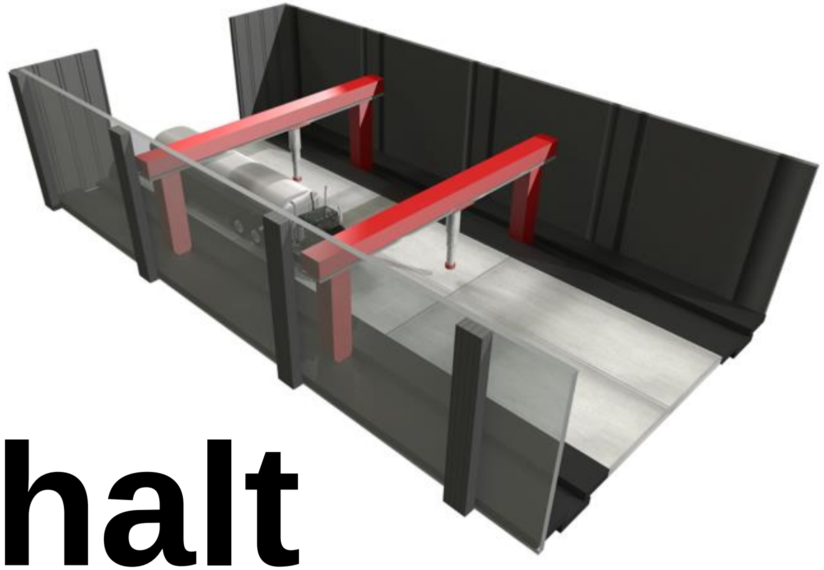


Innovations in Asphalt Concrete Cracking Tests

Progress toward better prediction of cracking

Arizona State University

Cracking in asphalt pavements is the new epidemic problem

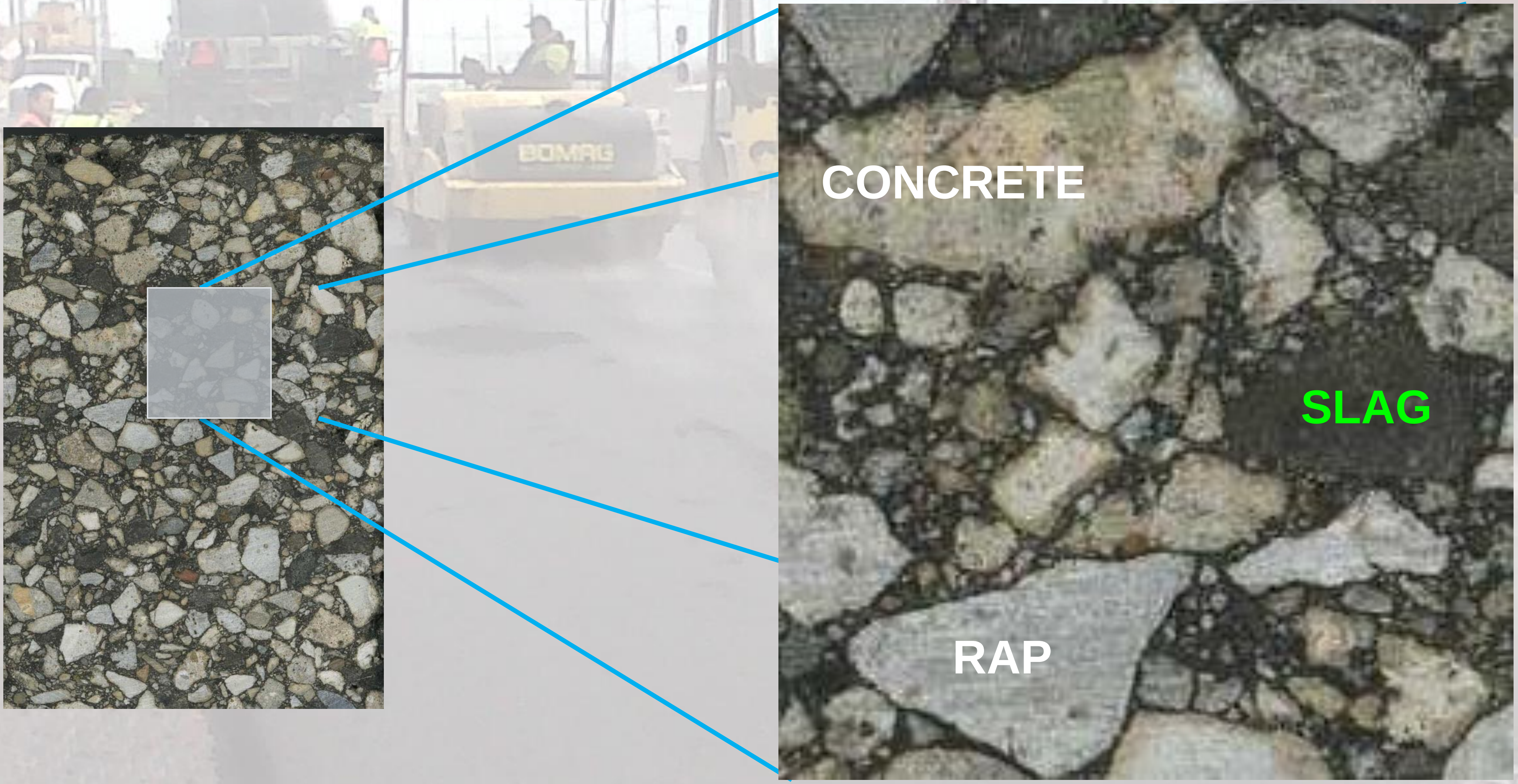
Less of this…

More of those…

How can you design a mix to survive challenging conditions?



Mixes are becoming quite different too…
97% recycled mix (3% binder is the only virgin)



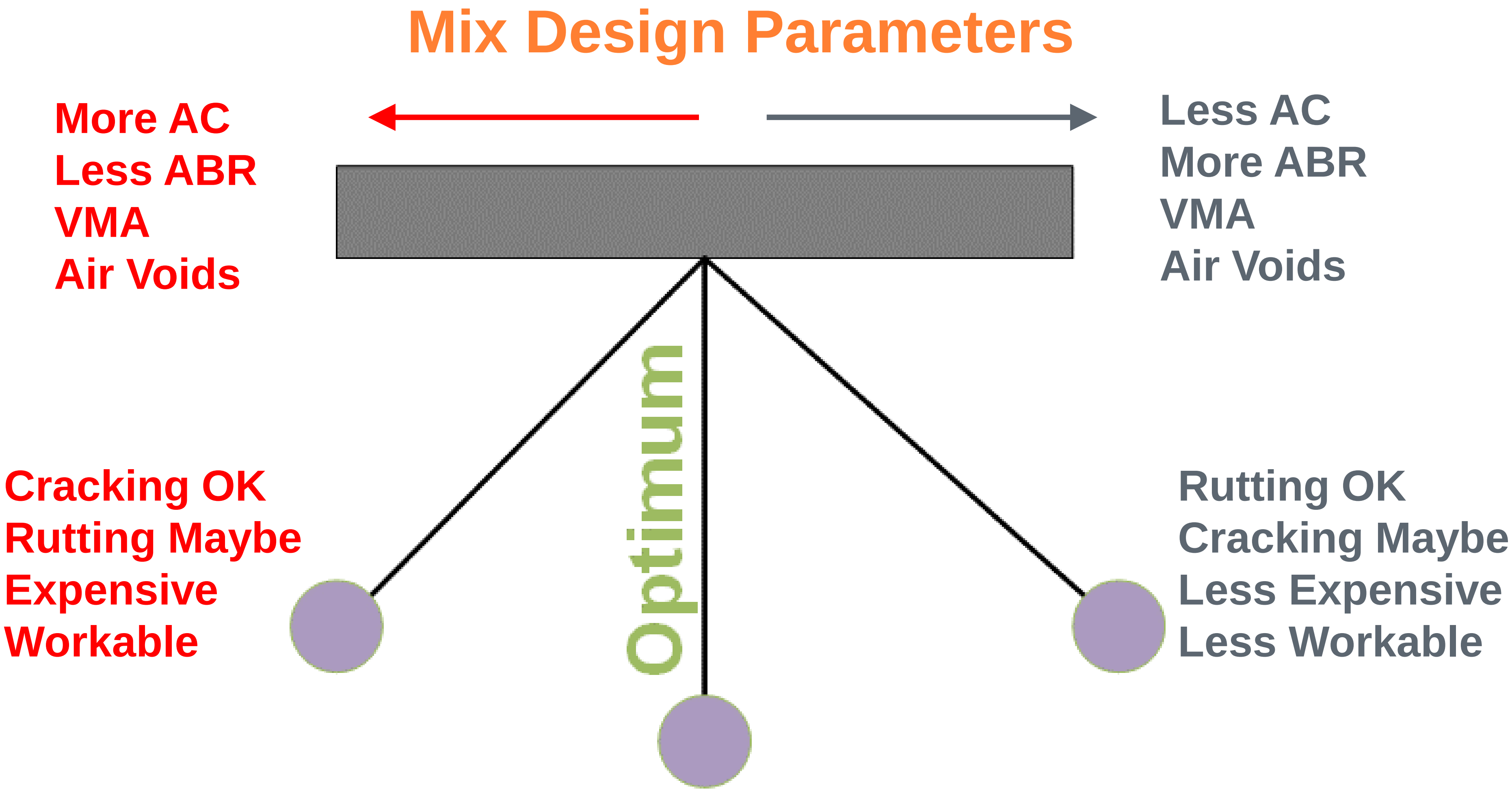
Mixes for Rolling Resistance (from Europe)

SMA8 REF	SMA8 COOEE	SMA6 COOEE
Reference mix	Better rolling resistance	Best rolling resistance
PEN70/100	PEN40/100	PEN40/100
AC 7%	AC 7.4%	AC 7.9%
Air void 2.7%	Air void 2.5%	Air void 2.4%

Can we find an optimized mix to reduce fuel, perform good, and cost-effective?

Optimizing Mixes

for Performance, Production, Economy, and Sustainability

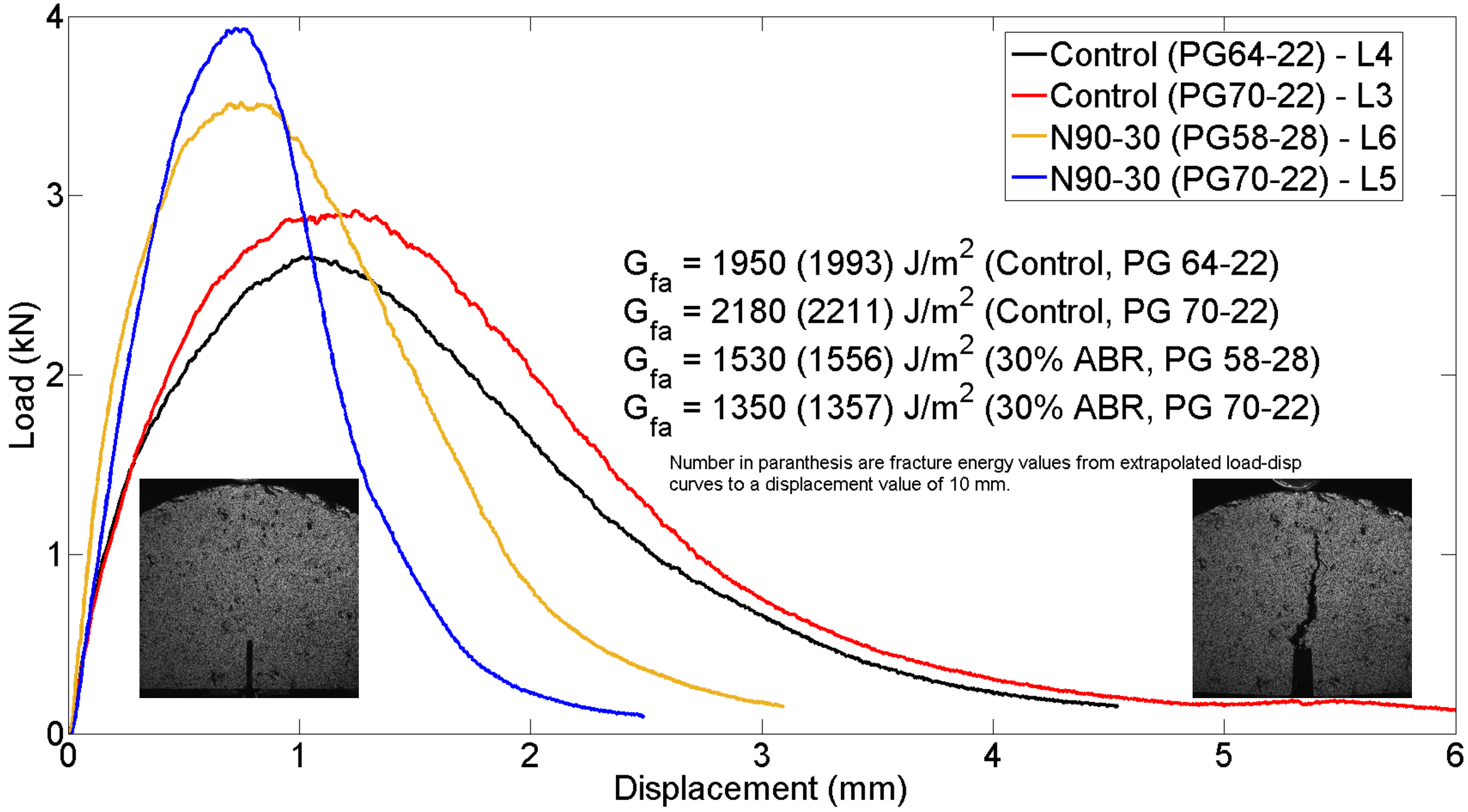


Cracking in Asphalt Mixes with Illinois Flexibility Index Test (I-FIT)

- Modified SCB fracture test conducted at 25˚C
- LVDT control load rate @ 50 mm/min
- Parameters calculated:
  - Fracture energy (G_f)
  - Flexibility index (FI)
- AASHTO specification TP 124 was developed

Typical Response from the Test

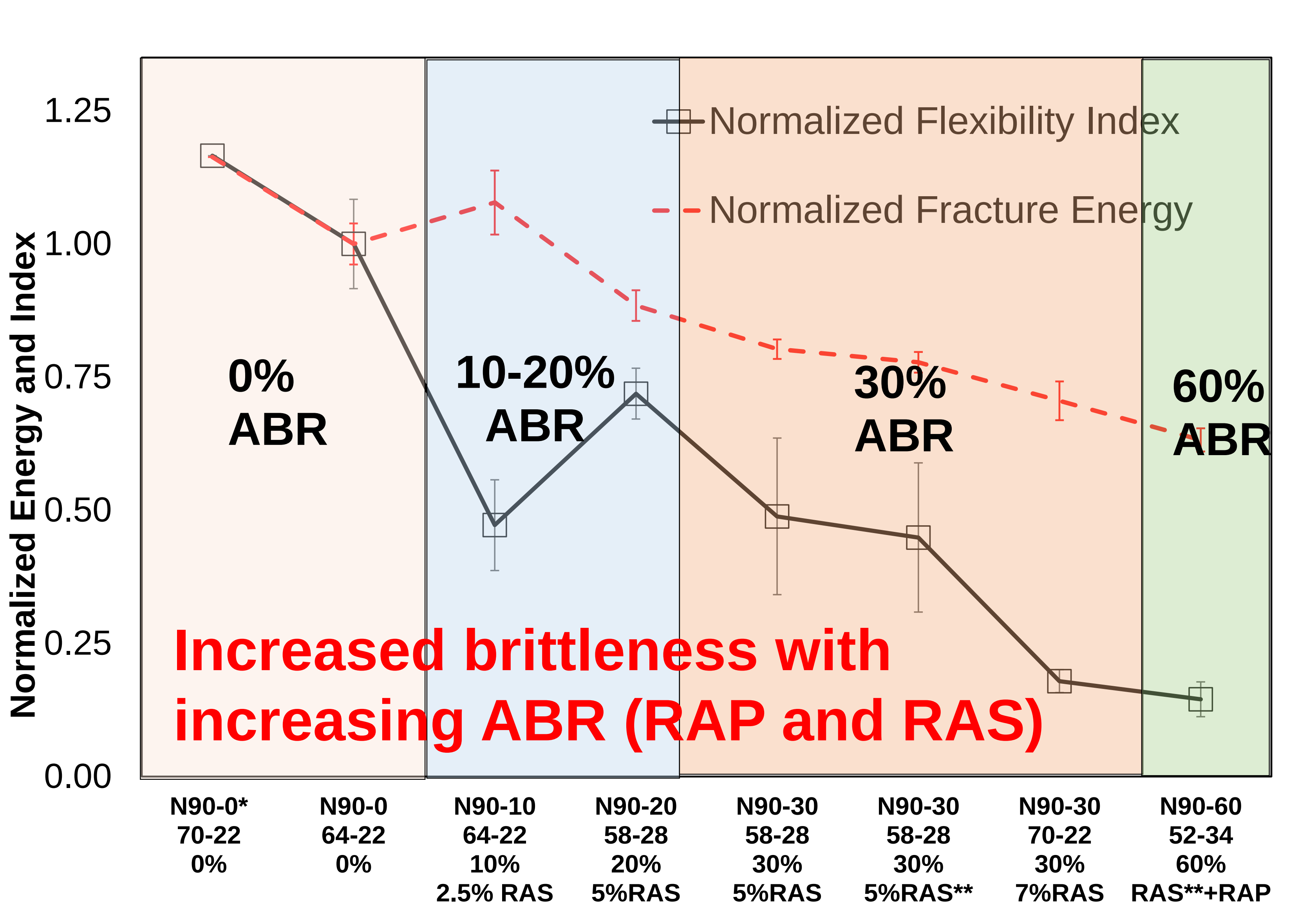
- Load-displacement curves and fracture energy changing with increasing RAP/RAS



Summary of Laboratory Produced Mixes

Mix ID	Mix Name	Binder Grade	RAP (%)	RAS (%)	ABR (%)	AC (%)	VMA (%)
L3	N90 0 CG	70-22	-	-	-	6.0	15.3
L4	N90 0 CG	64-22	-	-	-	6.0	15.3
L5	N90 30 CG S1	70-22	-	7	29.8	6.0	15.3
L6	N90 30 CG S1	58-28	-	7	29.8	6.0	15.3
L7	N90 20 CG S1	58-28	-	5	21.2	6.0	15.3
L8	N90 10 CG S1	64-22	-	2.5	10.5	6.0	15.3
L9	N90 30 CG S2 AS	58-28	11	5	30.5	6.0	15.2
L10	N90 60 CG S2 AS	52-34	40	7	60.8	6.1	15.2
L11	N90 0 CG AS	64-22	-	-	-	6.0	15.3
L12	N90 30 CG S2 AS	58-28	-	7	30.6	6.0	15.2
L13	N90 30 CG S1 AS	58-28	-	7	29.8	6.0	15.3

Cracking Susceptibility and ABR



*: N90-0 indicates 90 gyrations and ABR %

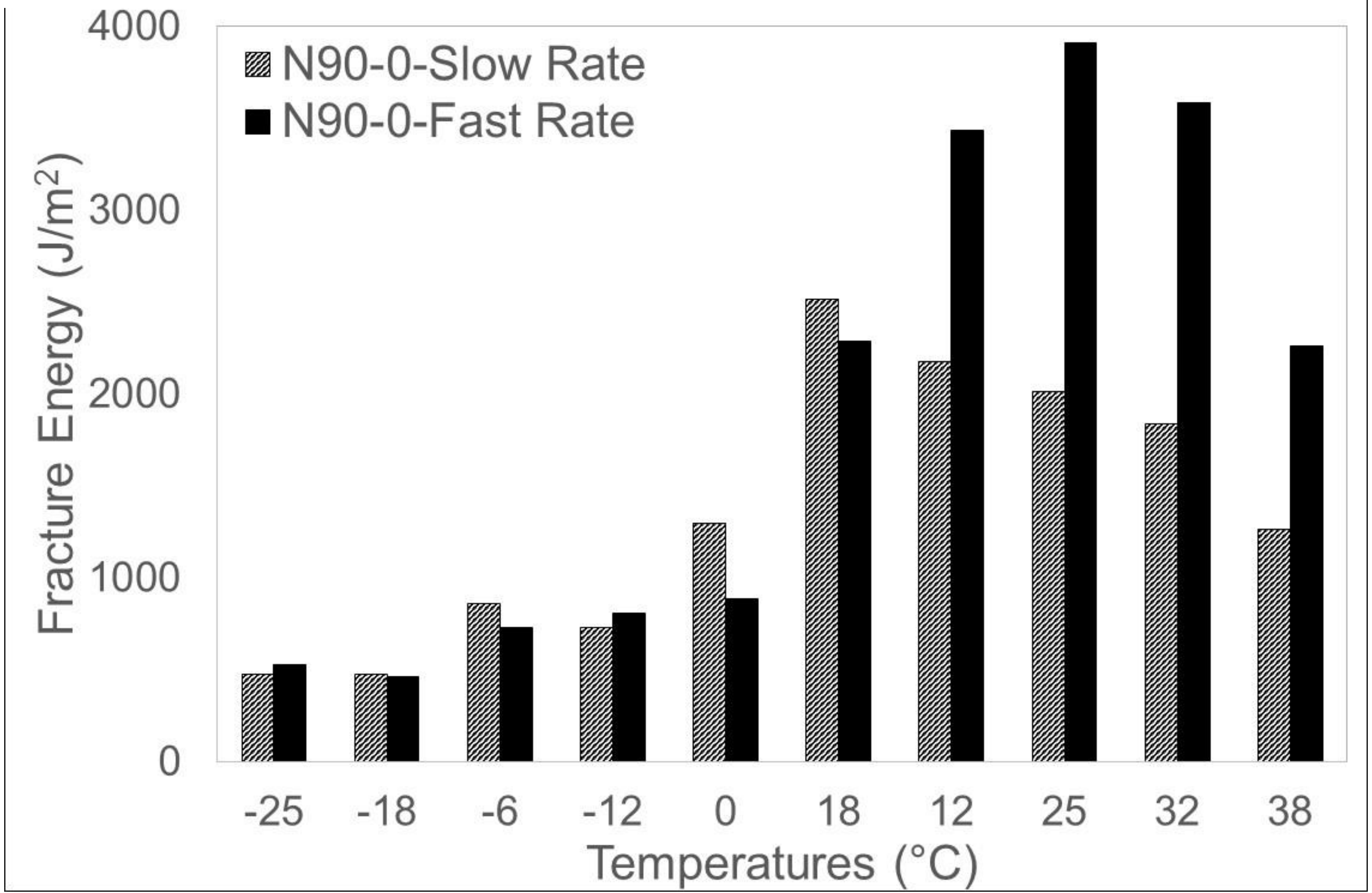
** Different source of RAS

What did it take to develop a performance-related test?

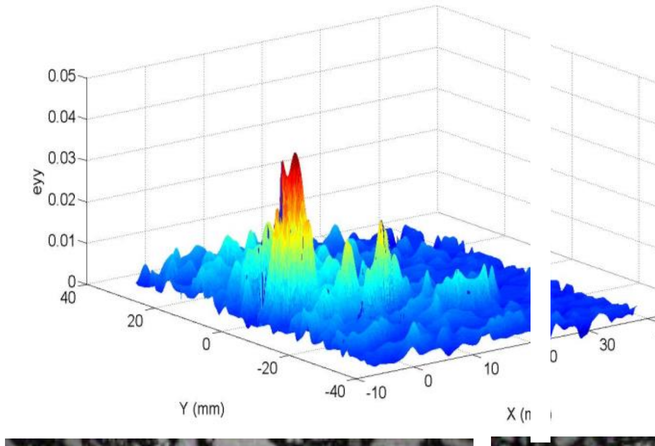
- Test geometry and parameter optimization
- Meaningfulness
- Discrimination potential (precision)
- Ruggedness and robustness
- Theoretical validation
- Field validation
- Thresholds and implementation

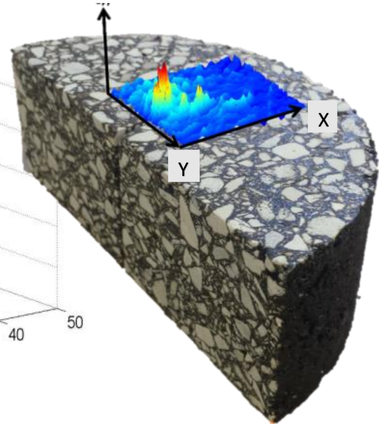
Why Intermediate Temperature?

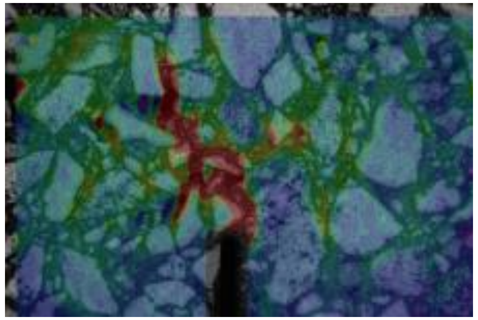
Best discrimination potential at intermediate temperatures 25 to 50 mm/min

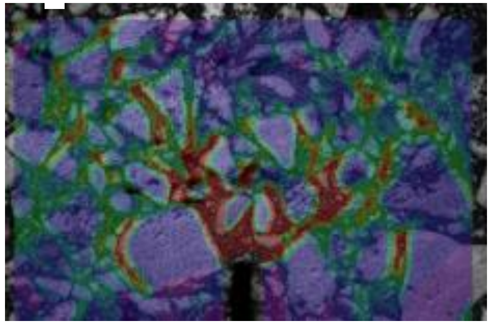


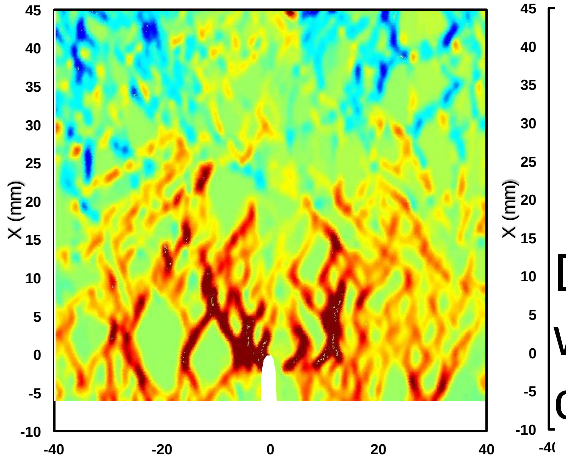
Development of the Test using DIC/FEM

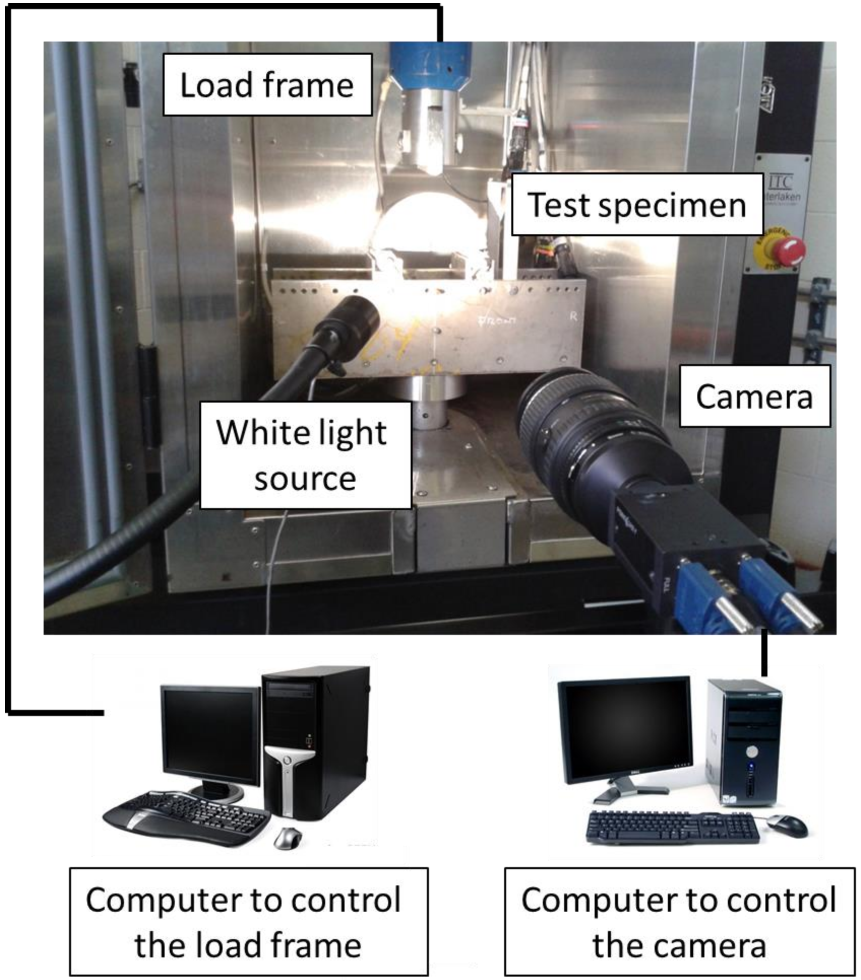










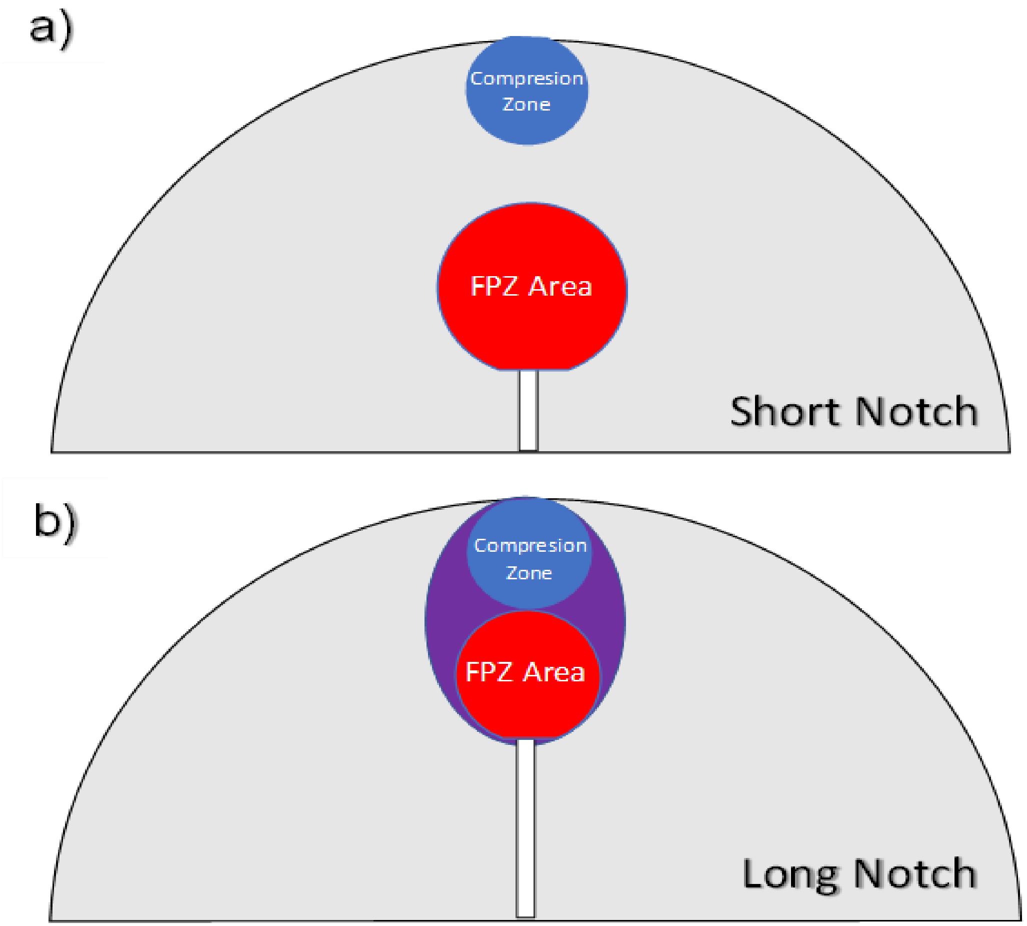


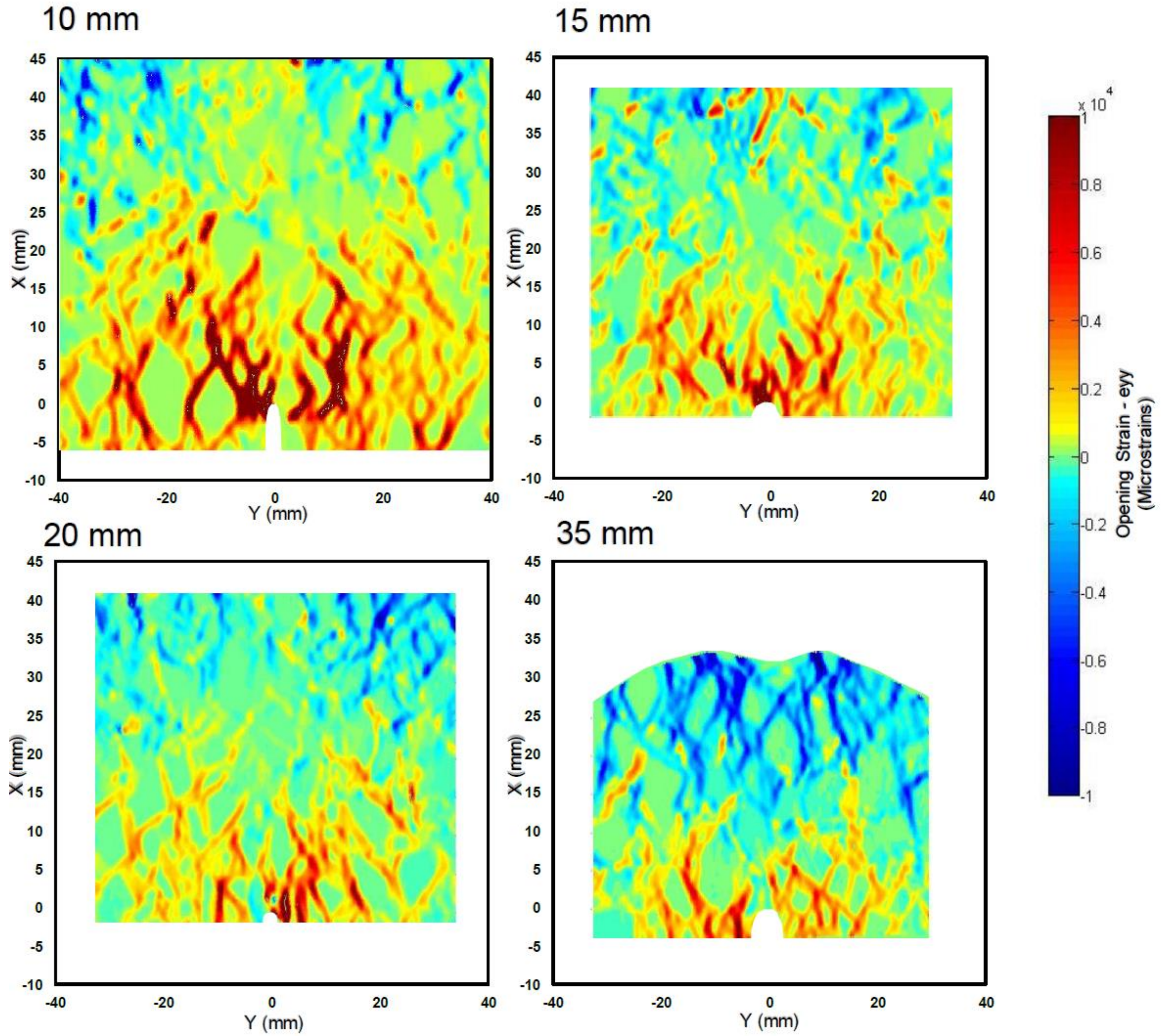
Doll* (2015) – MS Thesis
Doll et al. (2017a,b)
Rivera (2017) - MS Thesis
*Supervised by J. Lambros (in collaboration for this work)

Digital image correlation (DIC) system with high and regular resolution cameras

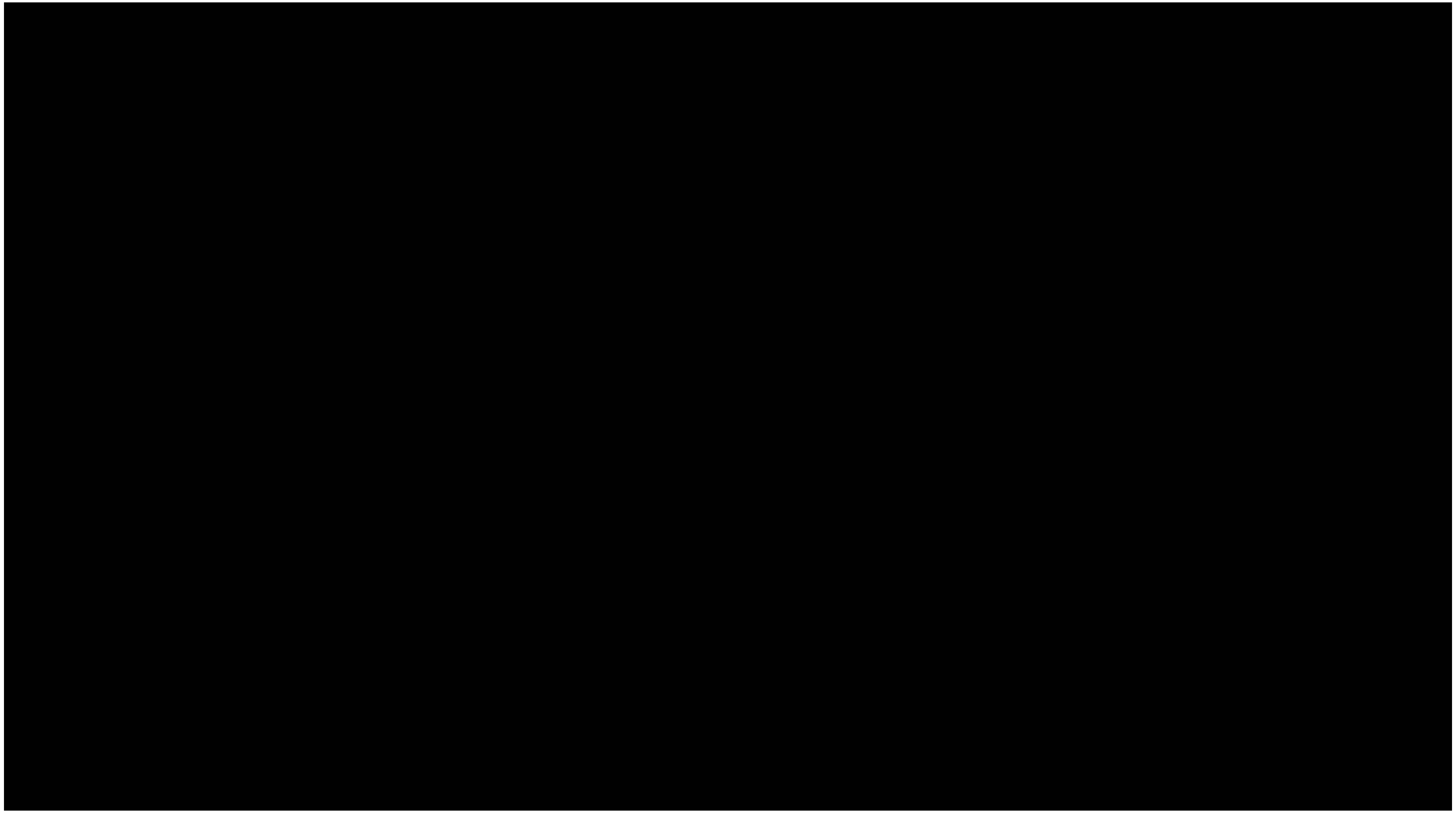
Compressive Fields at Long Notches

- For long notches, compressive fields under loading head governs crack path

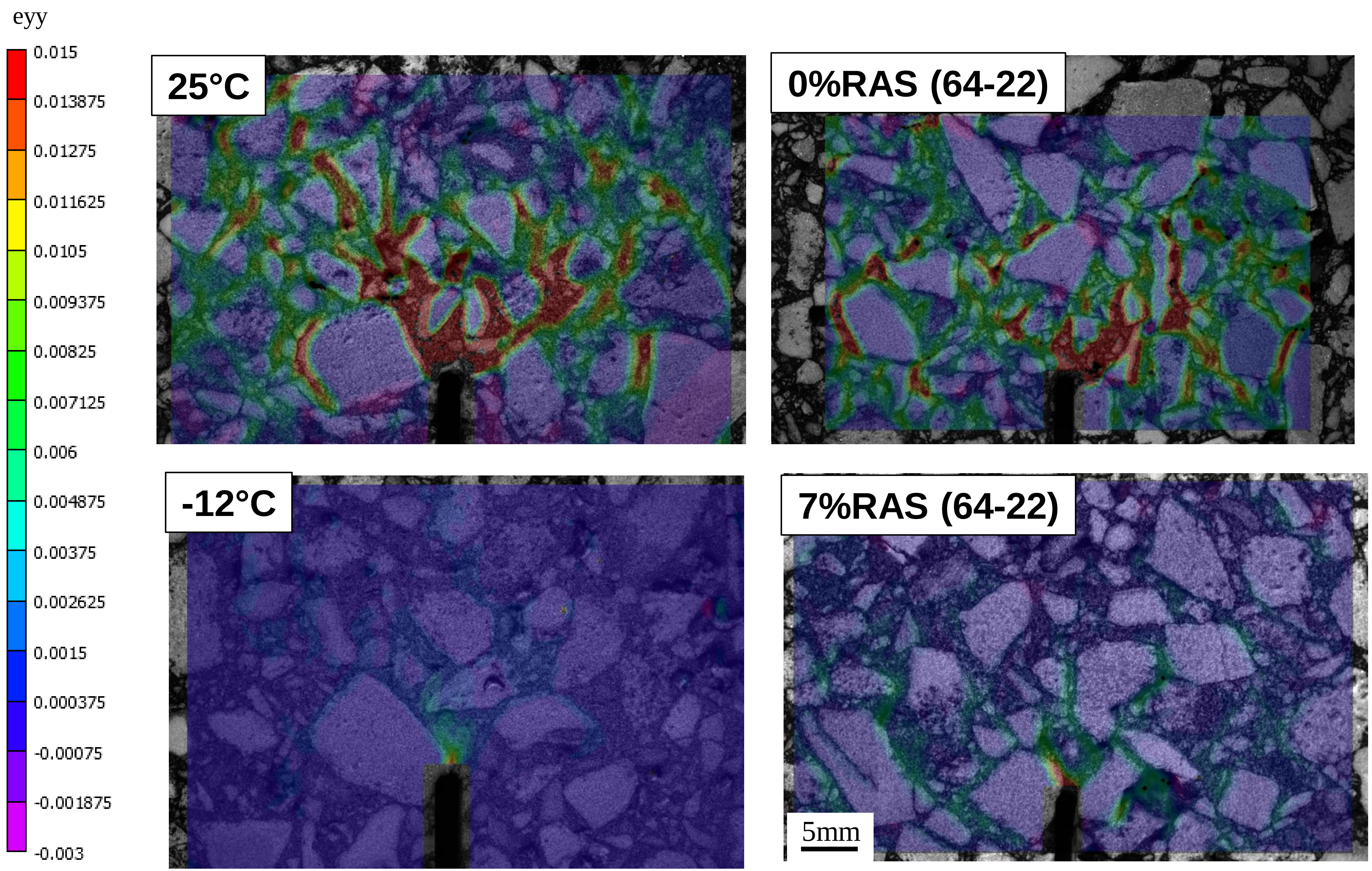




Microstructure and Damage



FPZ (Temperature and RAS Effect)



FHWA's ALF Experiments

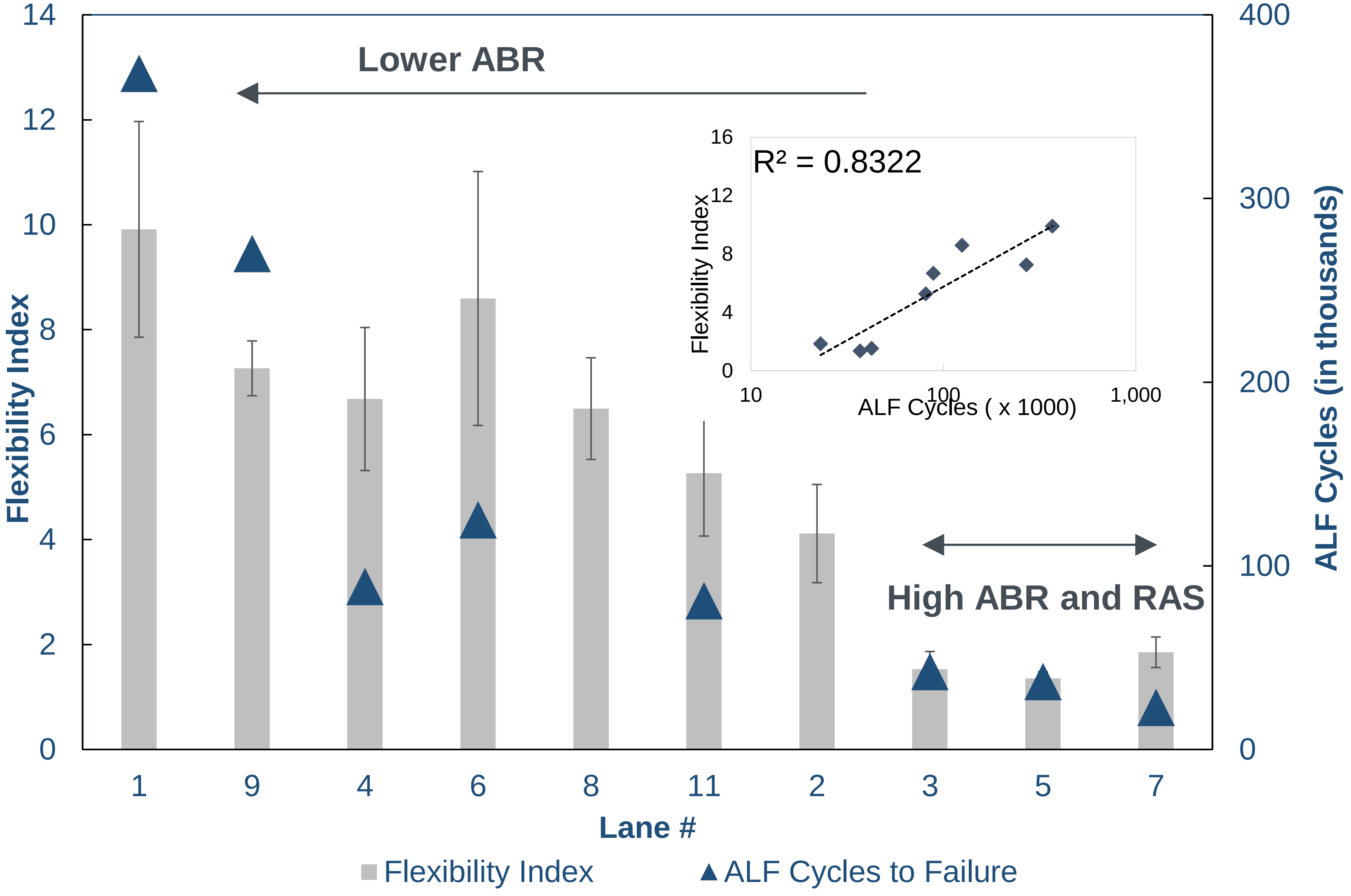
Lane	Mix	WMA	Binder Grade	Cycles to Failure
1	Control	-	PG64-22	368,254
9	20% ABR with RAP	Foam	PG64-22	270,058
6			PG64-22	122,363
4		Chemical	PG64-22	88,740
8	40 % ABR with RAP		PG58-28	-
11		Chemical	PG58-28	81,044
2		Foaming	PG58-28	-
5		-	PG64-22	23,005
3	20 % ABR with RAS		PG64-22	36,946
7			PG58-28	42,399

Best

Increasing ABR

Worst

Results



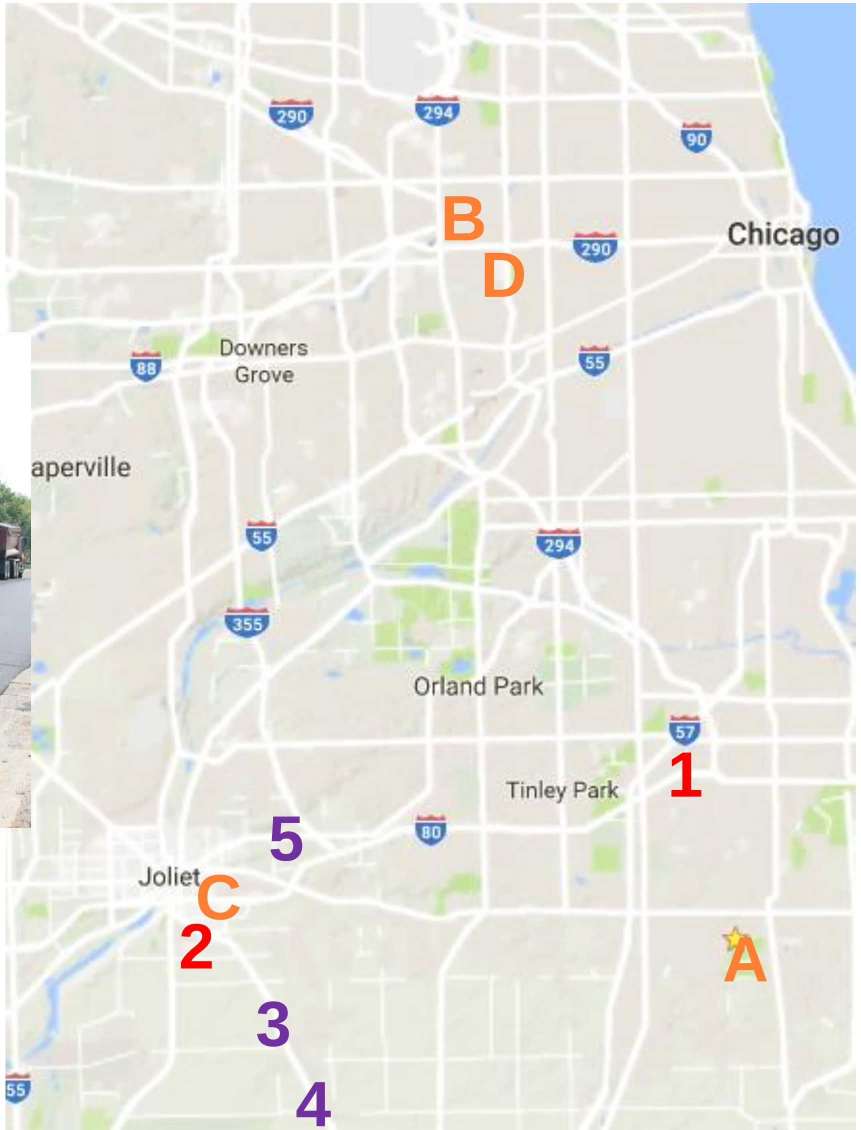
Lower ABR
High ABR and RAS
Flexibility Index
ALF Cycles (in thousands)
Lane #
1
9
4
6
8
11
2
3
5
7
R² = 0.8322
ALF Cycles (x 1000)
Flexibility Index
ALF Cycles to Failure

Field Projects for Validation

2013 Projects:
A – 26th St.
B – Harrison
C – Richards
D – Wolf

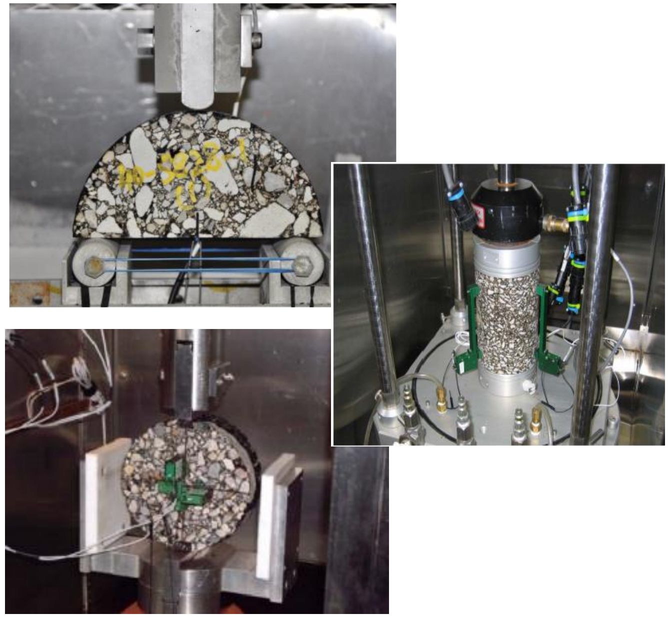
2014 Projects:
1 – Crawford
2 – US 52 Section 1

2015 Projects:
3 – US 52 Section 2
4 – US 52 Section 3
5 – Washington



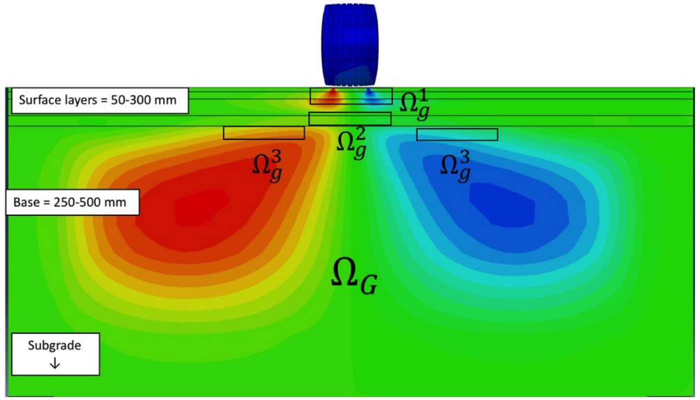
Scaling from Lab to Field Predictions

to specifications and implementation



$$log\beta = -0.61119 - 0.017638W_c$$

$$N_f = 0.00432 \cdot k_1' \cdot C \left(\frac{1}{\varepsilon_t}\right)^{3.9492} \left(\frac{1}{E}\right)^{1.281}$$



Small-scale laboratory experiments

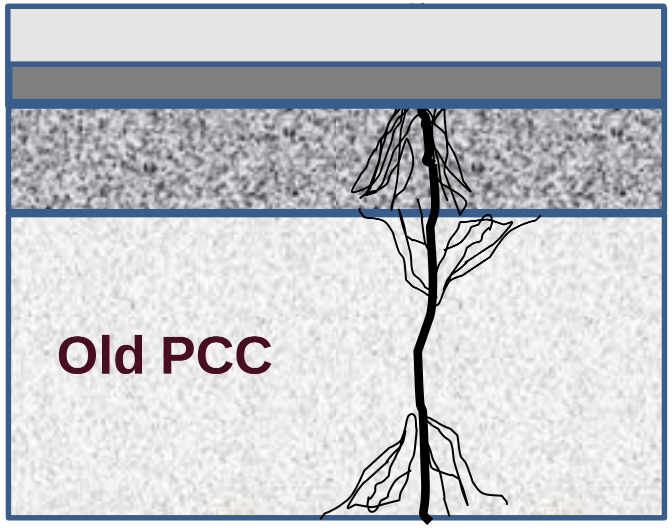
Cracking in full-scale

Alternative approach is to run the experiments at large or full-scale

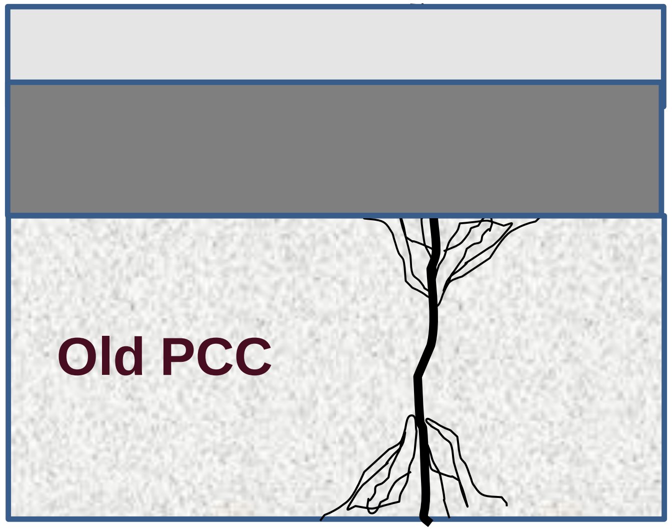
Overlay Optimization

- Is there a unique recipe for overlay strategy?
- Which one would perform better?
- Are there other options?
- How can we know?
  - Modeling (maybe???)
  - Running actual experiments in full-scale

Leave the old HMA in place and put an overlay of 2¼ inch



Mill to bare concrete and put an overlay of 2¼ inch



Testing at Full-Scale for Overlay Optimization

Alternative overlay scenarios are now tested as part of an IDOT project in Illinois

Illinois Center for Transportation's loading facility used in testing base layers.

Large-scale testing facility for slab experiments

Overlay Lift Configurations

15+ overlay scenarios for Interstate and Non-Interstate pavements

Support overlay policy development at IL

Control Scenario (3.75 in)
IL-9.5 Surface Course @ 1.50 in
IL-19.0 Binder Course @ 2.25 in
Concrete Slab

Scenario # 5 (3.0 in)
SMA 9.5 Surface Course @ 1.50 in
IL-9.5 Surface Course @ 1.50 in
Concrete Slab

Scenario # 2 (3.5 in)
SMA 9.5 Surface Course @ 1.50 in
SMA 12.5 Binder Course @ 2.00 in
Concrete Slab

Scenario # 1 (3.5 in)
IL-9.5 Surface Course @ 1.50 in
IL-12.5 Binder Course @ 2.00 in
Concrete Slab

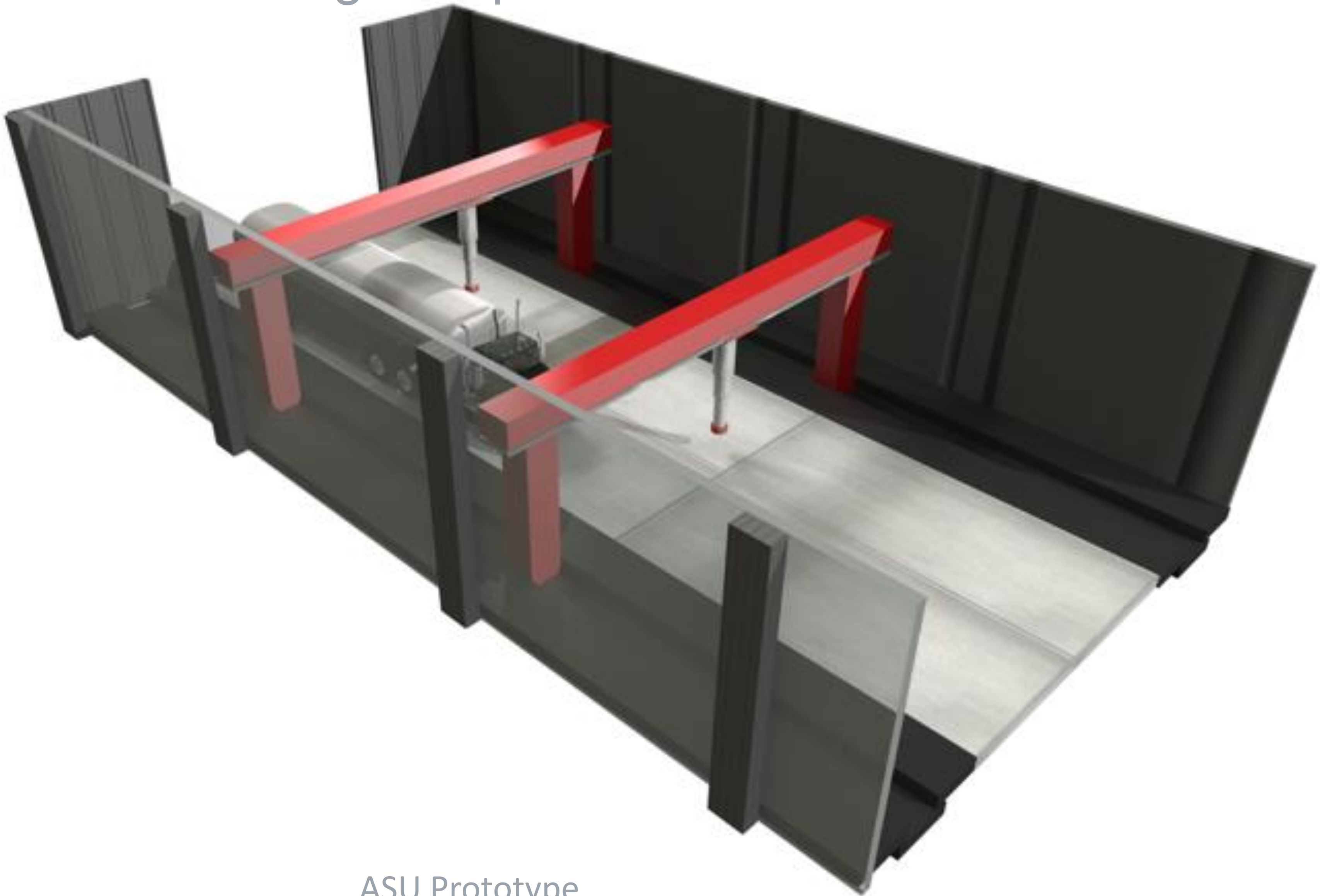
Scenario # 3 (4.25 in)
SMA 12.5 Binder Course @ 2.00 in
IL-19.0 Binder Course @ 2.25 in
Concrete Slab

Scenario # 4 (5.00 in)
SMA 12.5 Binder Course @ 2.00 in
IL-19.0 Binder Course @ 3.00 in
Concrete Slab

Constant parameter | Changing parameter

AZ’s full-scale testing system

to make rapid and meaningful impact on AZ’s infrastructure assets



ASU Prototype

A Full-Scale Testing System for Pavements

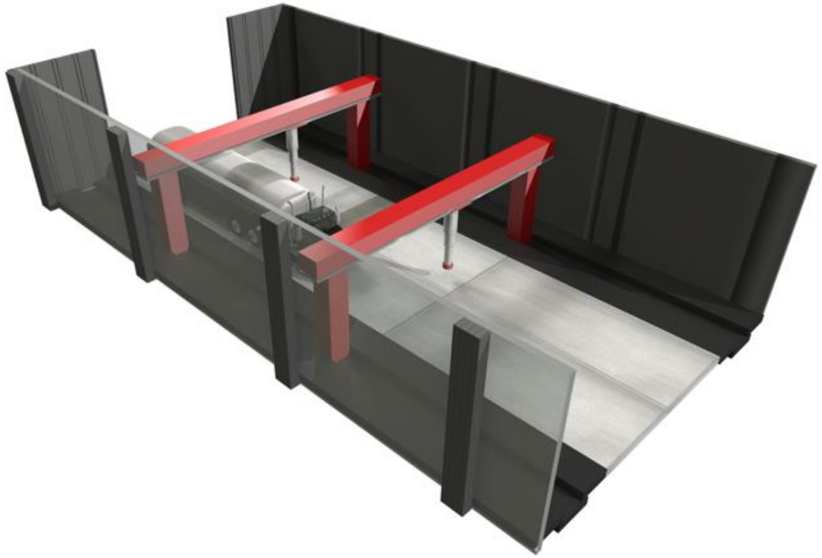
- Applies loading through dynamic actuators carried by a portable crane
- Innovative test bed design
- Allows actual truck travel for response monitoring

ASU Prototype

Germany’s Federal Highway Research Institute (BASt)

Thank you!

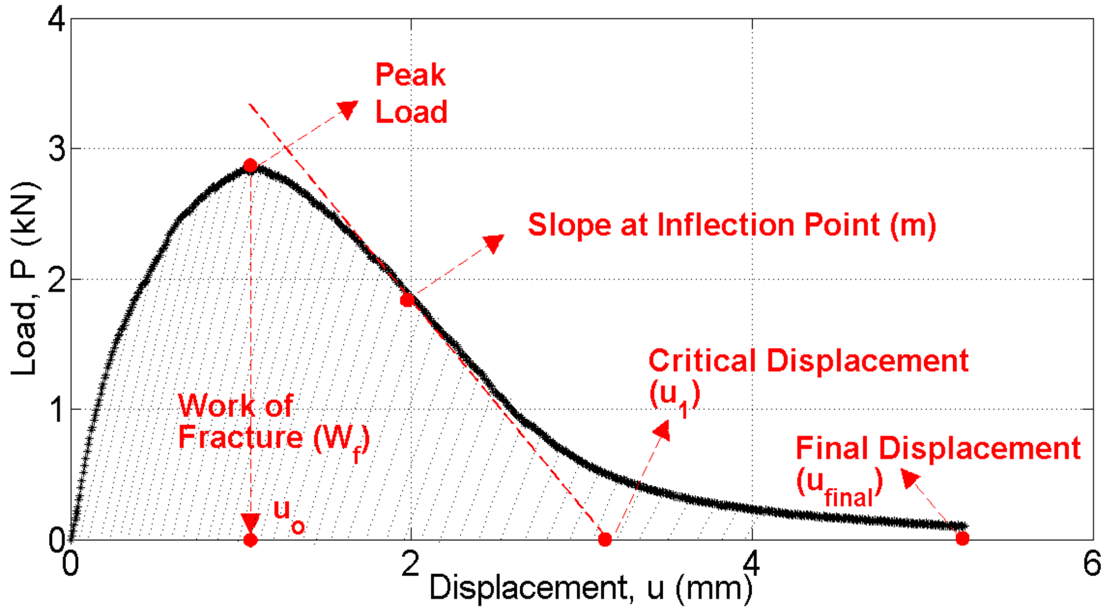
hasan.ozer@asu.edu



Arizona State University

Development of Flexibility Index (FI)

- A practical cracking index to discriminate between mixes
- An empirical correlation between brittleness and rate of crack growth is exploited to formulate the index parameter



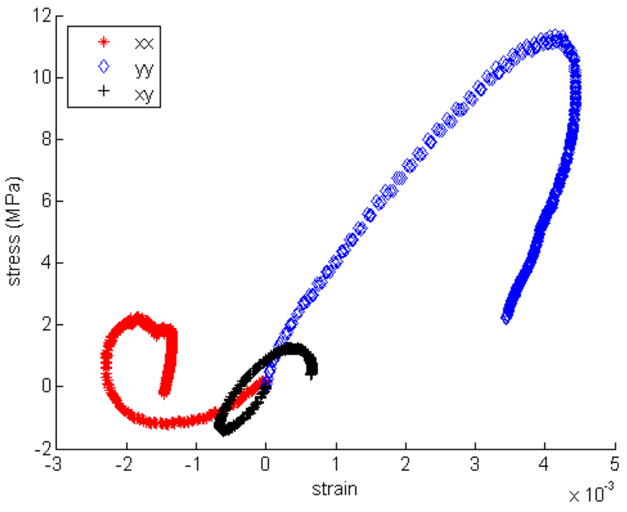
$$\text{Flexibility Index (FI)} = G_F \times \frac{1}{abs(m)}$$

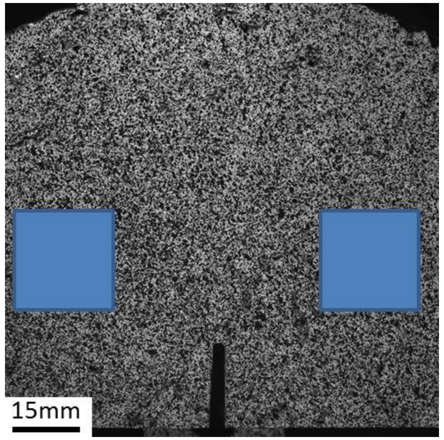
FI describes overall pattern of the load-displacement curve.

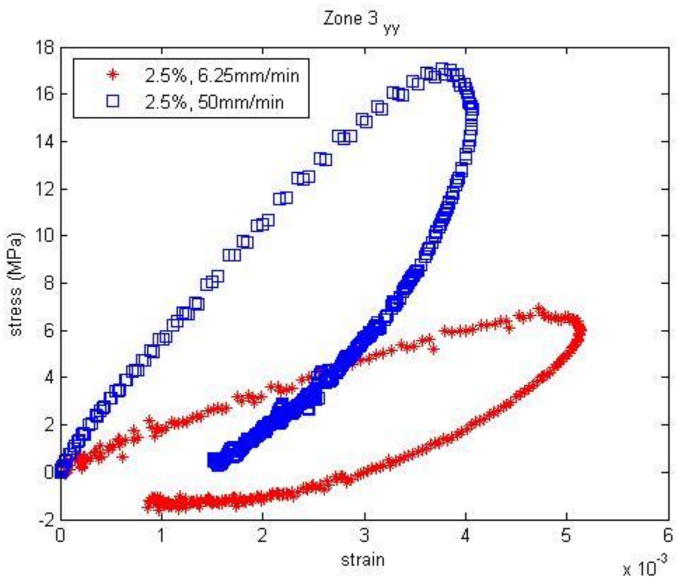
Fracture at Intermediate Temperatures

Spurious Inelastic Dissipation

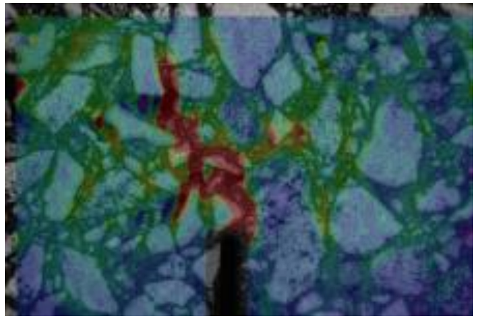
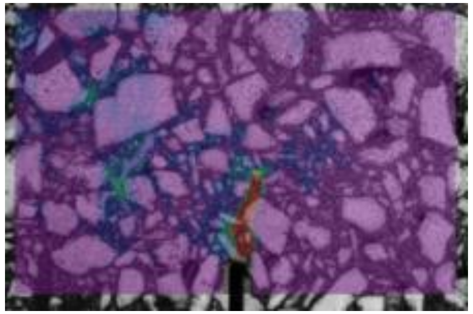
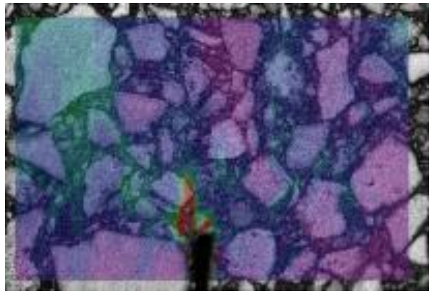
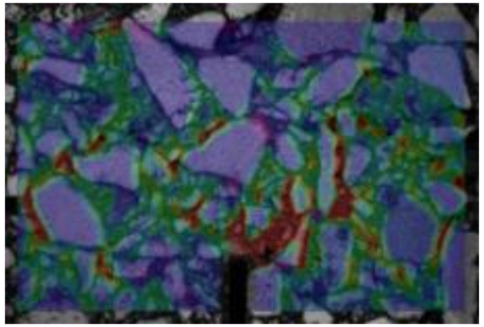
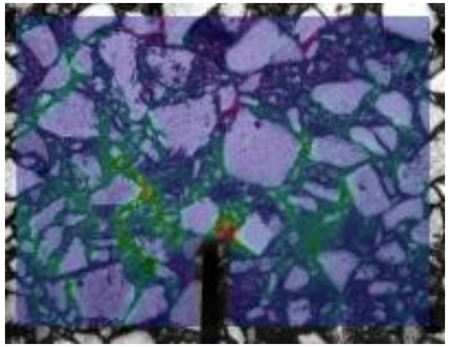
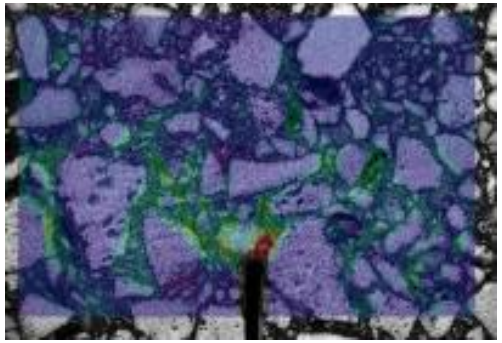
- Extraction of strain history in the farfield areas
  - Loading head and supports
  - Bulk material away from crack front
- Evaluate strain levels and recovery in these areas
- Quantify the effect with DIC data and numerical simulations







Effect of RAS at the Crack Front

Mix / Test Condition	L4 (0%RAS)	L6 (7%RAS)	L9 (7%RAS)
-12°C, 0.7mm/min 0.0015 -0.0003			
25°C, 6.25mm/min 0.015 -0.003			
25°C, 50mm/min 0.015 -0.003