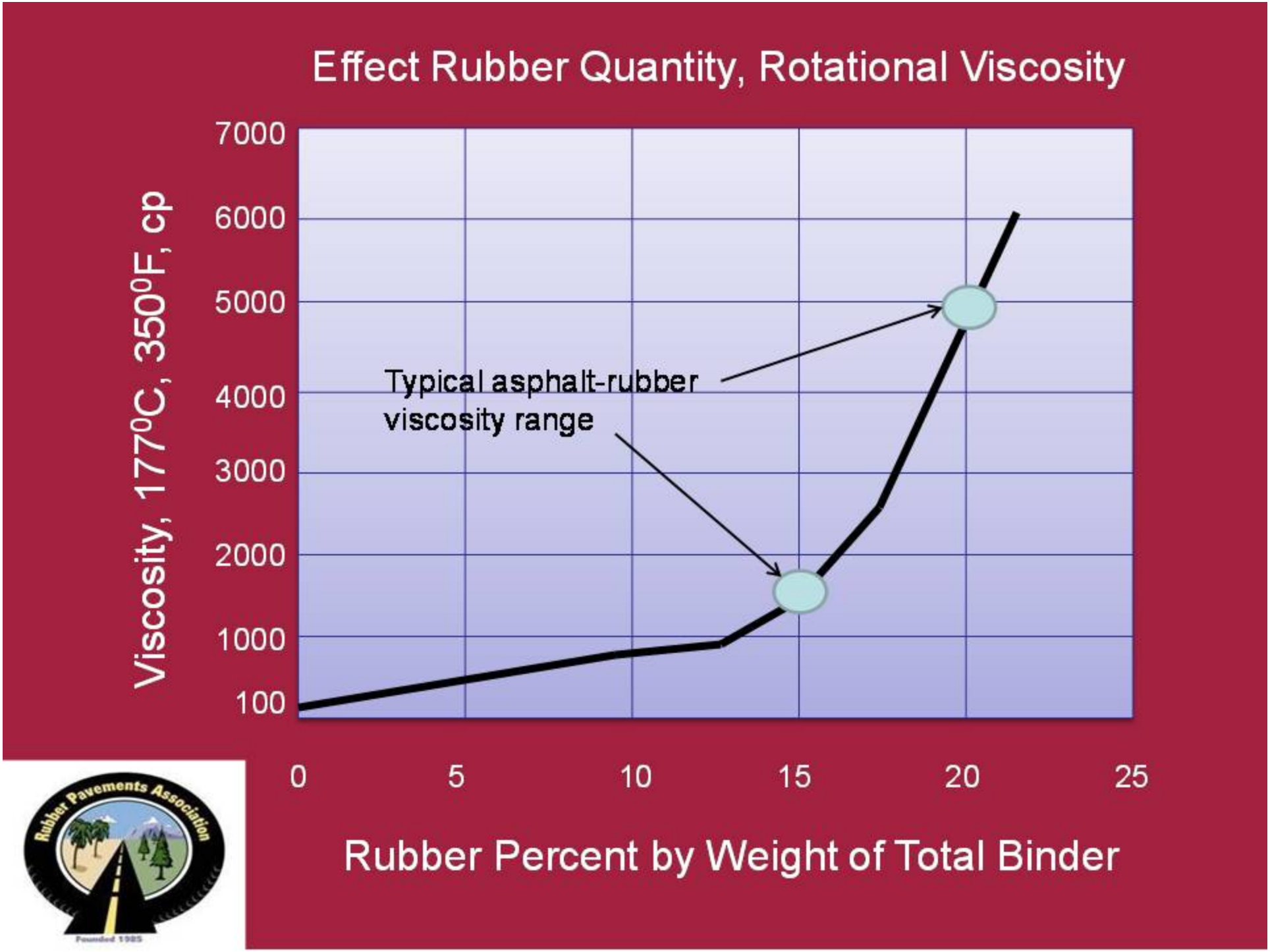


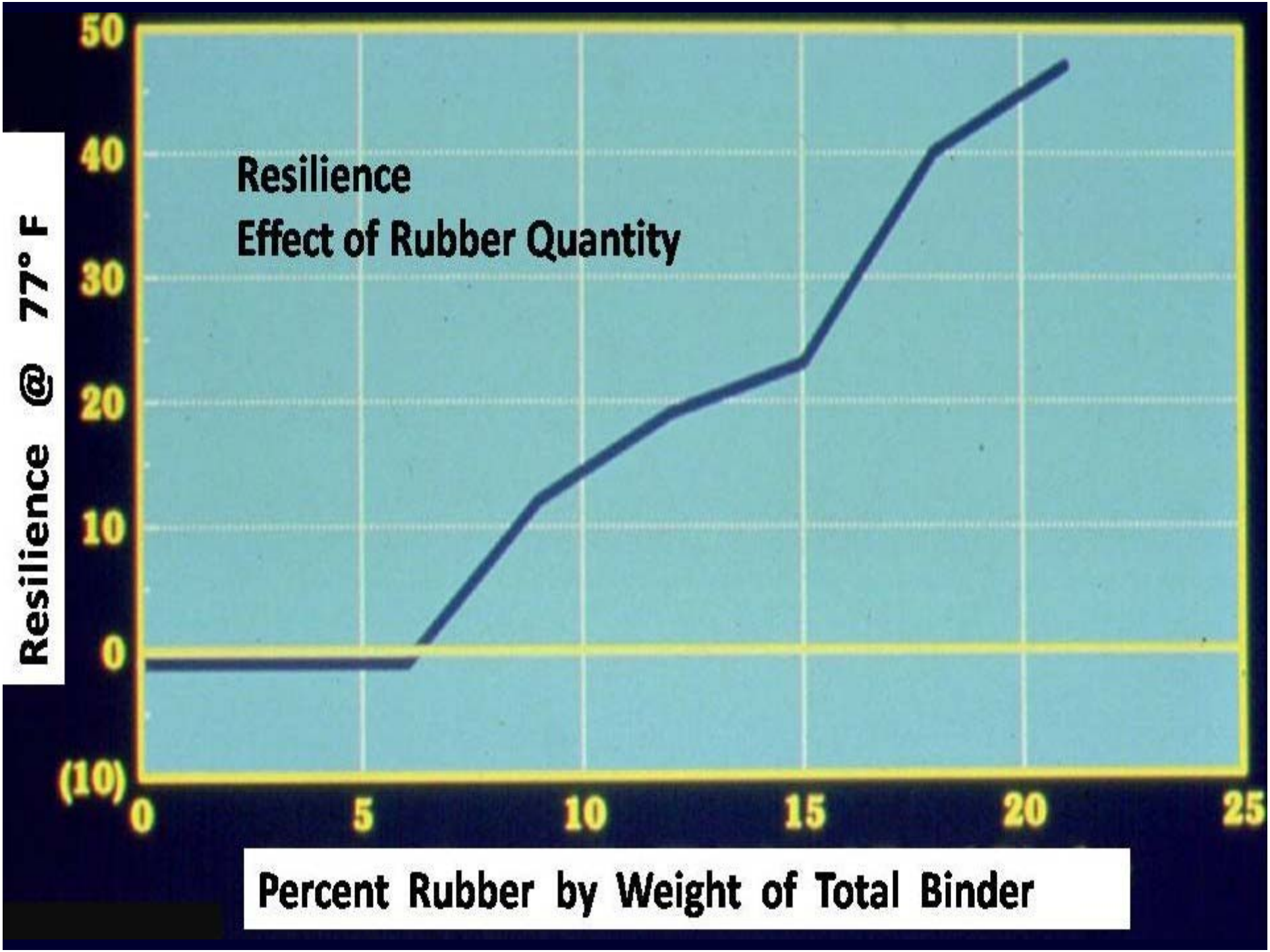
Before



After

Quality Control Circa 1982


Effect Rubber Quantity, Rotational Viscosity
Viscosity, 177°C, 350°F, cp
7000
6000
5000
4000
3000
2000
1000
100
Typical asphalt-rubber
viscosity range
0
5
10
15
20
25
Rubber Percent by Weight of Total Binder


Resilience
Effect of Rubber Quantity
Resilience @ 77° F
50
40
30
20
10
0
(10)
0
5
10
15
20
25
Percent Rubber by Weight of Total Binder

Agency	ADOT[1]	ADOT[1]	ADOT[1]	ASTM	Caltrans	FDOT[4]	TxDOT[1]	TxDOT[1]	TxDOT[1]
Binder Type	1	2	3	1	2	ARB 12	I	II	III
CRM Type: Scrap tire (ST)	ST	ST	ST	ST	75±2% ST	ST	ST	ST	ST
High Natural (HN)	---	---	---		25±2% HN	---	---	---	---
Minimum CRM by total weight of binder, %							15	15	15
Minimum CRM by weight of asphalt cement, %	20	20	20	15	18	12			
Base Asphalt Cement Grade	PG 64-16	PG 58-22	PG 52-28	Not Specified[2]	AR-4000	PG 64-22	PG 58-28 PG 64-22	PG 58-28 PG 64-22	PG 58-28 PG 64-22
Asphalt Modifier (extender oil) by weight of asphalt cement, %	Not Allowed	Not Allowed	Not Allowed	May be allowed but not specified	2.5-6.0	Allowed but not used	Allowed but not used	Allowed but not used	Allowed but not used
Minimum Interaction Temperature	163°C 325°F	163°C 325°F	163°C 325°F	177°C 350°F	190°C 375°F	150°C 300°F	---	---	---
Maximum Interaction Temperature	190°C 375°F	190°C 375°F	190°C 375°F	190°C 375°F	218°C/425° 226°C/440°F	175°C 350°F	---	---	---
Minimum Interaction Time	60 minutes	60 minutes	60 minutes	User Defined	45 minutes	15 minutes	---	---	---

1 ADOT and TxDOT specifications are published in English units; for this table, temperature values were converted from °F to °C and rounded.

2 ASTM directs the user to select binders based on climate

3 Caltrans dual units specifications are presented in this table.

4 FDOT provides respective values for °C and °F that are not exact conversions of each other; temperature limits presented in this table are as shown in the FDOT Standard Specifications and have not been adjusted.

Sieve Size	Caltrans	Caltrans	TxDOT	TxDOT	TxDOT	ADOT	ADOT	FDOT	FDOT	FDOT
% Passing	Scrap Tire	High Nat'l	Grade A	Grade B	Grade C	Type A	Type B	Type A	Type B	Type C
	(Green-book)	(Green-book)								
2.36 mm (#8)	100	100	100			100				
2.00 mm (#10)	98-100	100	95-100	100		95-100	100			
1.18 mm (#16)	45-75	95-100		70-100	100	0-10	65-100			100
600 µm (#30)	20-Feb	35-85		25-60	90-100		20-100		100	70-100
425 µm (#40)					45-100					
300 µm (#50)	0-6	30-Oct	0-10				0-45	100	40-60	20-40
150 µm (#100)	0-2	0-4						50-80		
75 µm (#200)	0	0-1		0-5			0-5	--	--	--

Binder Designation Climate Zone		CRA 1 Hot	CRA 2 Mild	CRA 3 Cold
Grade of base asphalt cement PG recommended; Pen suggested Grade		PG 64-16 Pen 60/70	PG 58-22 Pen 85/110	PG 52-28 Pen 120/200
Rotational Viscosity; 350° F (C) Spindle 3, 20 RPM, Pa·s, [cp] ASTMD2196		1.5-4.0 [1500-5000]	1.5-4.0 [1500-5000]	1.5-4.0 [1500-5000]
Penetration; 77 F (C), , 60 sec. (ASTM D 5)	Min	10	15	25
Softening Point; (AASHTO T-53 or ASTM D 36) °C or F	Min	57 [135]	54 [130]	52 [125]
Resilience 77 F (C) ASTM D 5329 %, min.	Min	30	25	15

Test Performed	Minutes of Reaction					Specified Limits
	60	90	240	360	1440	
Viscosity, Haake at 177°C, Pa-s Centipoise cP	2.7 2700	2.8 2800	2.8 2800	2.8 2800	2.0 2000	1.5-4.0 1500-4000
Resilience at 25°C, % Rebound (ASTM D3407)	34		36		32	30 Minimum
Ring & Ball Softening Point, °F (ASTM D36)	150.0	150.5	152.5	154.5	145.0	135 Minimum
Needle Penetration at 4°C, 200g, 60 sec., 1/10mm (ASTM D5)	22		24		26	10 Minimum

Where are the RPA members?

Germany, United Kingdom, Mexico, Canada, United States, Austria, Portugal, Saudi Arabia, Australia, South Korea, South Africa, Netherlands, China, Brazil, Poland, Barbados, Saudi Arabia, Italy and Sweden

TAB Members

George Way

Kamil Kaloush

Jorge Sousa

Doug Carlson

Mark Belshe

Anne Stonex

Jack Van Kirk

Richard Stubstad

Barry Takalou

Hussain Bahia

Robert McGinnis

Joe Cano

Serji Amirkhanian

Byron Lord

Jon Epps

Maghsoud Tahmoressi

K. C. Evans

Dale Rand

Doug Bernard

Peter Seebaly

Shakir Shatnawi

TAB ASTM Activities

Standards Developed

ASTM 6114 Asphalt-Rubber Specification

ASTM 6932 Open-Graded Friction Course Design & Construction

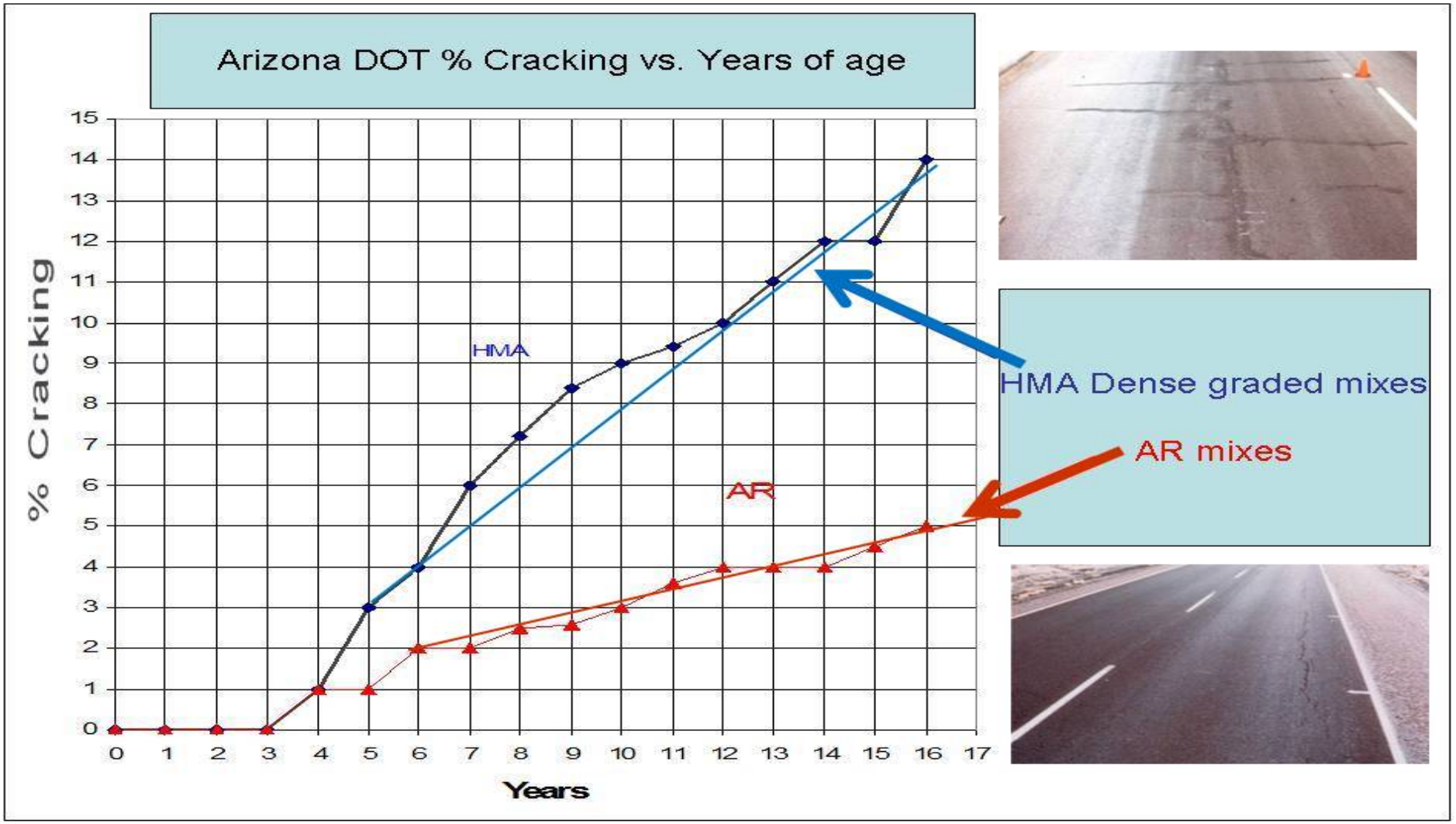
ASTM 7064 Open-Graded Friction Course Mix Design

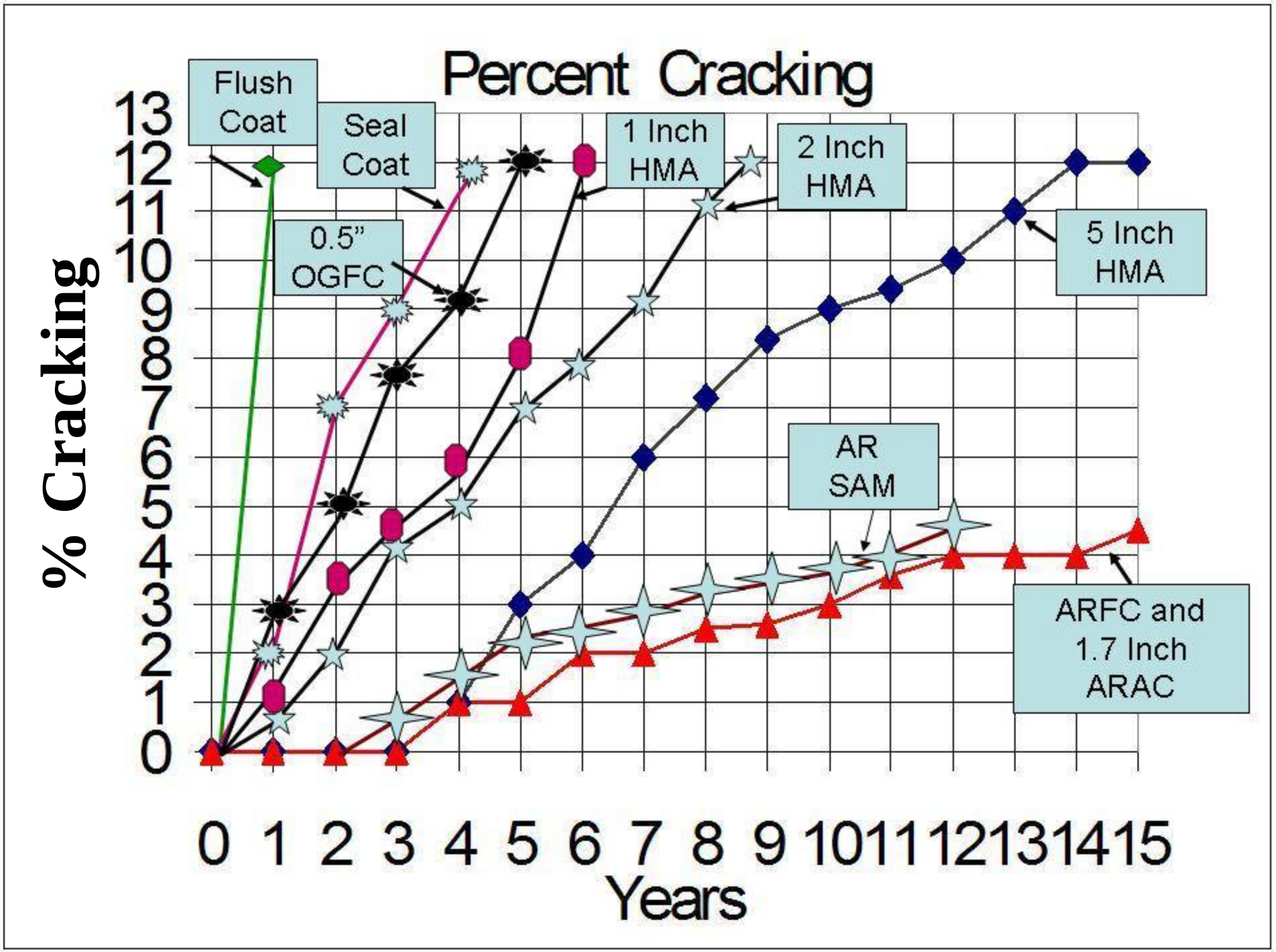
ASTM 7584 Asphalt-Rubber Cape Seal

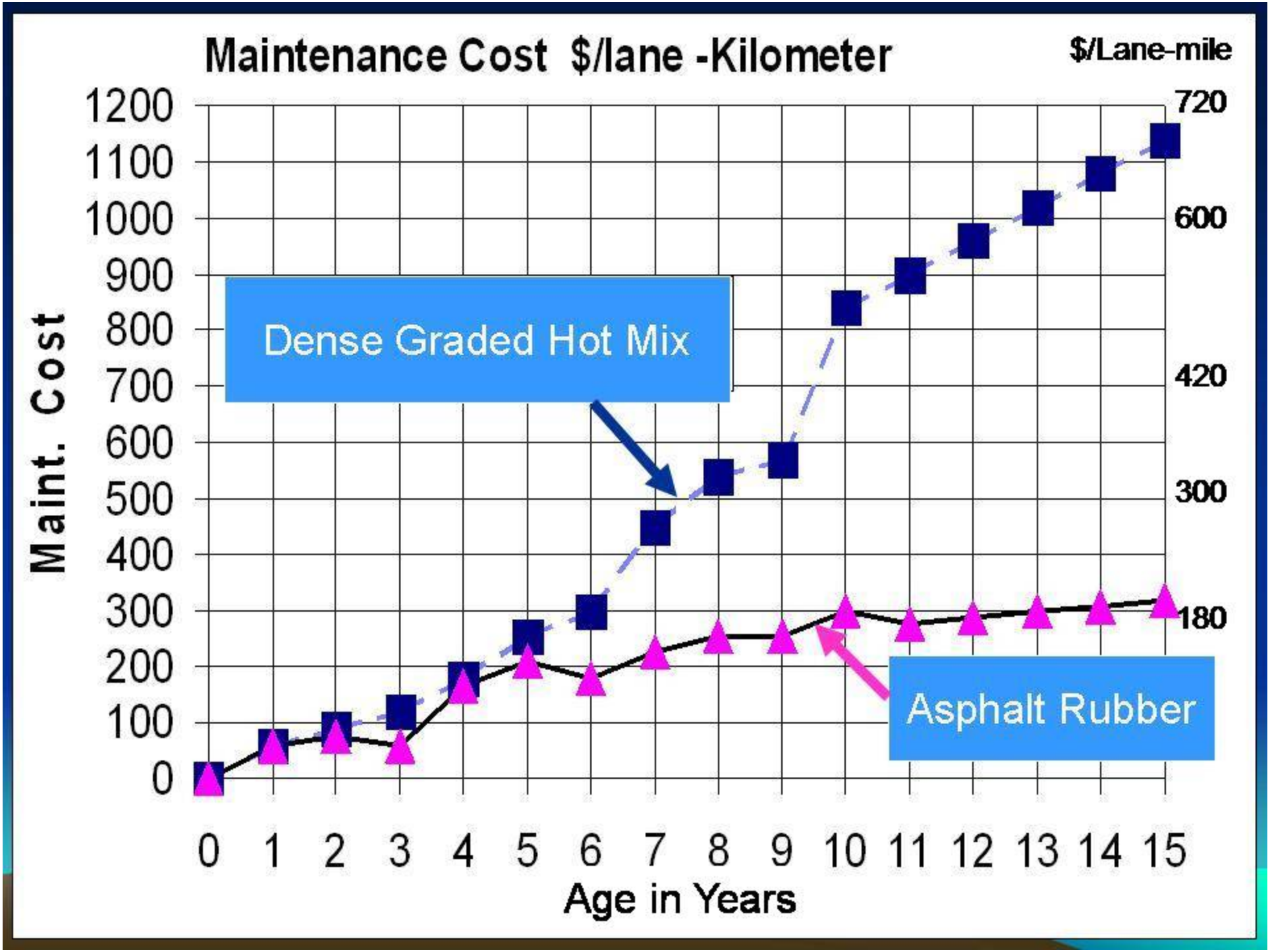
Newly developed Standard

ASTM 7741 Test Method for Measurement of Apparent Viscosity of Asphalt-Rubber or Other Asphalt Binders by Using a Rotational Hand Held Viscometer

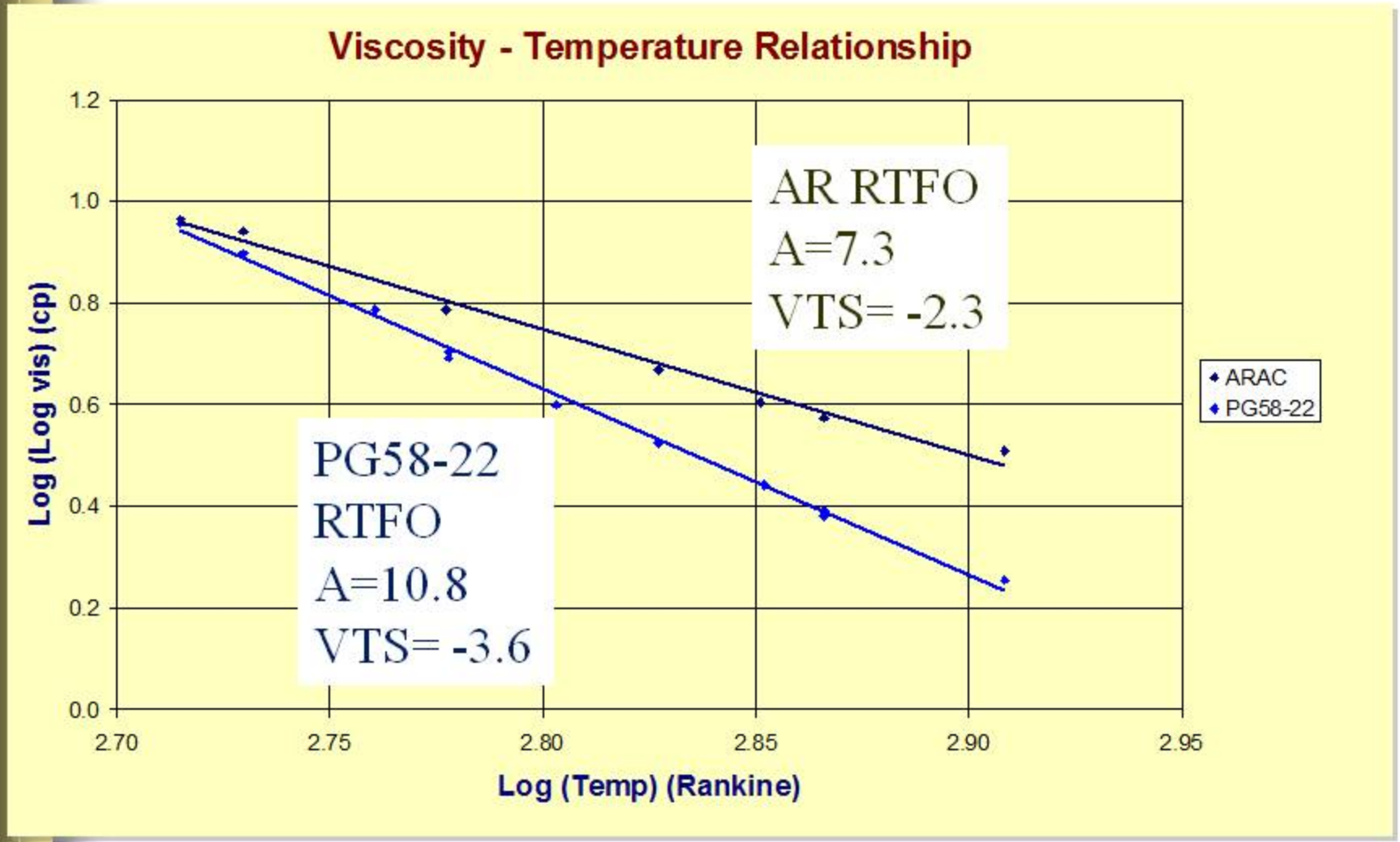
2000's Performance, Research, Environment & Costs




Percent Cracking
% Cracking
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Years
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Flush Coat
Seal Coat
0.5" OGFC
1 Inch HMA
2 Inch HMA
5 Inch HMA
AR SAM
ARFC and 1.7 Inch ARAC

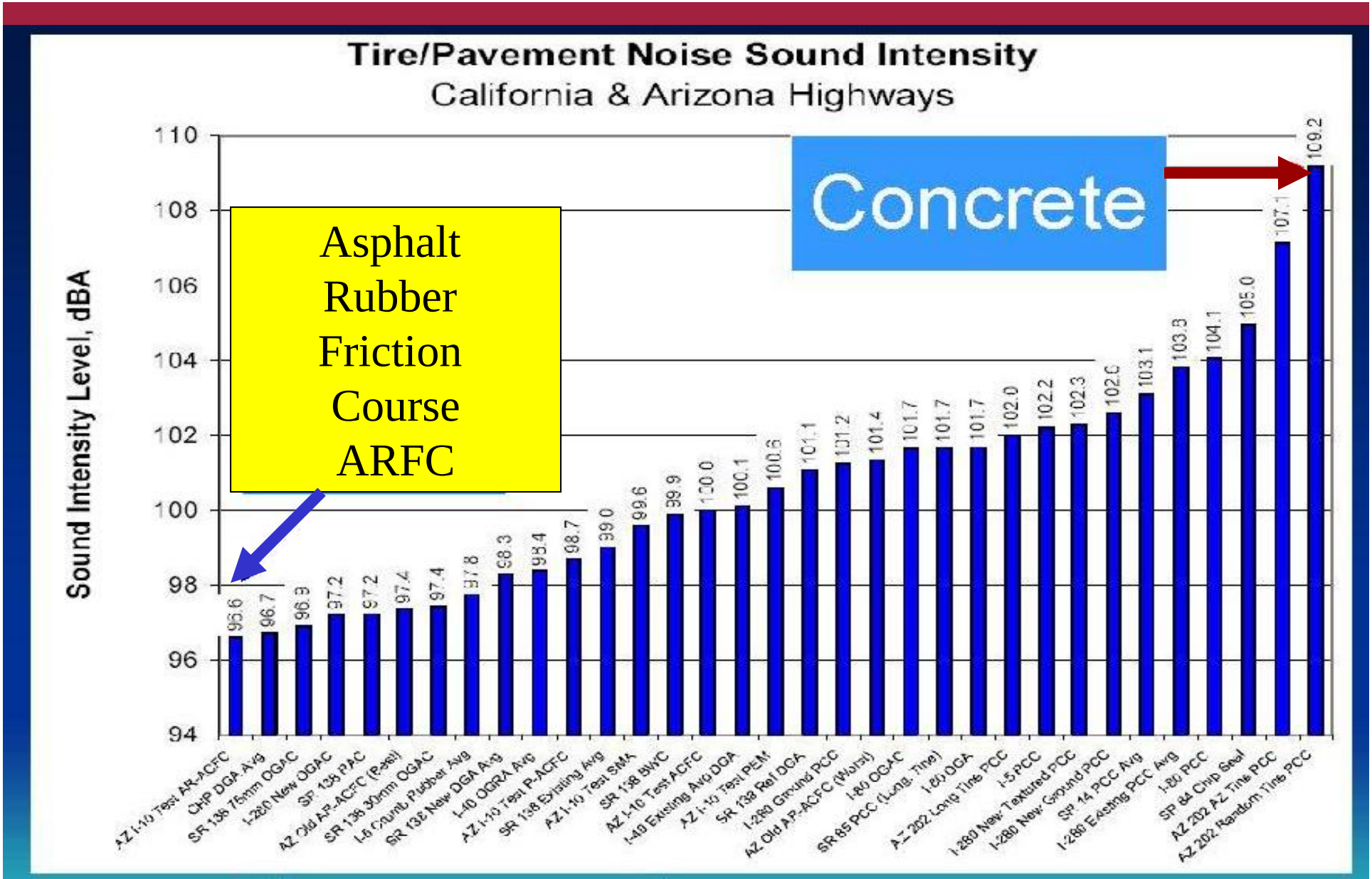

Maintenance Cost $/lane -Kilometer
$/Lane-mile
Maint. Cost
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
720
600
420
300
180
Dense Graded Hot Mix
Asphalt Rubber
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Age in Years

PG 58-22 With and Without Rubber



Binder Type	Original	Original	RTFO	RTFO
	A	VTS	A	VTS
PG 58-22 base asphalt	11.164	-3.764	11.076	-3.722
PG 58-22 after rubber added (AR)	8.3595	-2.726	8.0475	-2.598
AR binder equivalent A VTS like a PG 70-40	*8.129*	*-2.648*	*8.129*	*-2.648*
PG 64-16 base asphalt	11.163	-3.755	11.116	-3.728
PG 64-16 after rubber added (AR)	8.39	-2.738	8.543	-2.781
AR binder equivalent A VTS like a PG 76-34	*8.532*	*-2.785*	*8.532*	*-2.785*

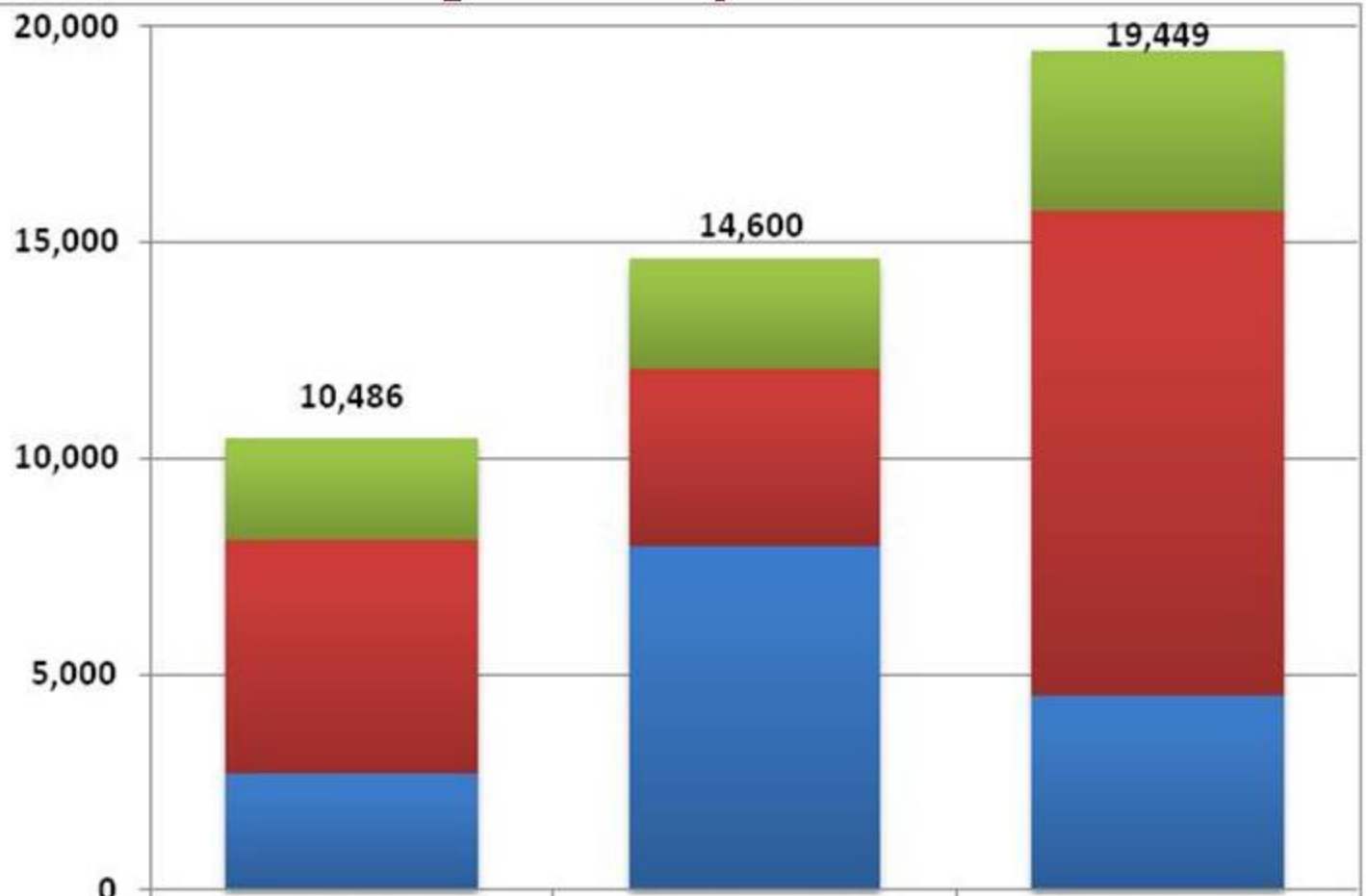
Location	Before Dba	After Dba	Difference Dba
Shoulder (15m)	79.8	72.6	7.2
Soundwall (30m)	76.6	67.1	9.5
Residential (120m)	51.7	45.6	6.1



Asphalt Rubber Open Graded
Quietest Surface


Overlay with
Asphalt Rubber
Concrete
Pavement
PLAZA

Total Annual kg CO2 Eq. / km

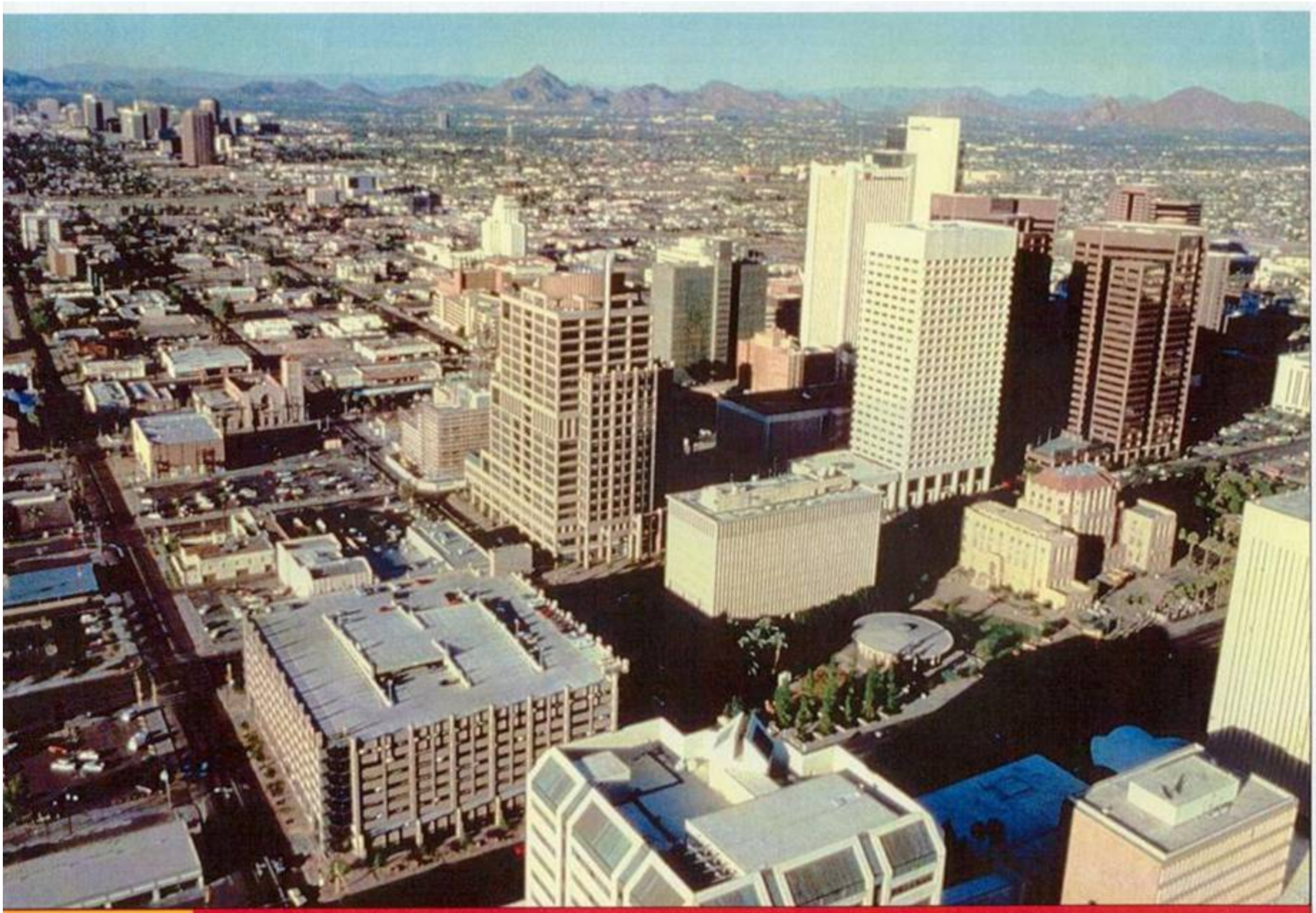


	AR 50mm, Base 150mm	UTW 50mm, HMA 50mm, Base 150mm	HMA 100mm, Base 150mm
Transportation kg An. CO2 Eq. / km	2,386	2,526	3,722
Mixing kg An. CO2 Eq. / km	5,381	4,124	11,210
Production kg An. CO2 Eq. / km	2,718	7,951	4,517

Recycling of Asphalt-Rubber Mix 2007

ARFC Hot Plant Recycled mix into I-19 Frontage Road

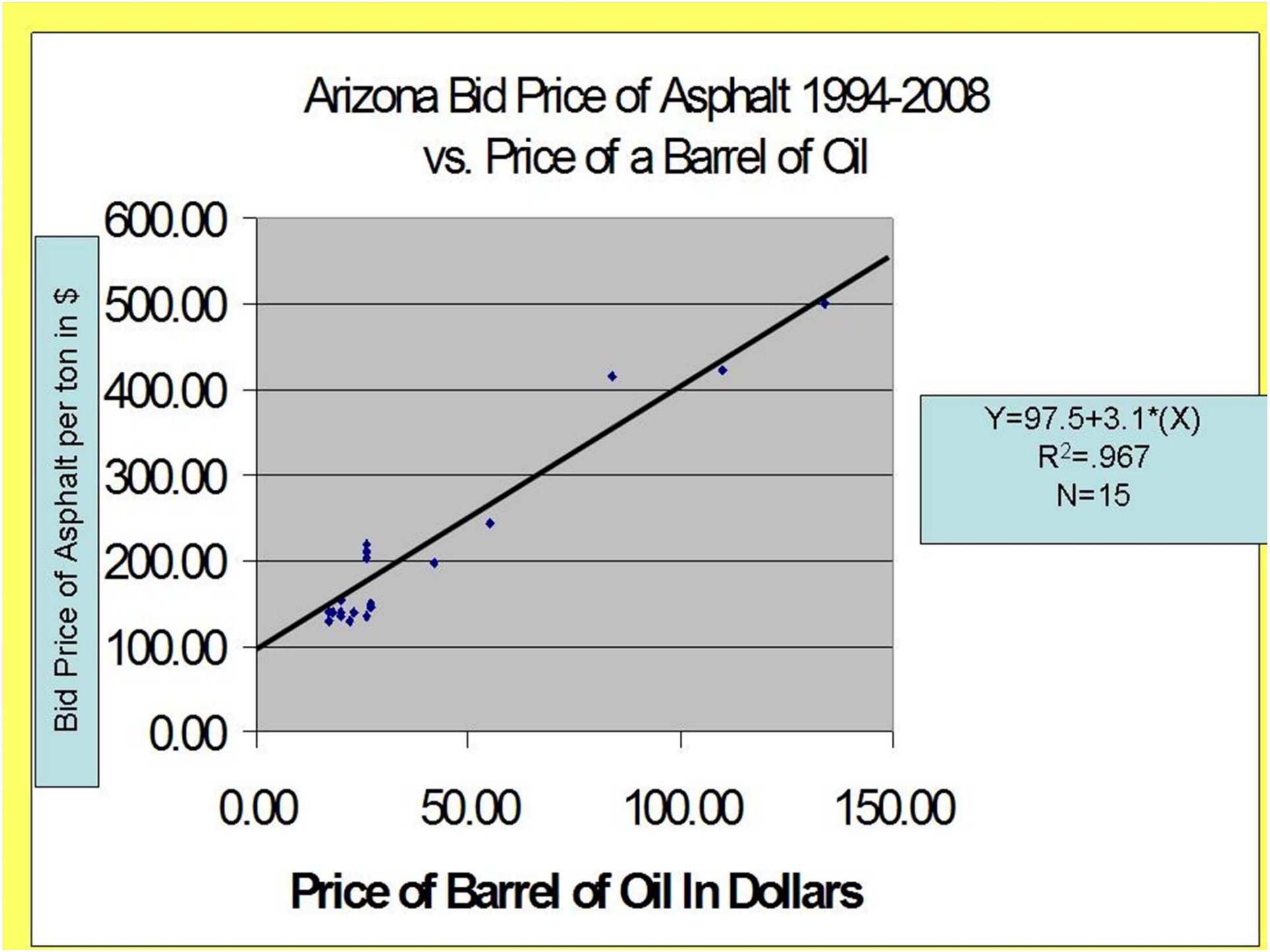
ARFC Recycled in Place on I-19, note Joint cracks



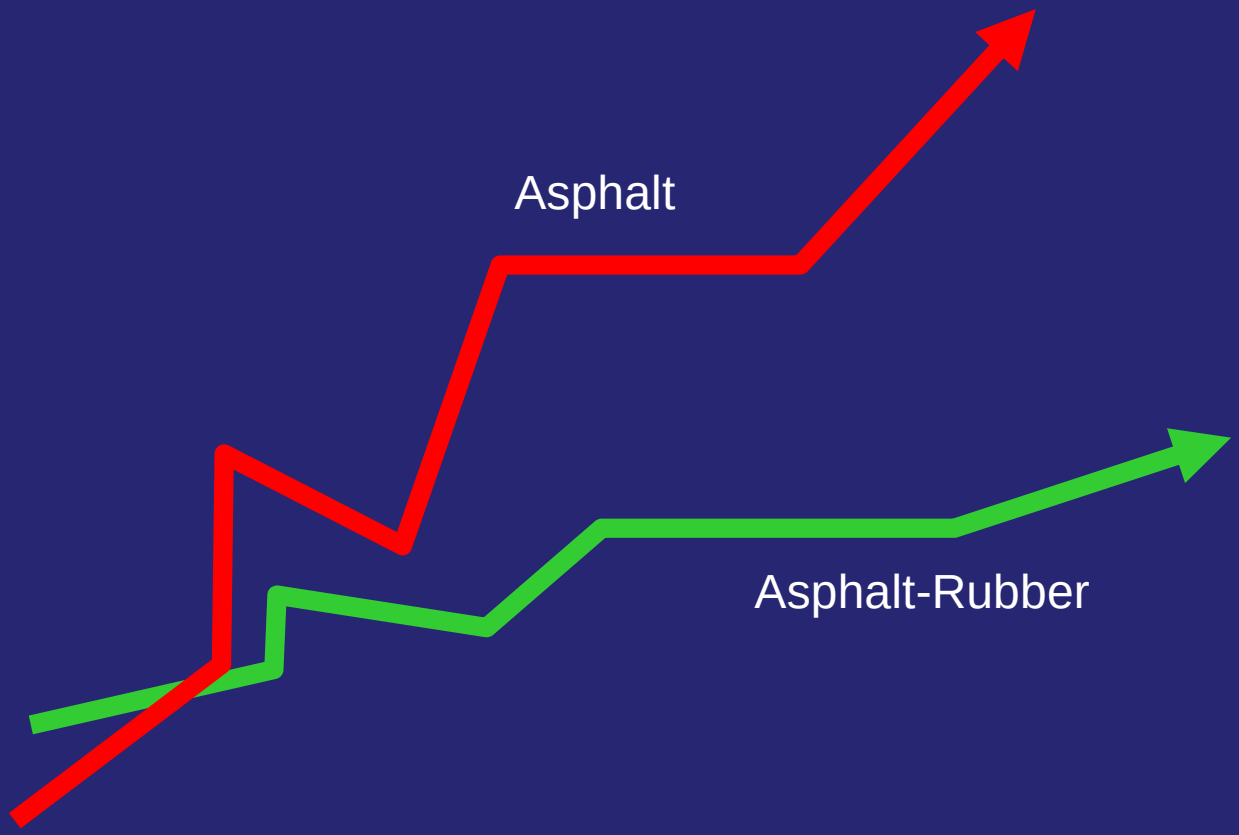
ASU
ARIZONA STATE UNIVERSITY

Phoenix
Arizona

Urban Heat Island Initiative for Material & Technology Innovations


Arizona Bid Price of Asphalt 1994-2008
vs. Price of a Barrel of Oil
Bid Price of Asphalt per ton in $
600.00
500.00
400.00
300.00
200.00
100.00
0.00
0.00
50.00
100.00
150.00
Price of Barrel of Oil In Dollars
Y=97.5+3.1*(X)
R2=.967
N=15

A 20% scrap tire rubber content is very attractive with the high cost of asphalt.



When in 2008 asphalt passed $300/ton, the raw material cost for A-R became less.

2010+ Market Changes, International

- Cost of Asphalt
- Cost of Polymer
- Availability of Polymer
- Tighter Highway Funding Budgets
- Pavement Preservation Needs
- Thinner Pavements and/or Surface Treatments
- Reasons to Consider Rubberized Asphalt with GTR

$ $ $ $ $ $ $ $ $ $ $

Asphalt-Rubber PG Binder Grading

Example satate PG grading asphalt with crumb rubber - Louisiana – PG 82-22rm

- Wet Process
  - Asphalt Rubber (15% + Rubber and Other Additives Optional)
  - GTR Modified with Suspending Agent or other additives (30 mesh rubber, 8-12% content)
  - Terminal blend (dissolved rubber, a recycled polymer modified asphalt)
    - AC-20-5TR
    - MAC-10TR
    - PG 76-22TR

NCAT GTR Performance Grade Study

- 11 rubber sizes and sources
- 10% Rubber Content
  - One binder had 15%
- PG 67-22 Base Binder
- Graded by Following AASHTO specification
- 1 mm gap on DSR
  - Only one had particulate where 2 mm gap is needed
- Binders will be put into OGFC mixes and tested

GTR Source	Original DSR	RTFO DSR	PAV DSR	BBR – S	BBR – m	True Grade
1	83.6	87.0	17.1	-34.8	-24.9	83.6 – 24.9
2	72.8	77.8	19.4	-31.2	-25.1	72.8 – 25.1
3	80.4	88.0	15.6	-36.1	-24.2	80.4 – 24.2
4	79.0	86.7	17.1	-35.6	-23.0	79.0 – 23.0
5	77.9	82.0	17.6	-35.8	-25.6	77.9 – 25.6
6	80.7	85.6	17.7	-34.5	-23.6	80.7 – 23.6

Asphalt-Rubber PG Binder Grading

AASHTO States balloting on PG grading asphalt with crumb rubber, 2 mm DSR gap

In addition Binder ETG developing a new DSR Geometry for AR Testing

Asphalt-Rubber PG Binder Grading

New DSR Geometry for AR Cup and Bob

Shear Stress and Strain

$$\tau = \frac{T}{2\pi L R^2}$$

$$\gamma = \frac{\theta R_e}{(R - R_e)}$$

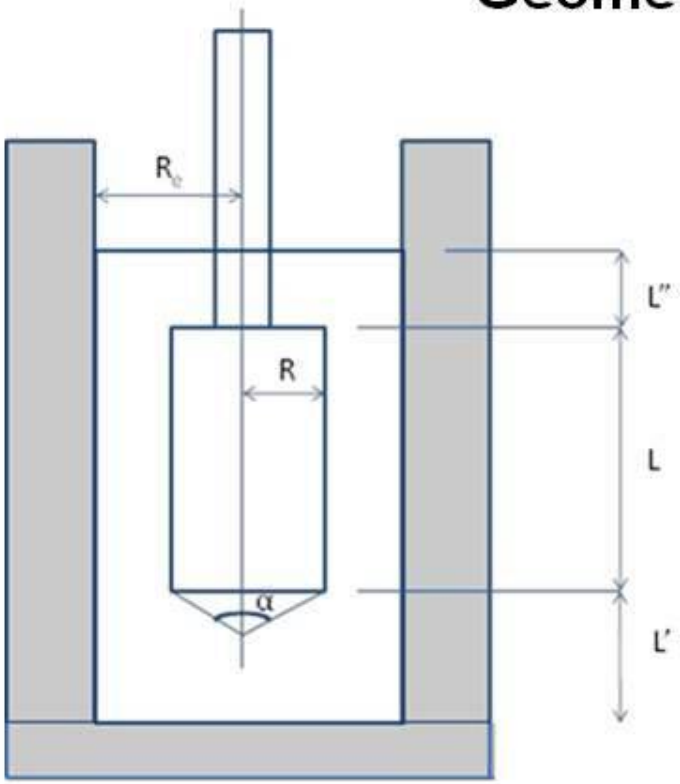
T= torque

R_e= radius of the cup

R= radius of the bob

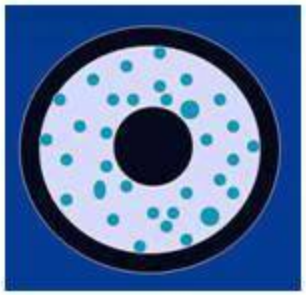
Θ= angular rotation of the bob

DSR Cup and Bob Geometry



DSR Geometries

- Parallel plate to plate
  - Plate Diameter: 12.5 mm
  - Gap: 1 mm or 2 mm
- Cup and bob
  - Cup diameter: 27.5 mm
  - Bob diameter: 14 mm
  - Effective gap: 6.75 mm



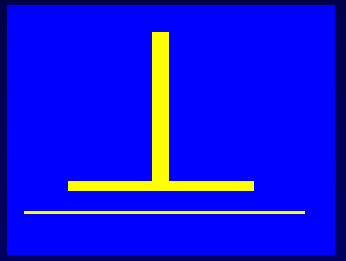
4 mm Gap Trial

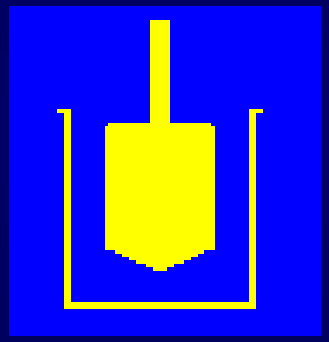
Objective

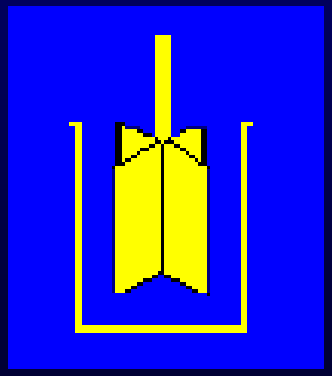
- Identify suitable testing methods for GTR under the Superpave procedures
  - Using smooth parallel plates for testing
- Concerns
  - Large gap requirements due to large particle size
  - Trimming of parallel plates
  - Sedimentation of particulates
  - Deformation of Asphalt at geometry surface, rather than entire volume of GTR sample

Geometries Used

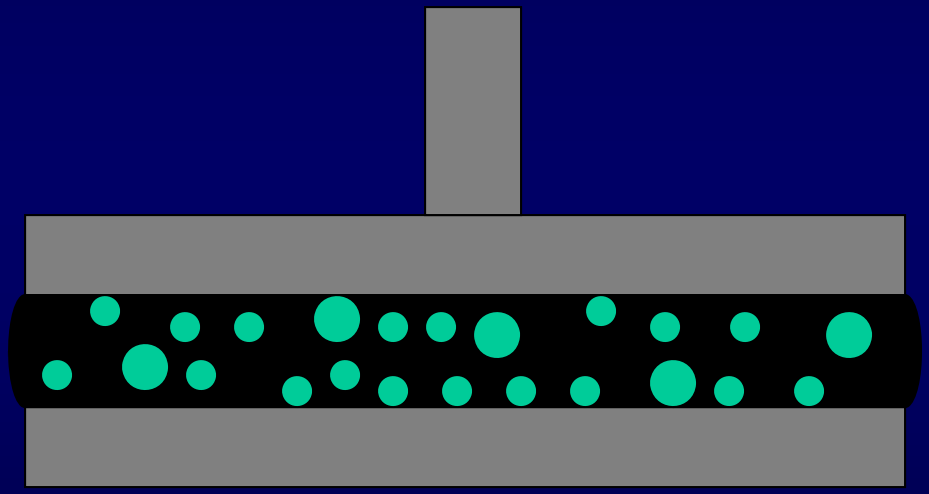
- Parallel Plate
  - Plate Diameter: 12.5 mm
  - Gap: 1 mm
- Couette Set (Cup and Bob)
  - Cup Diameter: 27.5 mm
  - Bob Diameter: 14 mm
  - Effective Gap: 6.75 mm
- Vane 14mm Set (Cup and Vane)
  - Cup Diameter: 27.5 mm
  - Vane Diameter: 14 mm
  - Effective Gap: 6.75 mm



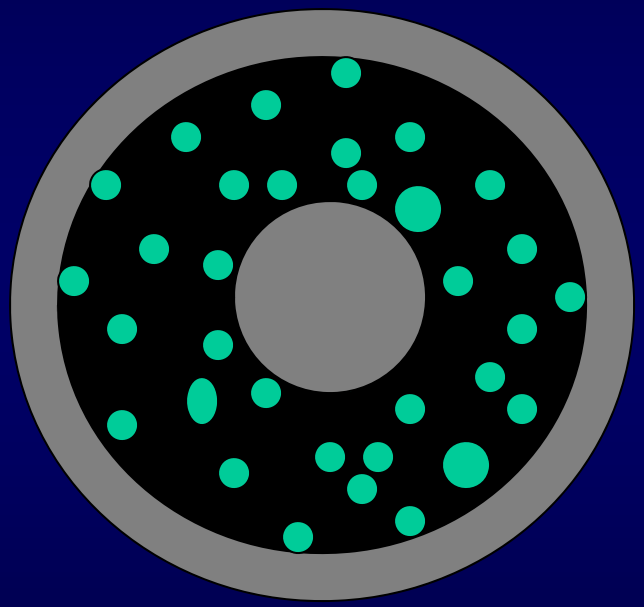




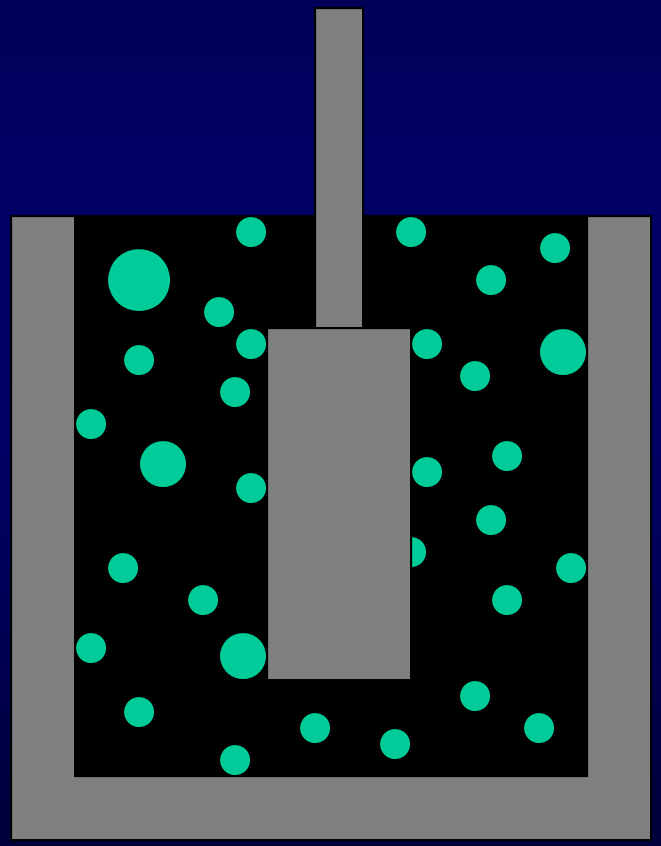
Parallel Plate



Cup & Bob



Top View



New Geometry Evaluation

- Preliminary testing indicates that new geometry may give similar results.
- More extensive evaluation is needed to fully validate geometries.
  - Multiple grade binders
  - Full PG grading and MSCR

Rubber Grading Experiment for Cup and Bob

Binders
64-22, 76-22, 70-22PPA
Full PG grading and MSCR; PP1, PP2, CB
64-22, 30 mesh rubber 10%, 15%
Full PG grading and MSCR; PP2, CB
64-22, 20 mesh rubber 15%, 20%
Full PG grading and MSCR, CB
64-22 60 mesh rubber 10%, 15%
Full PG grading and MSCR, PP1, PP2, CB
ALF AC rubber
Full PG grading and MSCR, CB
ALF Terminal blend
Full PG grading and MSCR, PP1, CB

Asphalt-Rubber PG Binder Grading

How to handle larger CRM

- 60 mesh material is easily handled in 1 mm gap.
- 30 mesh material handled in 2 mm gap.
- 20 mesh material may require 4 mm gaps.
- What is the limit of gap size?
- Are other geometries available to test larger particles?

Future Rubberized Asphalt PG Grading

PG grade all recycled tire rubber (RTR) asphalt binders; Percentage (5%) to percentage (22%)

Hybrid – RTR and polymer

RTR in all mixes, Dense graded, Gap Graded, SMA and Open Graded

Greater use of RTR in seal coats

Recognition that RTR in asphalt is a green product that saves energy and is good for the environment and very cost competitive

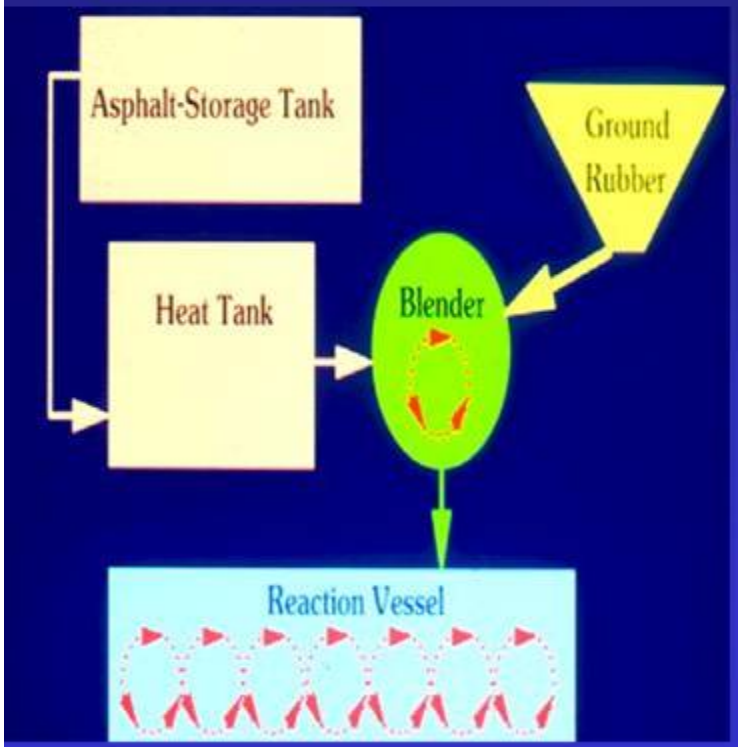
WMA ARAC California Example

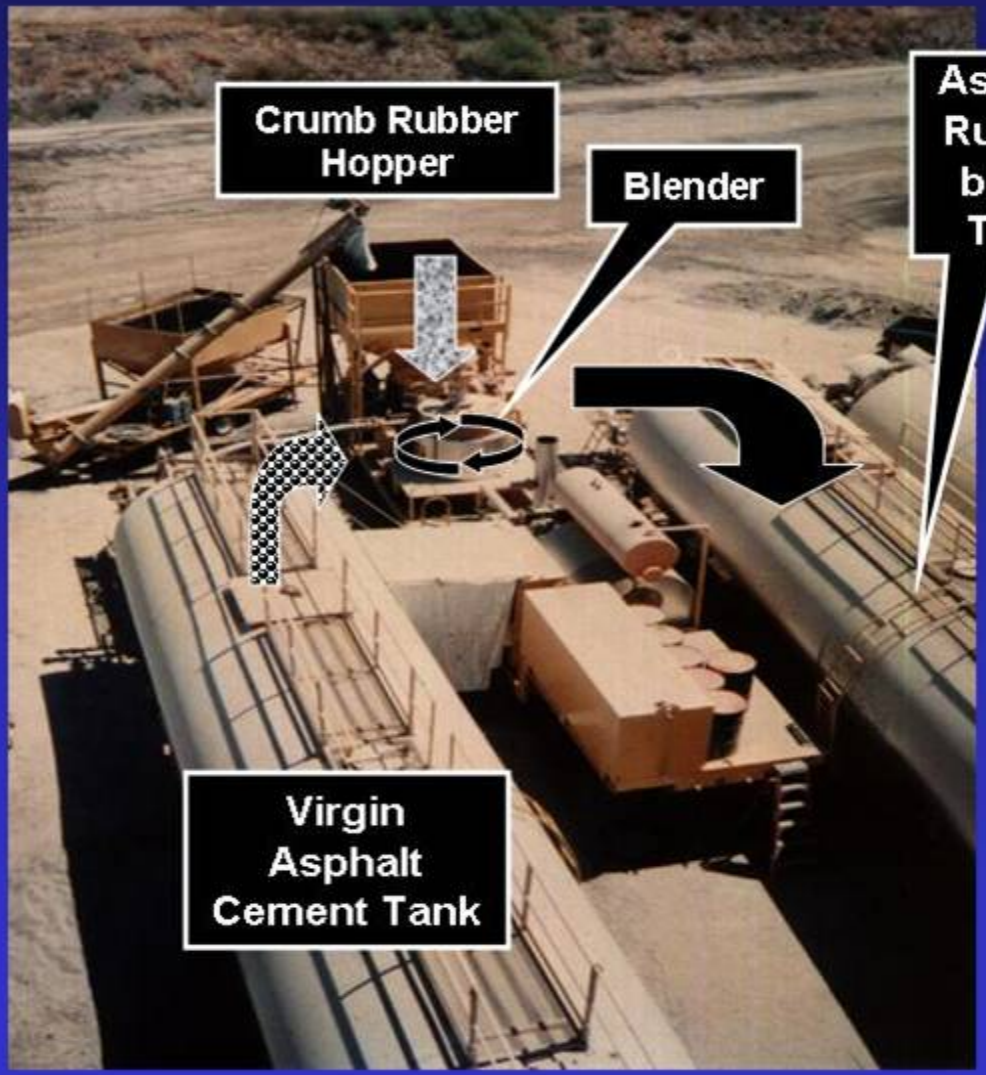
ARAC Prod/Place/Comp

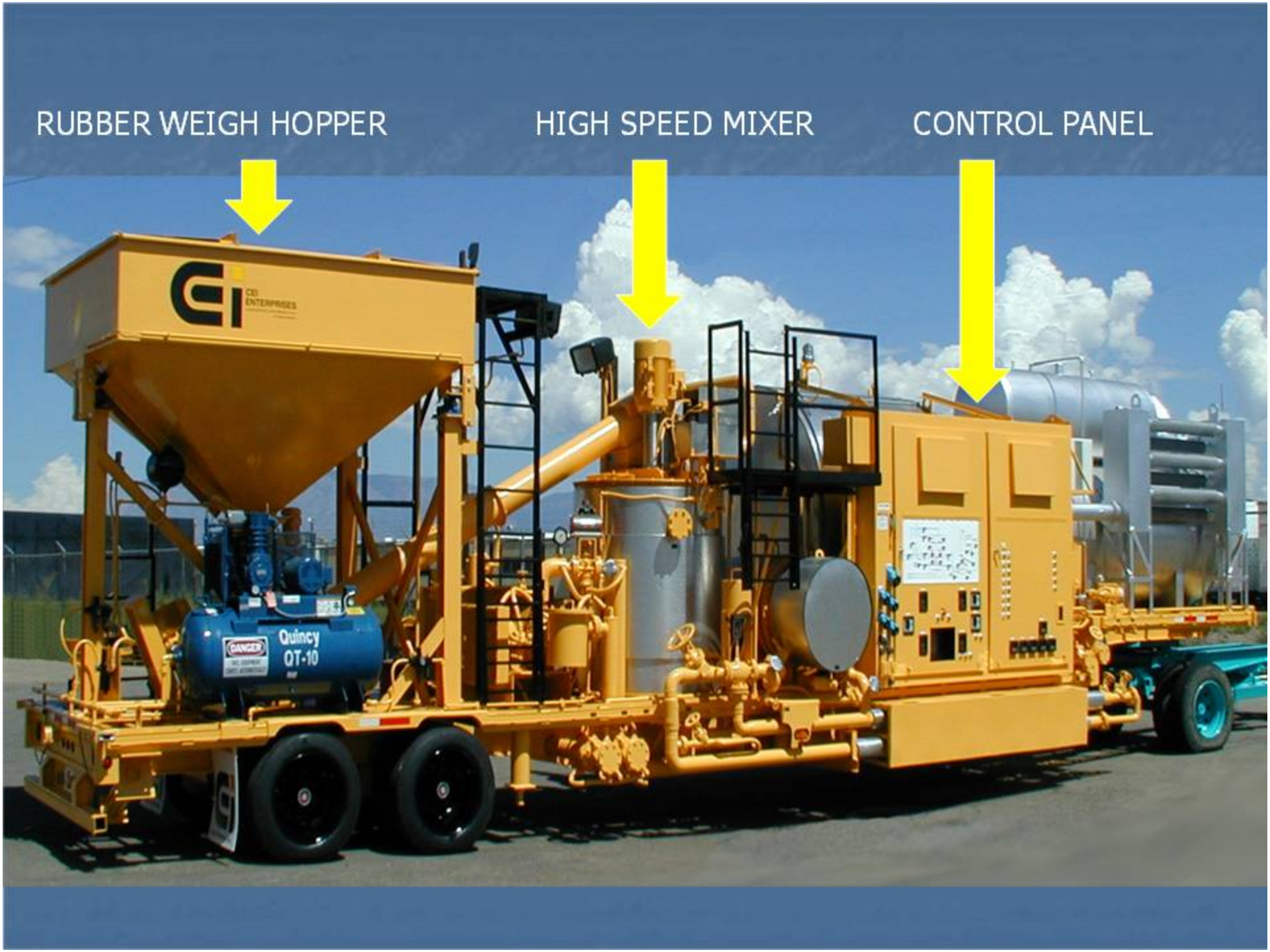
	Plant Mix Temp	Mix Behind Paver	Comp. Temp.
ARAC	163 °C	143/154°C	149/135°C
Astec W-ARAC	133/143°C	121/132°C	132/110°C
Astec/Evo W-ARAC	132 °C	116/121°C	127/104°C

Crumb Rubber Process

Once blended, the Asphalt-Rubber binder is heated, mixed and agitated in the blend tank from 45 to 60 minutes as specified by the agency.






RUBBER WEIGH HOPPER
HIGH SPEED MIXER
CONTROL PANEL
CEI ENTERPRISES
DANGER
Quincy
QT-10


CAT

States Where Tire Rubber is Used in Asphalt (DOT Spec or Special Provision)

Arizona Asphalt Rubber Benefits

Less Reflective Cracking
Less Maintenance/More Durable
Less Raveling
Good Rut Resistance
Good Skid Resistance
Smooth Ride
Good in hot & cold climates
Less Splash & Spray Better Drainage
Less Noise
Cost Effective
Engineering Use for Old Tires

Environmentally
Friendly

Asphalt Rubber a New Direction

Thank You!

www.rubberpavements.org

www.RA-Foundation.org