Good Performing RAP/RAS mixes

Brian Prowell, PhD, PE

1997 Virginia Asphalt Association Survey: What determines % of RAP used?

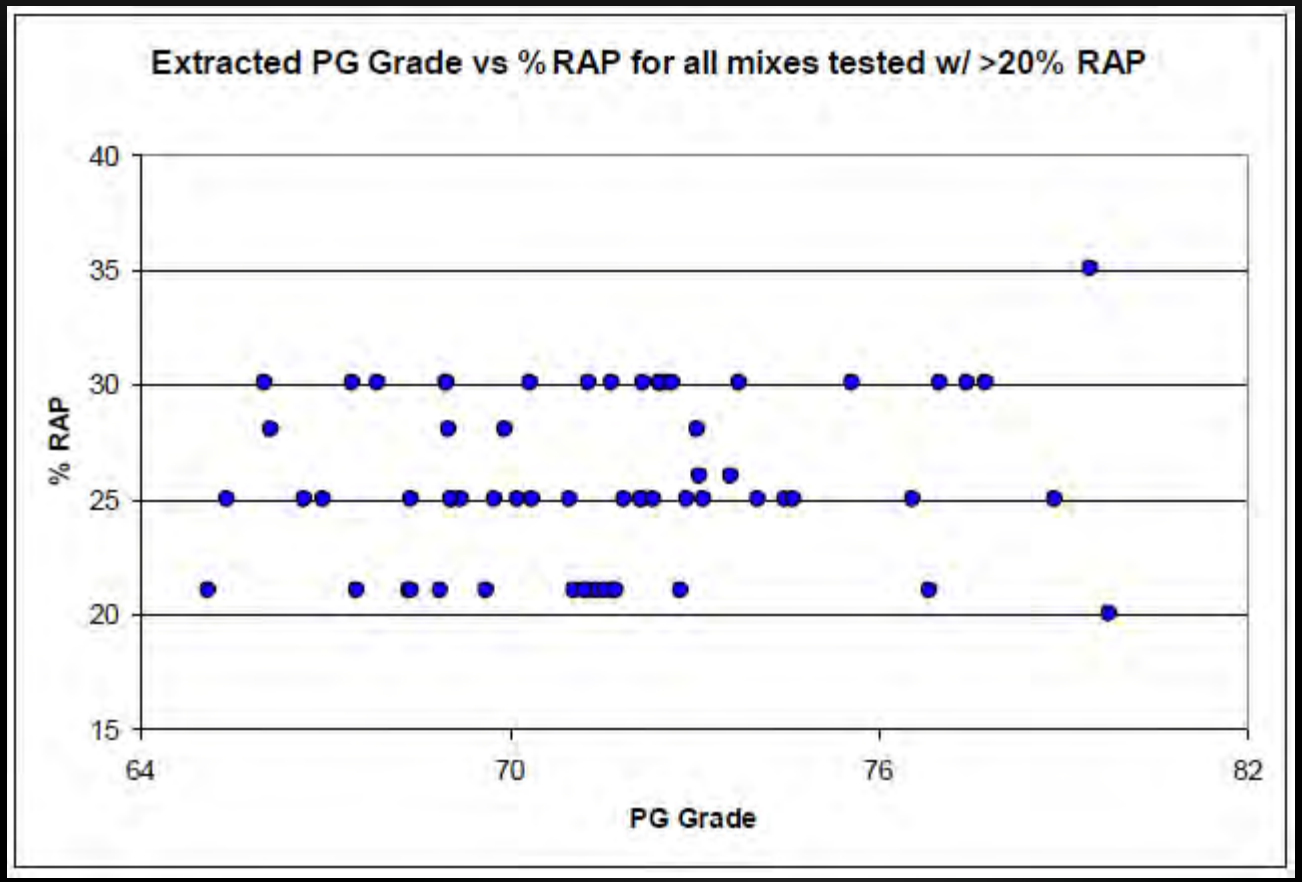
- **10%** of producers said specification limits set by VDOT (20% surface, 25% base).
- **34%** of producers said they used maximum permitted without changing binder grade.
- **58%** of producers said their RAP dust content (-200's) determined their RAP use.

C/o Richard Schreck

Superpave Implementation era FHWA Mix ETG Recommendations

- Up to 15% RAP
  - use specified grade
  - use G_{sb} of virgin material
- 15%-25% RAP
  - use one full grade lower, e.g., a PG 64-28 instead of a PG 70-22
  - estimate G_{sb} from G_{se} with 0.5% absorption
- Over 25% RAP
  - use blending charts to determine required grade
  - estimate G_{sb} from G_{se} with 0.5% absorption

TRUE GRADE OF RECOVERED RAP MIX BINDER



33/56 (59%) Mixes Graded Failed to Meet PG 70!

Abson Recovery Samples PG 64-22 Virgin AC

Percent RAP		15%	20%	35%
S @ -12°	Avg	138	147	181
	Std	32	22	14
M @ -12°	Avg	0.333	0.309	0.303
	Std	0.028	0.014	0.009

VTRC 2001

Why use a softer asphalt?

- Prevent thermal cracking?
- An attempt to improve the mixes' cracking resistance?
- PG fatigue parameter affected by high and low temperature grade?
- Consider blending and or rejuvenators to produce/mimic softer binders

ALDOT RAP/RAS Specifications

ALLOWABLE USE OF RAP AND RAS Maximum Allowable Percent of RAP and RAS in Total Aggregate Content		
Type of Mix	Maximum RAP Content #	Maximum RAP and RAS Content ** #
327, Plant Mix Bituminous Base	25 %	25 %
327-E, Permeable Asphalt Treated Base	10 %	RAS Not Allowed
420, Open Graded Friction Course	10 % RAP shall not contain chert	RAS Not Allowed
423, Stone Matrix Asphalt 424, Superpave	Surface Layers: 20 % with no more than 15 % containing chert *; All Other Layers: 25 %	Surface Layers: 20 % *; All Other Layers: 25 %

* This limitation applies even if the surface layer is to be covered by an Open Graded Friction Course. If the aggregate is chert gravel with a bulk specific gravity that is less than 2.550, a maximum of 15 % of the RAP will be allowed. RAP containing chert gravel shall be crushed so that 100 % of the RAP passes the 1/2 inch {12.5 mm} sieve. Additional RAP that does not contain chert gravel may be added to the mixture through a separate feeder.

** RAS shall be limited to 3 % of the total aggregate content when the RAS is consumer waste (from roofing materials) and shall be limited to 5 % of the total aggregate content when the RAS is manufacturing waste.

The Engineer will consider allowing the RAP and RAS content to be greater than 25 % if requested by the Contractor with the submittal of the required testing of the proposed mix.

ALDOT RAP/RAS

- Contractor may propose > 25% RAP or up to a maximum of 35% RAP/RAS for intermediate and base layers
- Adds:
  - Thin-film oven
  - DSR
  - Absolute viscosity requirements

ALDOT Section 424 Binder Requirements

ALLOWABLE ASPHALT BINDER GRADES FOR SUPERPAVE			
ESAL Range	Traffic (ESALs)	Base & Lower Binder Layers	Upper Binder & Wearing Surface Layers
A/B	ESALs $< 1.0 \times 10^6$	PG 67-22	PG 67-22
C/D	$1.0 \times 10^6 \leq$ ESALs $< 1.0 \times 10^7$	PG 67-22	PG 67-22
E	$1.0 \times 10^7 \leq$ ESALs $< 3.0 \times 10^7$	PG 67-22	PG 76-22*

* The asphalt binder shall be 76-22 for leveling when the top of the leveling is within 4 inches {100 mm} of the final pavement surface. The asphalt binder may be PG 67-22 for leveling that is not within 4 inches {100 mm} of the final pavement surface and for all patching and widening. If Open Graded Friction Course (Section 420) layers are required, the final pavement surface shall be the surface of the layer below these layers.

Asphalt Binders shall meet the requirements of Section 804.

VDOT's Binder Specifications

An equivalent single-axle load (ESAL) will be established by the Engineer, and SUPERPAVE mix types may be specified as one of the types listed as follows:

Mix Type	Equivalent Single-Axle Load (ESAL) Range (millions)	Minimum Asphalt Performance Grade (PG)[2]	Aggregate Nominal Maximum Size[1]
SM-9.0A	0 to 3	64-16	3/8 in
SM-9.0D	3 to 10	70-16	3/8 in
SM-9.0E	Above 10	76-22	3/8 in
SM-9.5A	0 to 3	64-16	3/8 in
SM-9.5D	3 to 10	70-16	3/8 in
SM-9.5E	Above 10	76-22	3/8 in
SM-12.5A	0 to 3	64-16	1/2 in
SM-12.5D	3 to 10	70-16	1/2 in
SM-12.5E	Above 10	76-22	1/2 in
IM-19.0A	Less than 10	64-16	3/4 in
IM-19.0D	10 to 20	70-16	3/4 in
IM-19.0E	20 and above	76-22	3/4 in
BM-25.0A	All ranges	64-16	1 in
BM-25.0D	Above 10	70-16	1 in

[1]**Nominal Maximum Size** is defined as one sieve size larger than the first sieve to retain more than 10 percent aggregate.

[2]**Minimum Asphalt Performance Grade (PG)** is defined as the minimum binder performance grade for the job mixes as determined by AASHTO T170 or AASHTO M320.

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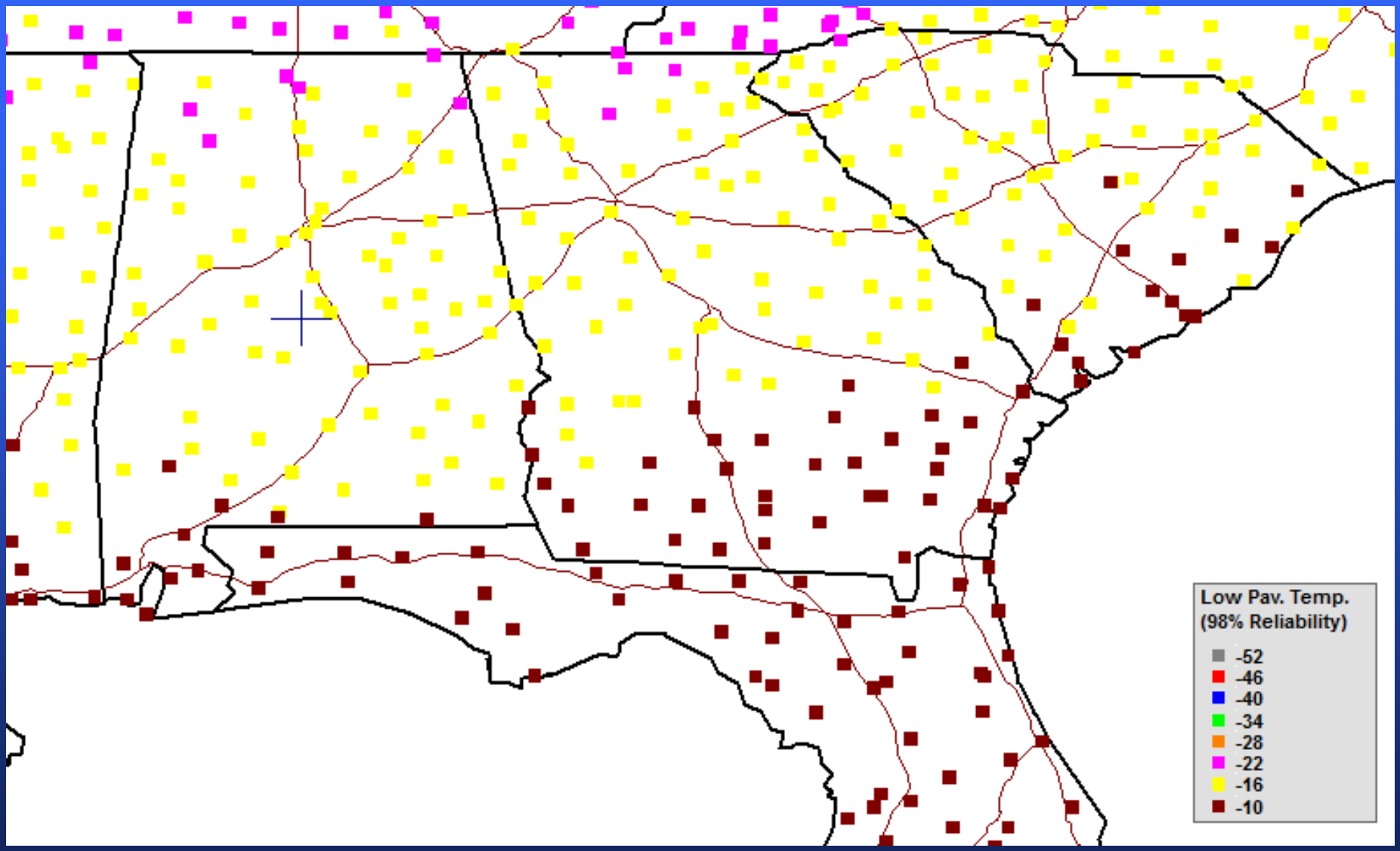
Low Pav. Temp.
(98% Reliability)
-52
-46
-40
-34
-28
-22
-16
-10

Binder Blending Calculations

- Samples, extract, recover, and grade RAP/RAS
- Determine critical failure temperature
- Obtain binder grading data for virgin binder
- Determine allowable RAP

Example

Sample ID		Plant Mix	+4 RAP	-4 RAP	RAS
Continuous PG Grade		71.6-25.6	84.7-20.7	94.3-18.7	238.4-+29.5
Full PG Grade		70-22	82-16	94-16	234-+32
Original Binder Tests					
Dynamic Shear Rheometer	AASHTO T315				
	Continuous PG	71.6	84.7	94.3	238.4
	Temp Pass	70	82	88	112
Phase Angle, degrees		81.6	78.6	77.5	39.5
G* @ 10 rad/sec, kPa		2.63	2.99	4.26	272
G*/sin delta @ 10 rad/sec, kPa		2.66	3.05	4.34	428
	Temp Fail	76	88	94	118*
Phase Angle, degrees		83.7	81.5	80.0	39.8
G* @ 10 rad/sec, kPa		1.32	1.47	2.23	205
G*/sin delta @ 10 rad/sec, kPa		1.33	1.48	2.27	321

Sample ID	-4 RAP	RAS
Continuous PG Grade	94.3-18.7	238.4-+29.5
Full PG Grade	94-16	234-+32
Bending Beam Rheomete		
	-6	18**
s, 60s, Mpa	92	95.6
m-value, 60s	0.360	0.239
	-12	24
s, 60s, Mpa	601	69.8
m-value, 60s	0.225	0.256
*: Temp Pass, **: Temp Fail		

Blending AASHTO M323

$$\%RAP = \frac{T_{Blend} - T_{Virgin}}{T_{RAP} - T_{Virgin}}$$

where,

T_{virgin} = critical failure temperature of virgin binder (high, intermediate, or low)

T_{blend} = critical failure temperature of virgin binder (high, intermediate, or low)

T_{RAP} = critical failure temperature of virgin binder (high, intermediate, or low)

$$\%RAP = \frac{70 - 64}{84.7 - 64} \times 100 = 29.0\%$$ minimum

If you soften the binder, but the mix still has poor intermediate cracking resistance, what else can you do to improve cracking?

Examine “effective” asphalt from recycled material

Look at Effective Binder Contribution

- AASHTO PP53 procedure to determine % binder contribution from RAS – typically 65-80%
- Determine optimum AC% with RAS
- Determine Opt. AC% of same gradation without RAS (extract RAS)
- Consider testing plant mix.

Example with RAP

Mix	AC%	Gmb	Gmm	Voids, %	VMA, %
LMLC w/ Extracted RAP	4.67	2.382	2.472	3.7	14.4
	5.17	2.412	2.454	1.7	13.7
LMLC w/ RAP	4.67	2.402	2.466	2.6	13.6
PMLC	4.75	2.397	2.477	3.2	13.9

LMLC without RAP: 4.8% AC = 3.2% voids
Therefore, RAP provides 100% binder contribution

How to deal with less than 100% binder contribution?

City of Overland Park, KS

RAP %	Mix Design Voids, %	Production Voids, %	VEA, % Min.
0	4.0	3.0-5.0	10.0
5-25	3.7	2.8-4.5	10.3
26-40	3.4	2.6-4.1	10.6

VEA = Volume of Effective Asphalt = VMA-Air Voids

N_{design} = 60 gyrations

Based on work by Allen Cooley, Jr., BCD

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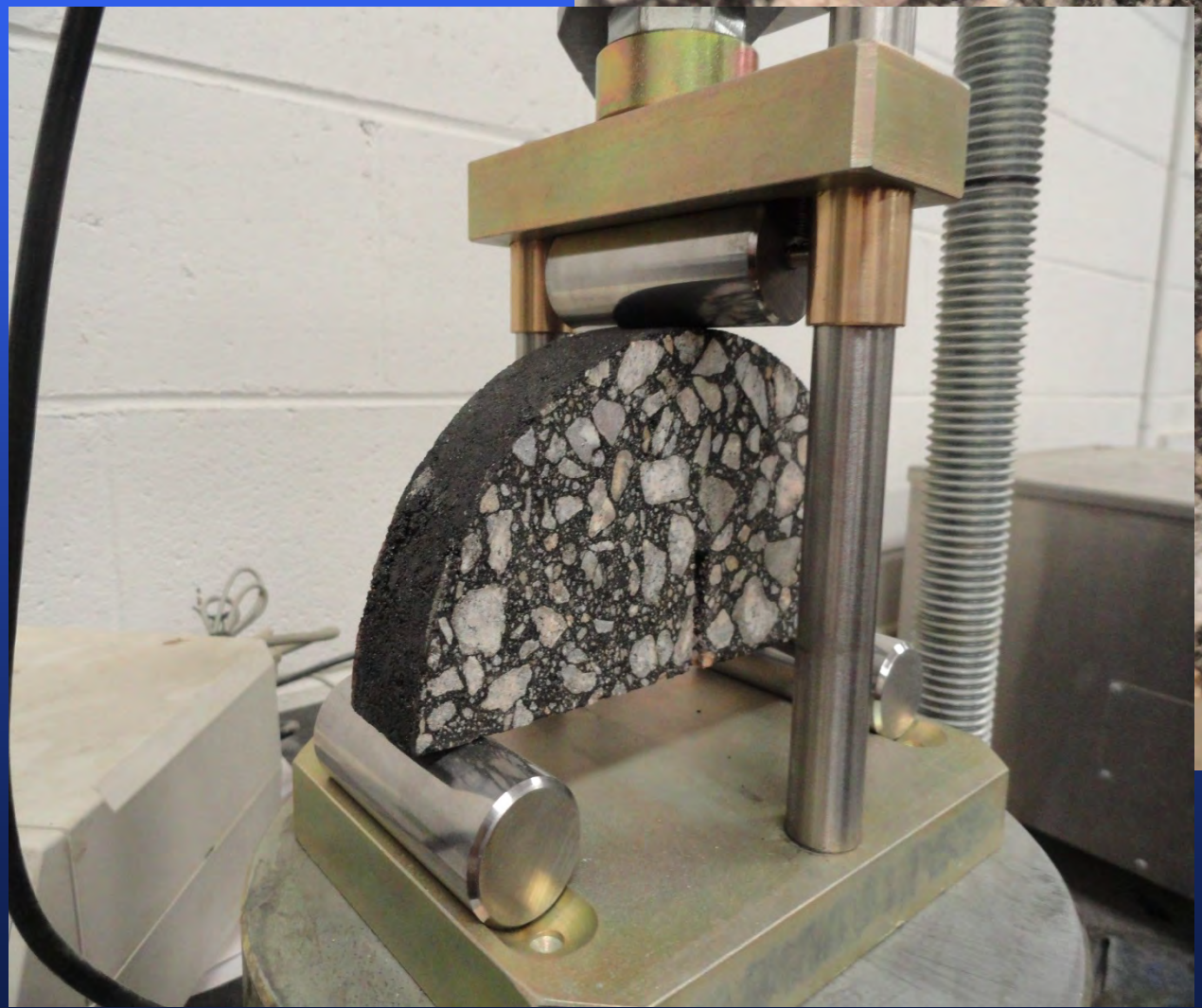
TX Overlay Example – 20% RAP/5% RAS

AC%	Voids	VEA	Cycles to Failure
4.4	4.0	8.6	N/T
5.2	1.9	10.5	8
5.5	0.9	11.3	195

Alternate Intermediate Cracking Test – Semi-Circular Bending (SCB) Test

- TX Overlay can produce very low cycles to failure – hard to compare rejuvenators
- SCB can be run with simple load frame (variable speed screw drive Marshall press)
- Performed at 77F
- Determine J-integral – fundamental measure of cracking

SCB Test Measures Fracture Toughness



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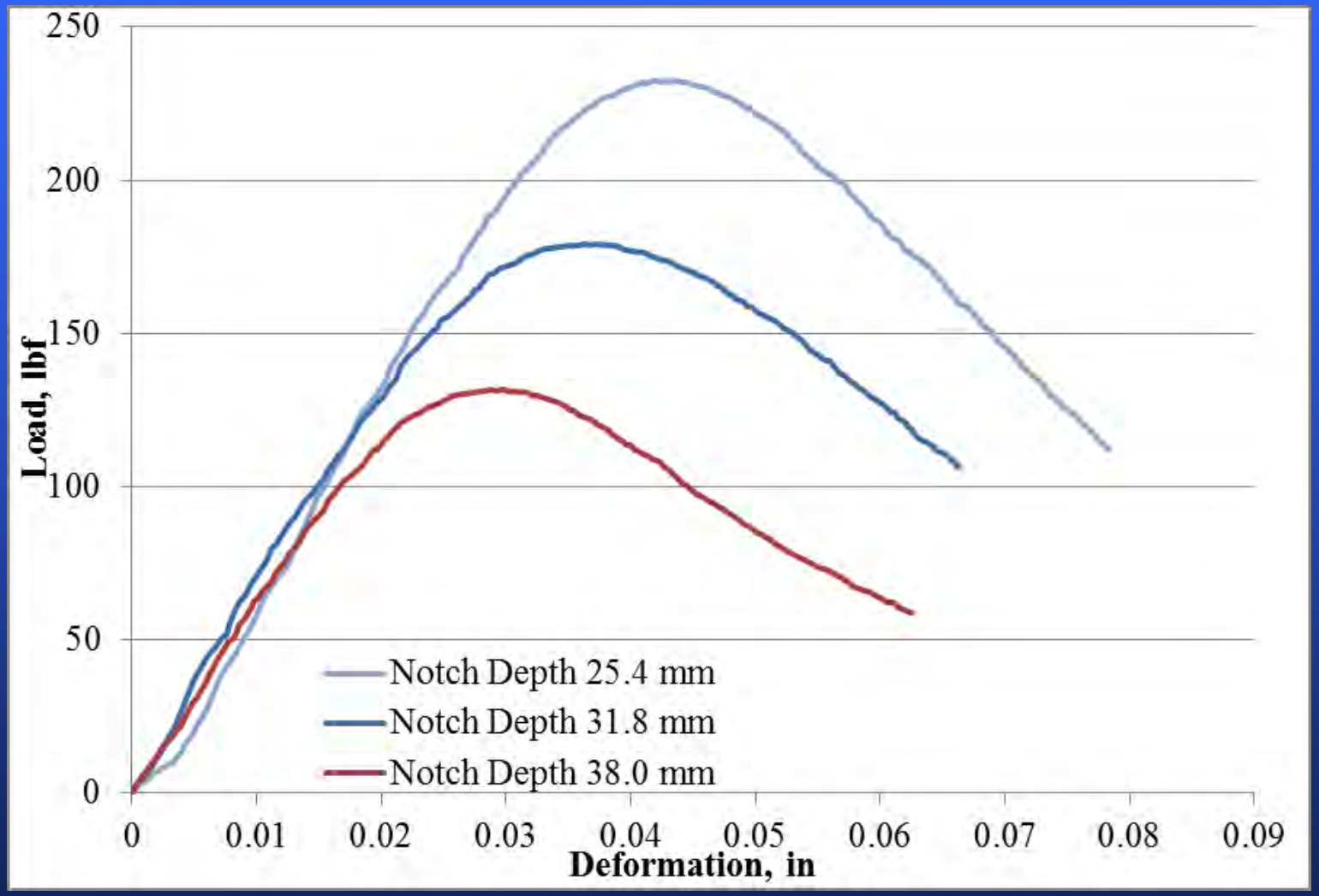
Example SCB Data



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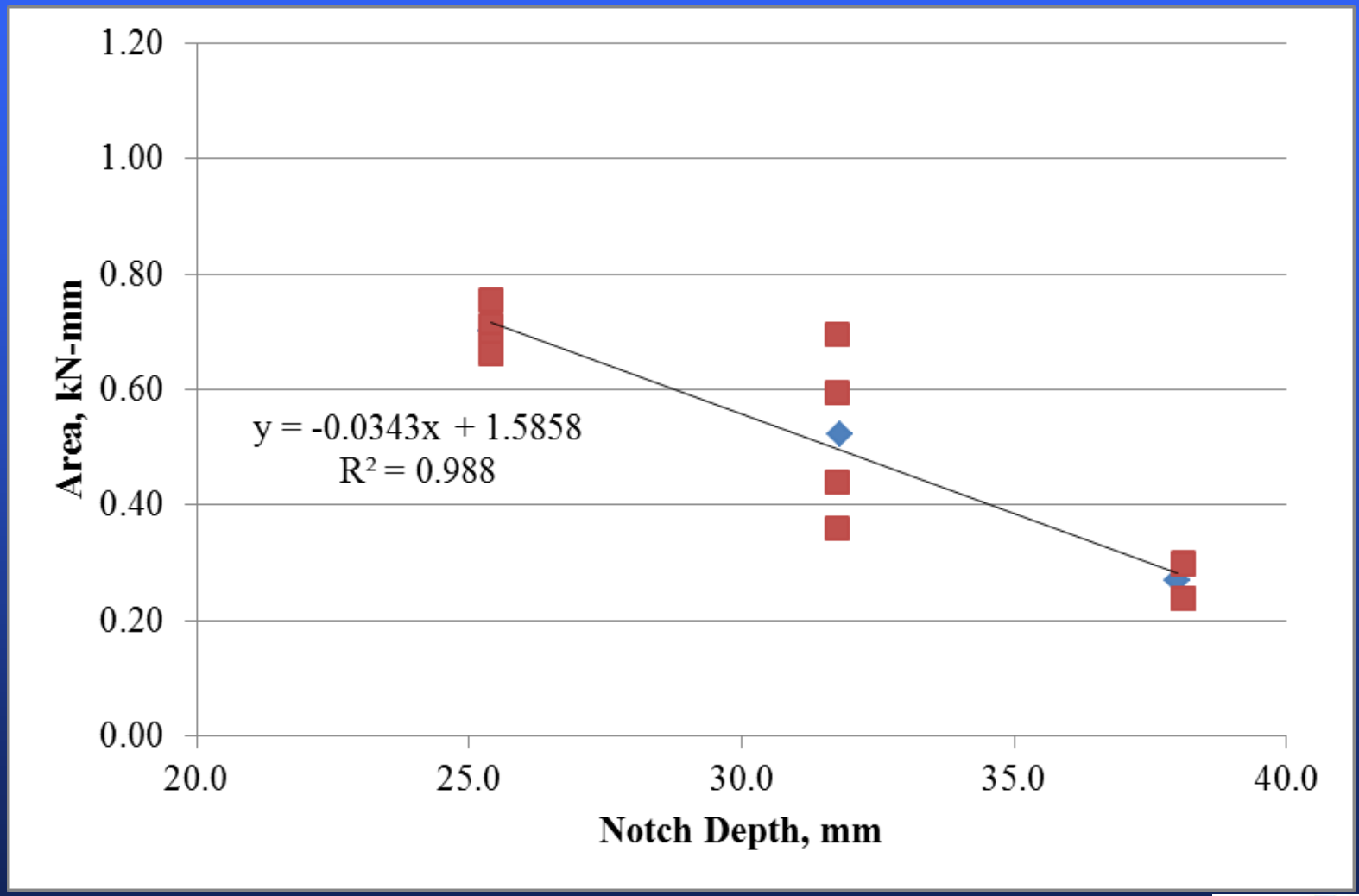
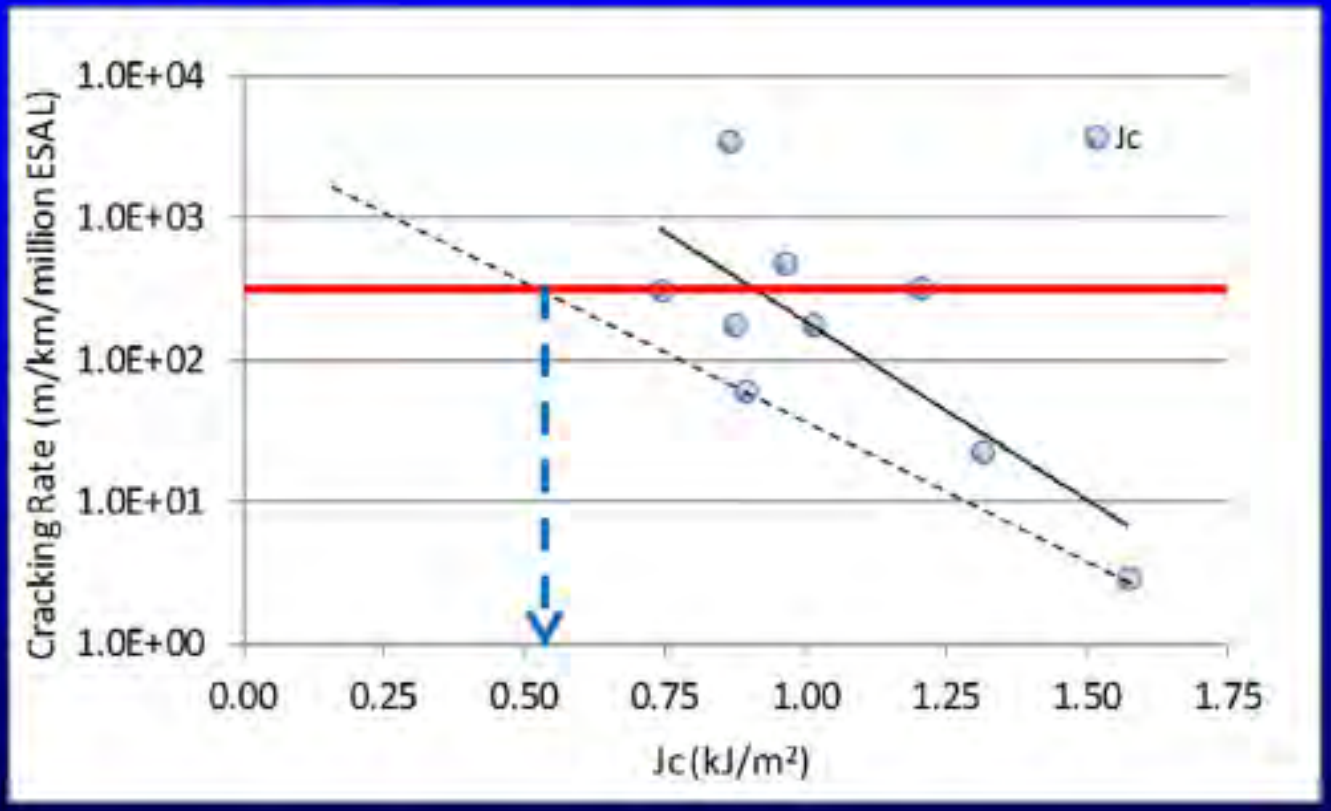
Examples SCB Data – Slope used to calculate J-integral



Proposed LA Criteria

Development of a Laboratory Criteria



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Example Data

Mix	RAP/RAS	Jc kJ/m
15% RAP FM	15/0	0.59
15% RAP FM w/ Additive 3	15/0	0.60
25% Fractionated RAP Cores	25/0	0.75
LMLC Extracted RAP	0/0	0.60
64-22 w/ 1% Additive	25/5	0.49
76-22 AR Terminal Blend	25/5	0.56
64-22 GTR+	25/5	0.39
PG 58-28	25/5	0.34
PG 58-28 + Additive 2	25/5	0.38
100% RAP w/Rejuvenator (Cores)	100/0	0.79

High RAP/RAS Challenges

- Achieve volumetric properties
  - Which aggregate gravity can you/should you use?
  - Millings and RAS high in P200
  - Need clean, angular natural sand or low dust washed screening
  - Lower lab compaction levels help
- Achieve acceptable low-temperature binder properties
- Evaluate intermediate cracking potential
  - How much of the aged binder is really effective?
  - Rejuvenate binder?
- Check rut resistance if using rejuvenators

How do you deal with RAP in lab?

- For ranges allowed by ALDOT:
  - Air dry RAP in front of fan in thin layer
  - Use processed RAP or hand sieve to remove oversize
  - Split out sample for batch
  - Place in oven 30 minutes prior to mixing

How do you deal with RAP in lab?

- For higher percentages not currently allowed:
  - Use processed RAP
  - Can simulate fractionation by hand sieving
  - Use RAP at stockpile moisture content
  - Superheat virgin aggregate – see plant guidelines

F82

RAP Content (%)	RAP Moisture Content (%)	Superheat Required (°F) 240°F Mix	260°F Mix	280°F Mix	300°F Mix
10	0	269	291	313	335
	1	274	296	318	340
	2	279	301	323	345
	3	284	306	328	350
	4	289	311	333	355
	5	294	316	338	360
20	0	292	317	342	367
	1	303	328	353	378
	2	314	339	364	389
	3	325	350	375	400
	4	336	361	386	411
	5	347	372	397	422
30	0	324	352	330	408
	1	343	371	599	427
	2	362	390	418	446
	3	381	409	437	465
	4	400	428	456	484
	5	419	447	475	503
40	0	366	397	430	463
	1	424	426	459	492
	2	453	455	488	521
	3	482	484	517	550
	4	511	513	546	579
	5	540	542	575	608
50	0	420	460	500	540
	1	464	504	544	588
	2	508	548	588	628
	3	552	592	632	672
	4	596	636	676	716
	5	640	680	720	760

NOTE: Calculations assume 10°F loss from dryer to pugmill and 70°F outside air temperature.

Standard Counterflow Dryer (superheat required)

Astec T127

AMS LLC

Basic Goals of Processing RAP

- Create uniform stockpile(s) of RAP from various sources,
- Separate large agglomerations (chunks) of RAP to a size that can be heated and broken apart during mixing, and
- Minimize generation of additional dust

Break asphalt bonds not rock!

RAP Processing Mistakes That Limit RAP Usage

- Sizing all RAP to a 5/8” or 9/16” top size - *crushing old asphalt mixes that contain aggregates larger than 1/2” creates excess fines (-200’s).*
- Combining milled material with material from the RAP crusher: *Milled material typically has 4-8% more fines (-200’s) than processed (crushed) RAP.*

Processing staff need to monitor pile for Deleterious

Don’t let this happen to you!

Don’t let this happen to you!

Fractionated RAP

Coarse Fraction

- Still contains particles finer than screen size
- Lower AC%
- Lower -200

Fine Fraction

- +1.0% higher AC than coarse fraction
- 2-3% higher -200

Keep RAP/RAS Dry to save Fuel!

RAP/RAS Summary

- Data exists to support good field performance with high RAP/RAS mixes
- Softer binder grades can:
  - Help compaction
  - Low temperature PG based on aged (PAV) material – may not need reduction
- Rejuvenators seem to be more effective than softer virgin binder
- Dust has a big impact when trying to meet VMA/film thickness
- Lower lab compaction effort and/or low voids help
- Not all recycled asphalt may be effective, particularly with RAS

RAP/RAS Summary

- Intermediate Cracking is the hard part!
  - Softening binder helps – to an extent
  - Adding extra binder helps – all recycled binder may not be “effective”
- Check rutting with softer binders/rejuvenators

How much RAP is in this mix?


Questions?