Invention of the Aggregate Avoidance Method For Evaluating Interfacial Bond in Pavement Materials

By

Bernard Igbafen Izevbekhai, P.E.; PhD

MnDOT Office of Materials & Road Research

Research Pays Off Series

September 15 2015

RAISON D'ETRE

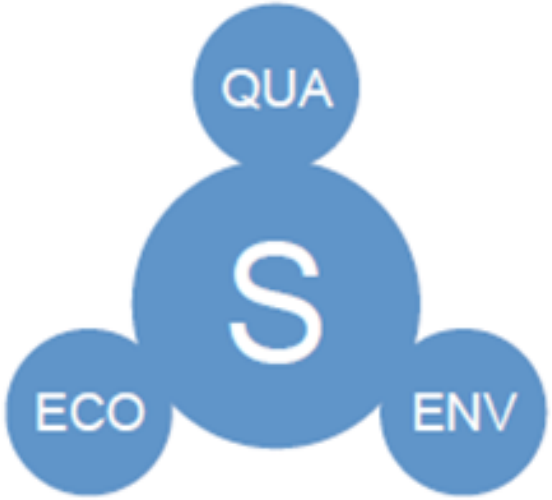
- Discuss research Work performed on RAC
- Why Consider RAC?
- Batching mixing Proportioning
- Preliminary Observation
- Fractured face examination and results
- AAI Alternative to fractured Aggregate count
- AAI meaning and formula
- Evaluation Results
- Conclusions

RECYCLED CONCRETE & SUSTAINABLE DEVELOPMENT

Depleting Virgin Aggregate sources: A serious issue

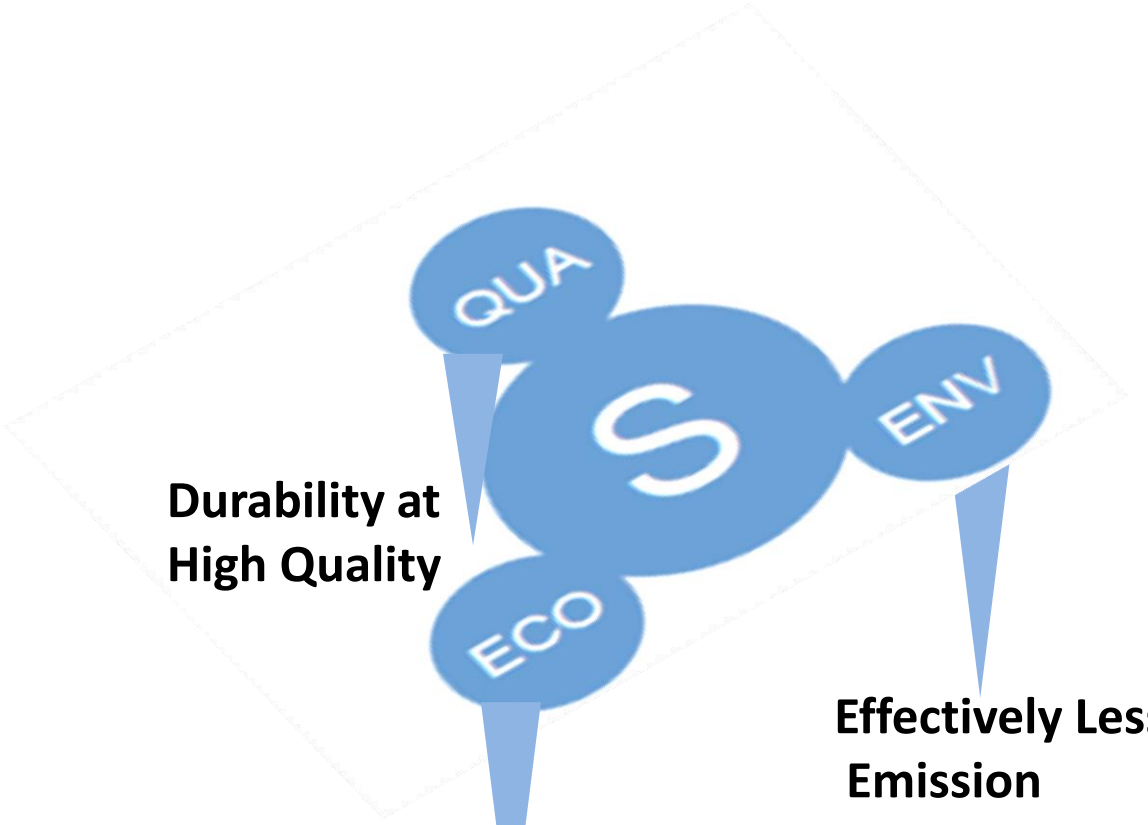
Meet Current Needs Without Jeopardizing ability to Meet Needs of Future generation

- Quality of Life
- Economic
- Environmental



- A Synergistic Balance of the 3 Support Enhances Sustainability

SUSTAINABILITY INITIATIVES

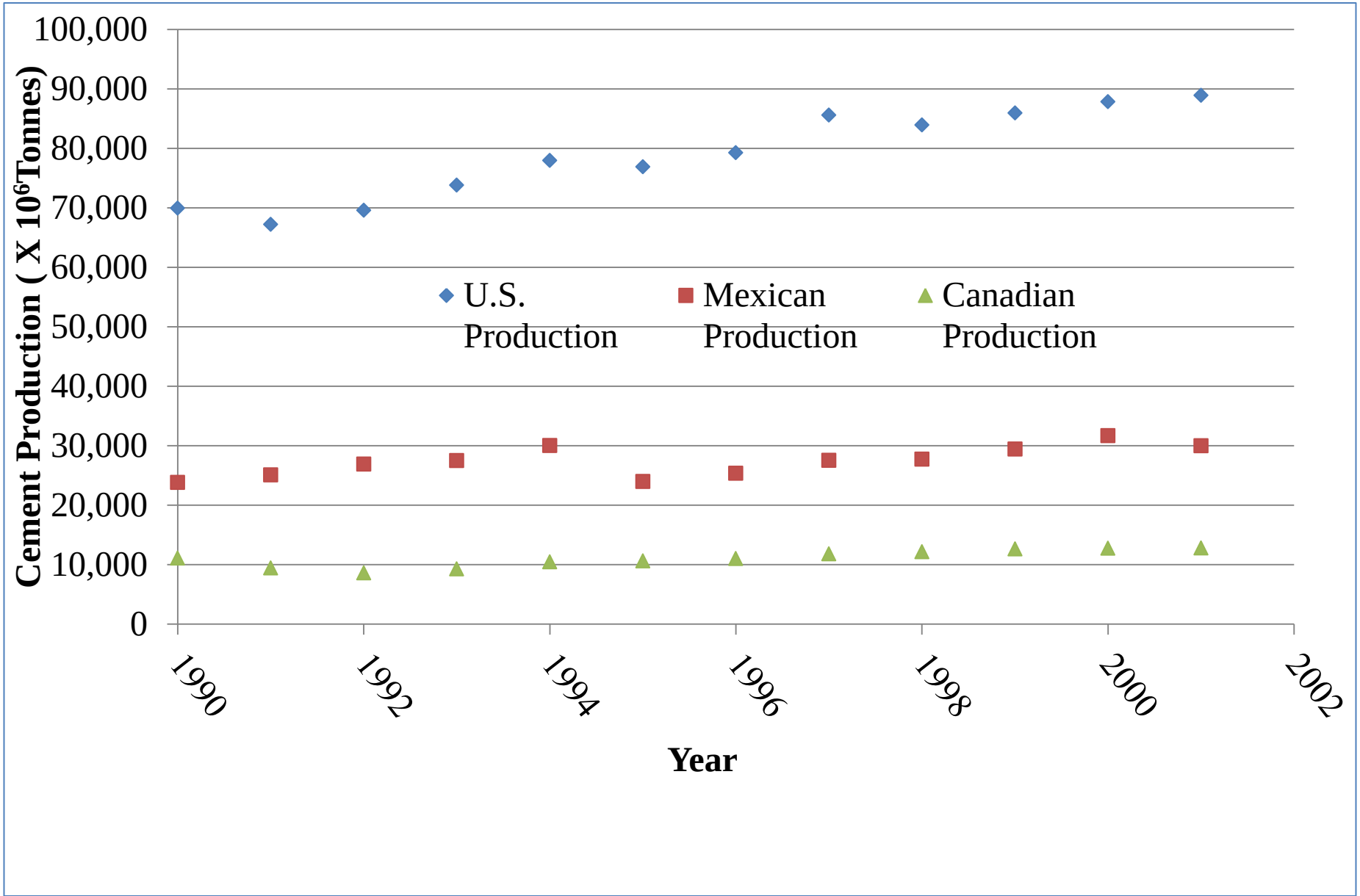


Durability at High Quality

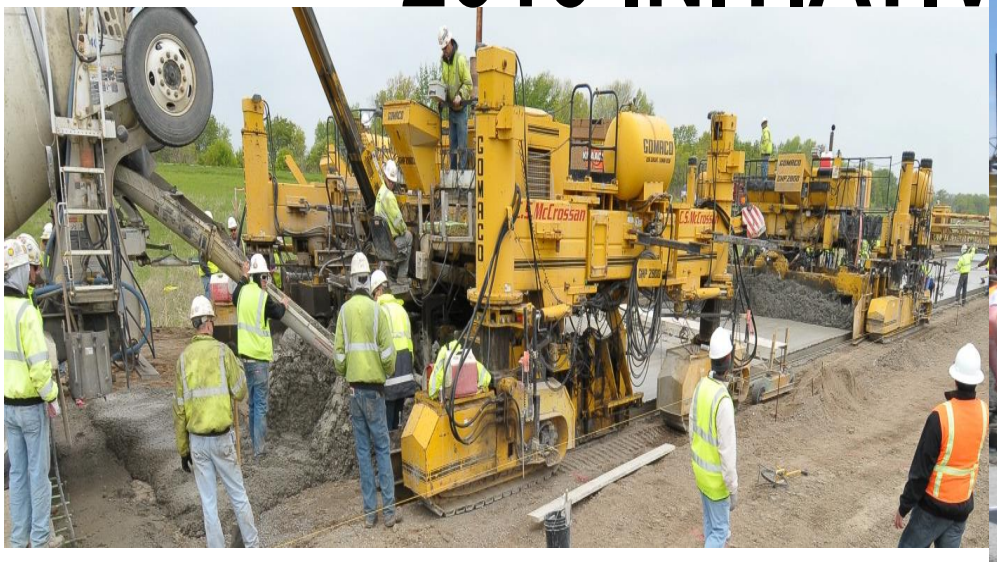
Effectively Lesser Emission

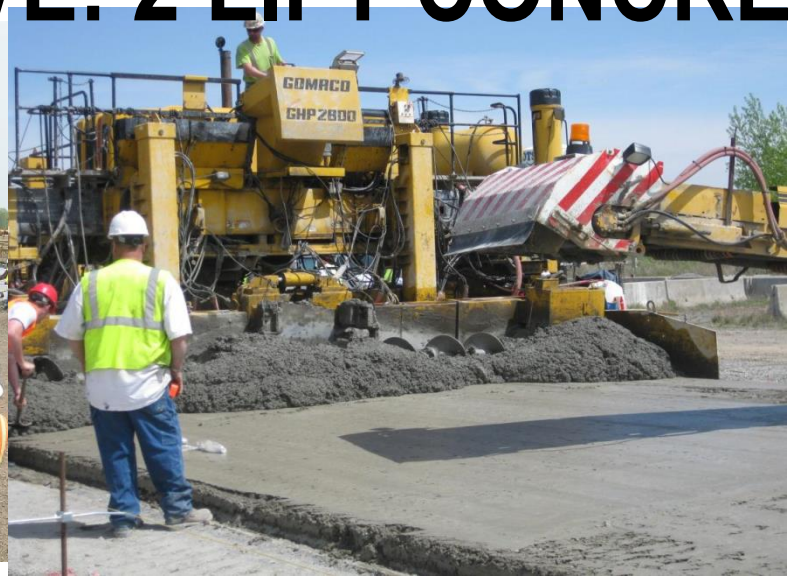
Reduced Material & Haulage Cost

EMISSION IMPLICATION



2010 INITIATIVE: 2 LIFT CONCRETE





Cell 70	Cell 71		Cell 73		Cell 72
	Innovative Diamond Grind	Traditional Diamond Grind	Traditional Diamond Grind	Traditional Diamond Grind	Exposed Aggregate
	3" EAC				3" EAC
6" RAC	6" RAC		6” LCST		6" LCST
8" Class 5	8" Class 6				8" Class 7
Clay	Clay				Clay

ECONOMIC: REUSE RECLAIM RECYCLE COST-EFFECTIVENESS

Conventional Paving	
Pave, Tie, Green Saw	
Sq. Yds.	310,000
Per Sq. Yd.	$ 2.98
Total Cost	$ 923,800.00
Structural Concrete	
Cubic Yards	80,000
Per CY	$ 71.54
Total Cost	$ 5,723,200.00
TOTAL COST	$ 6,647,000.00

Composite Paving	
Pave, Tie, Green Saw	
Sq. Yds.	310,000
Per Sq. Yd.	$ 3.70
Total Cost	$ 1,147,000.00
Structural Concrete	
Cubic Yards	80,000
Per CY	$ 69.31
Total Cost	$ 5,544,800.00
TOTAL COST	$ 6,691,800.00

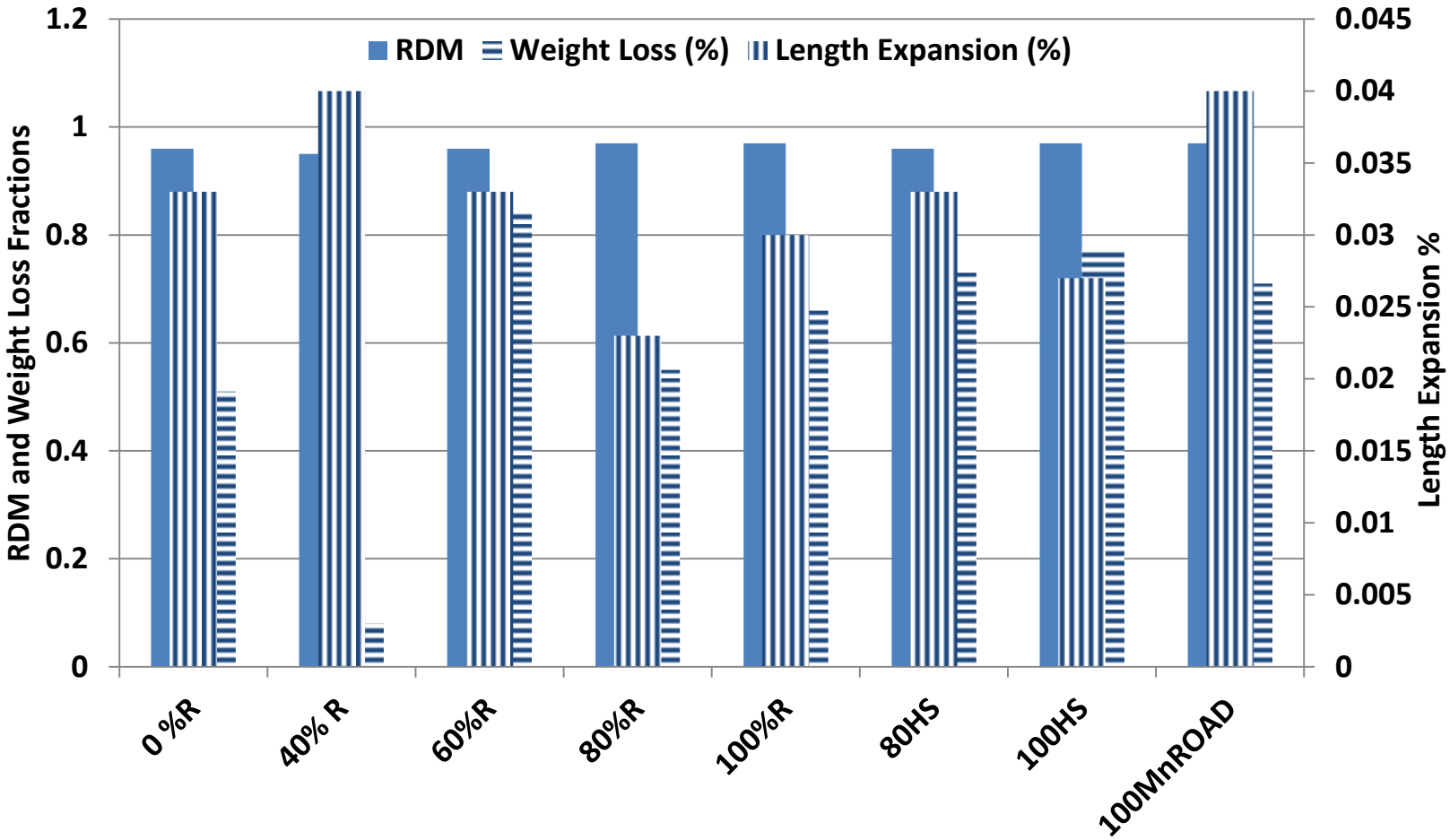
Source: C.S Mc Crossan

- Total cost difference is within margin of error
- Basis: Recycled Agg: $ 8.75/Ton vs. 20.72/Ton
- 2 –Lift LCCA may show better return on inv.

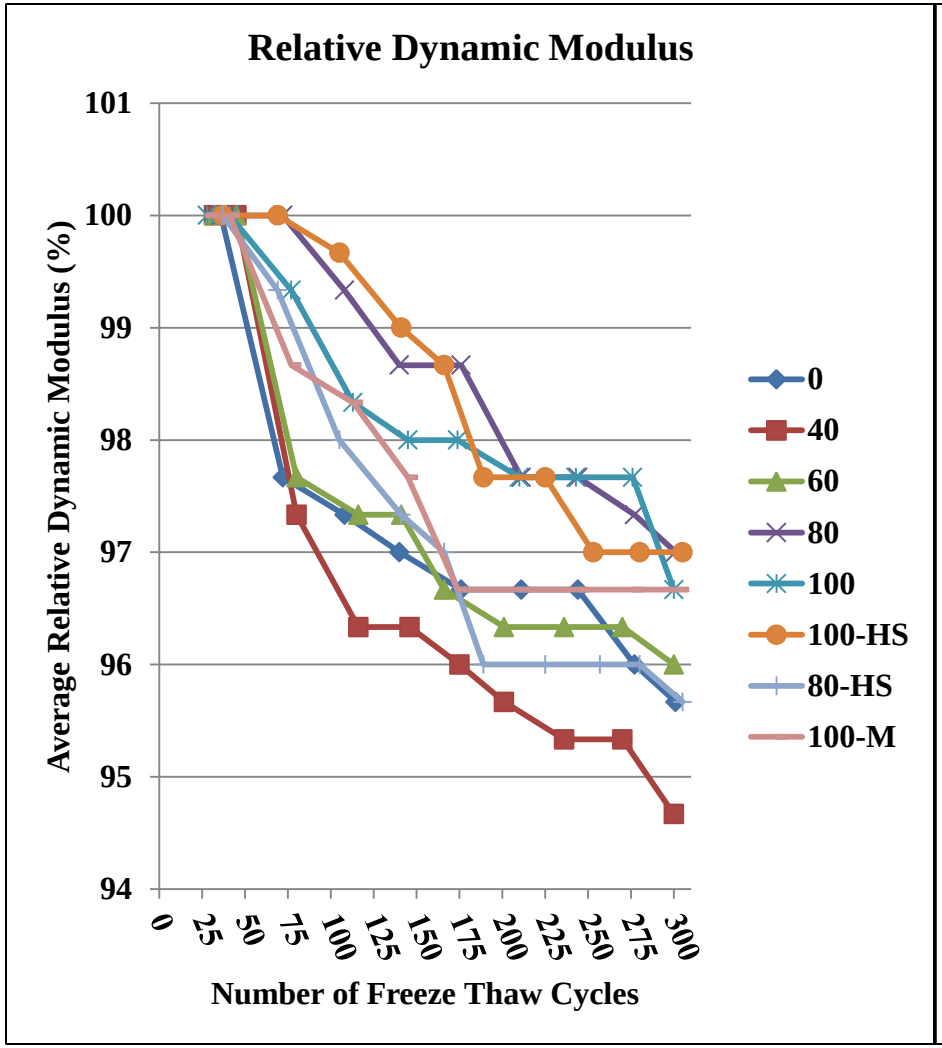
Performance and Quality of Life

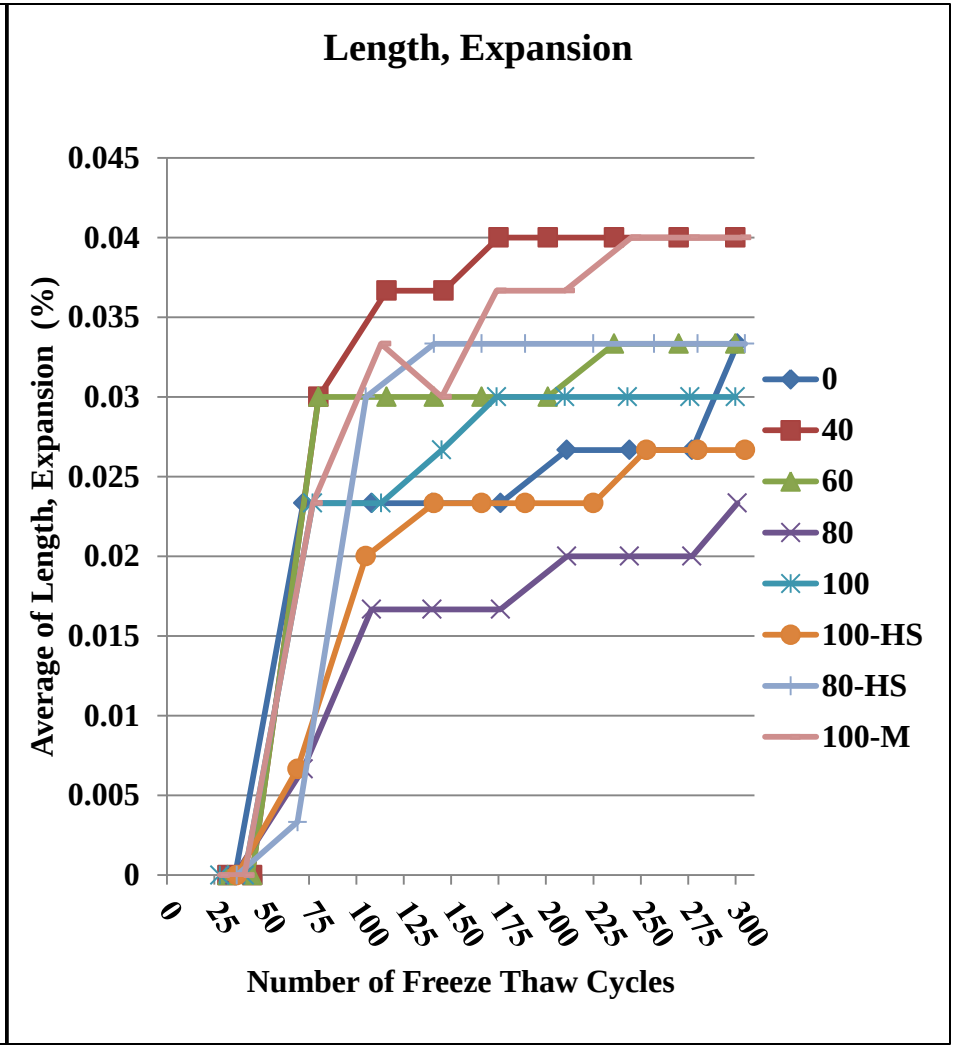
- Durability
- Mechanical Properties
  - Compressive Strength
  - Tensile Strength
- Elastic Properties
  - Elastic Modulus
  - Poisson’s Ratio
  - Coefficient of Thermal Expansion

DURABILITY PROPERTIES

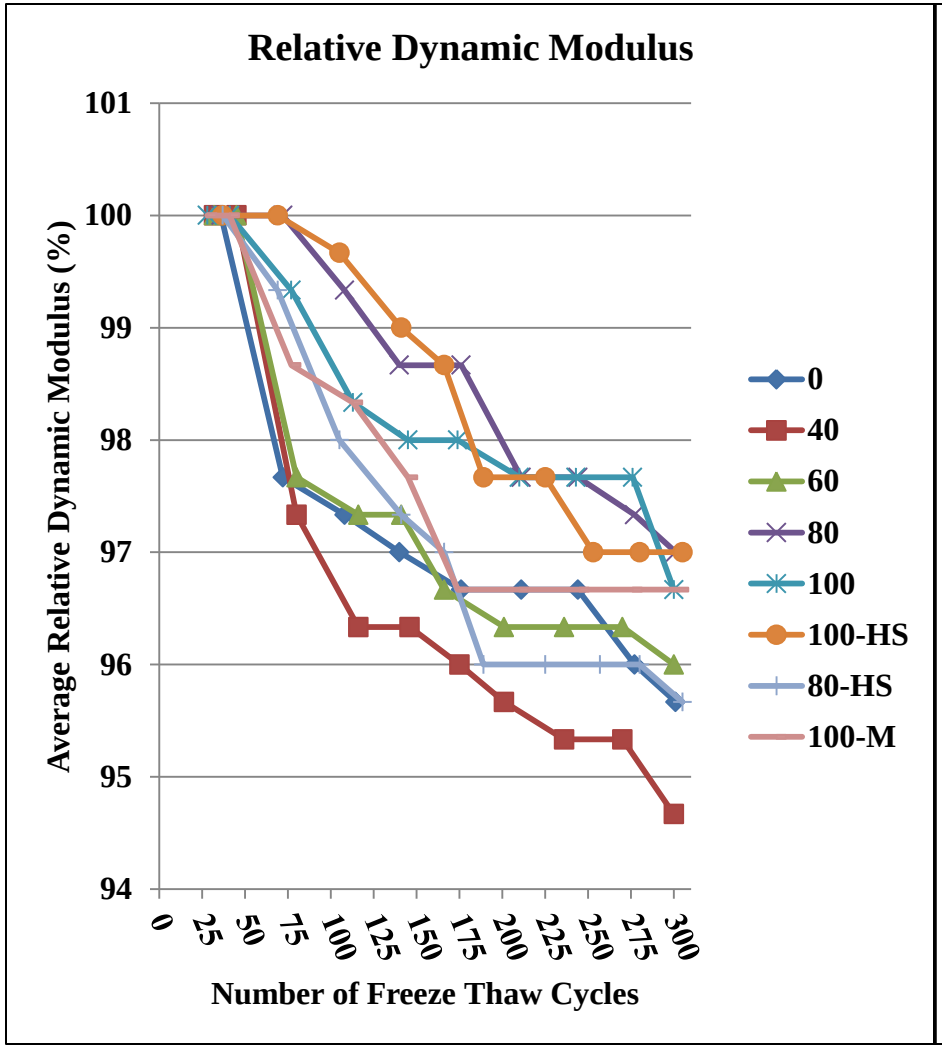


DURABILITY


Relative Dynamic Modulus
Average Relative Dynamic Modulus (%)
101
100
99
98
97
96
95
94
0
25
50
75
100
125
150
175
200
225
250
275
300
Number of Freeze Thaw Cycles
0
40
60
80
100
100-HS
80-HS
100-M


Length, Expansion
Average of Length, Expansion (%)
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0
25
50
75
100
125
150
175
200
225
250
275
300
Number of Freeze Thaw Cycles
0
40
60
80
100
100-HS
80-HS
100-M

DURABILITY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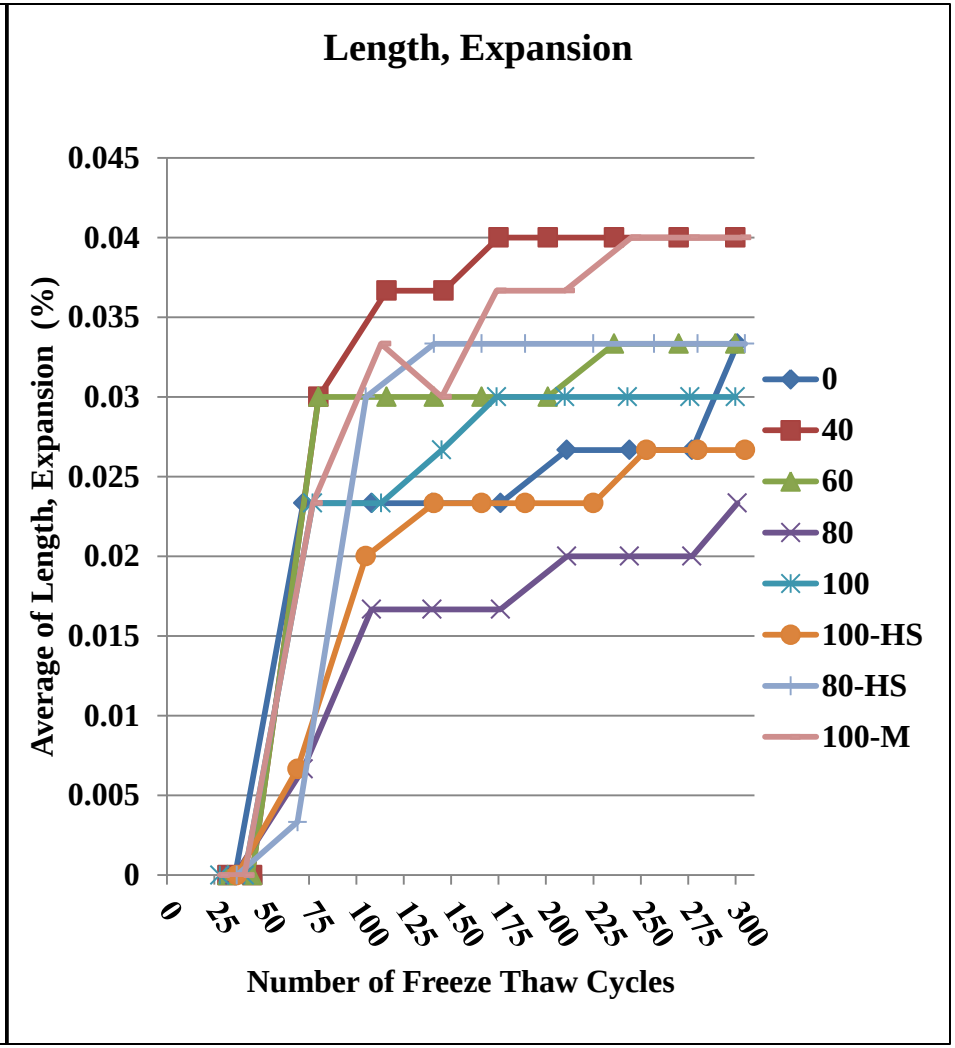
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Number of Freeze Thaw Cycles
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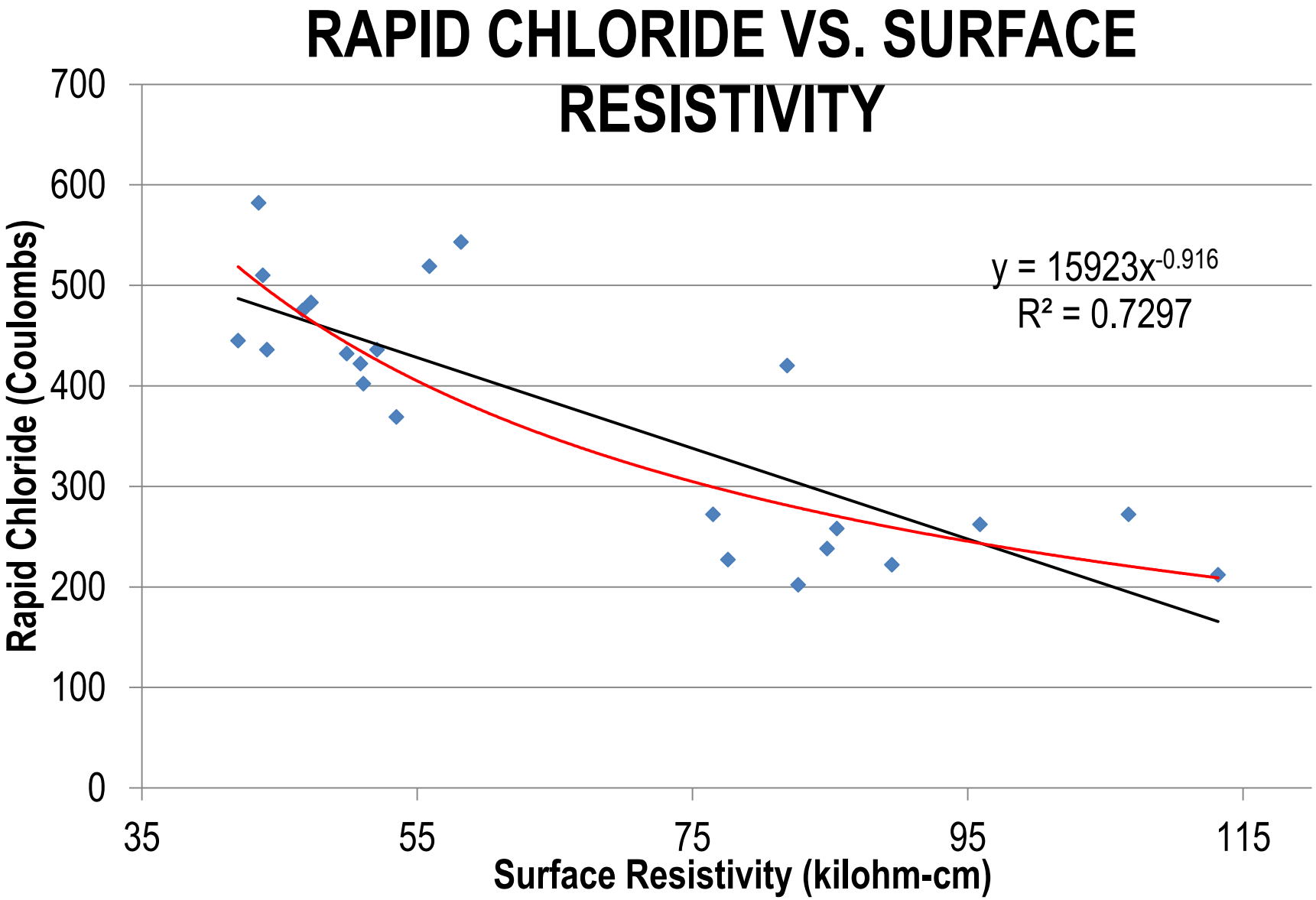
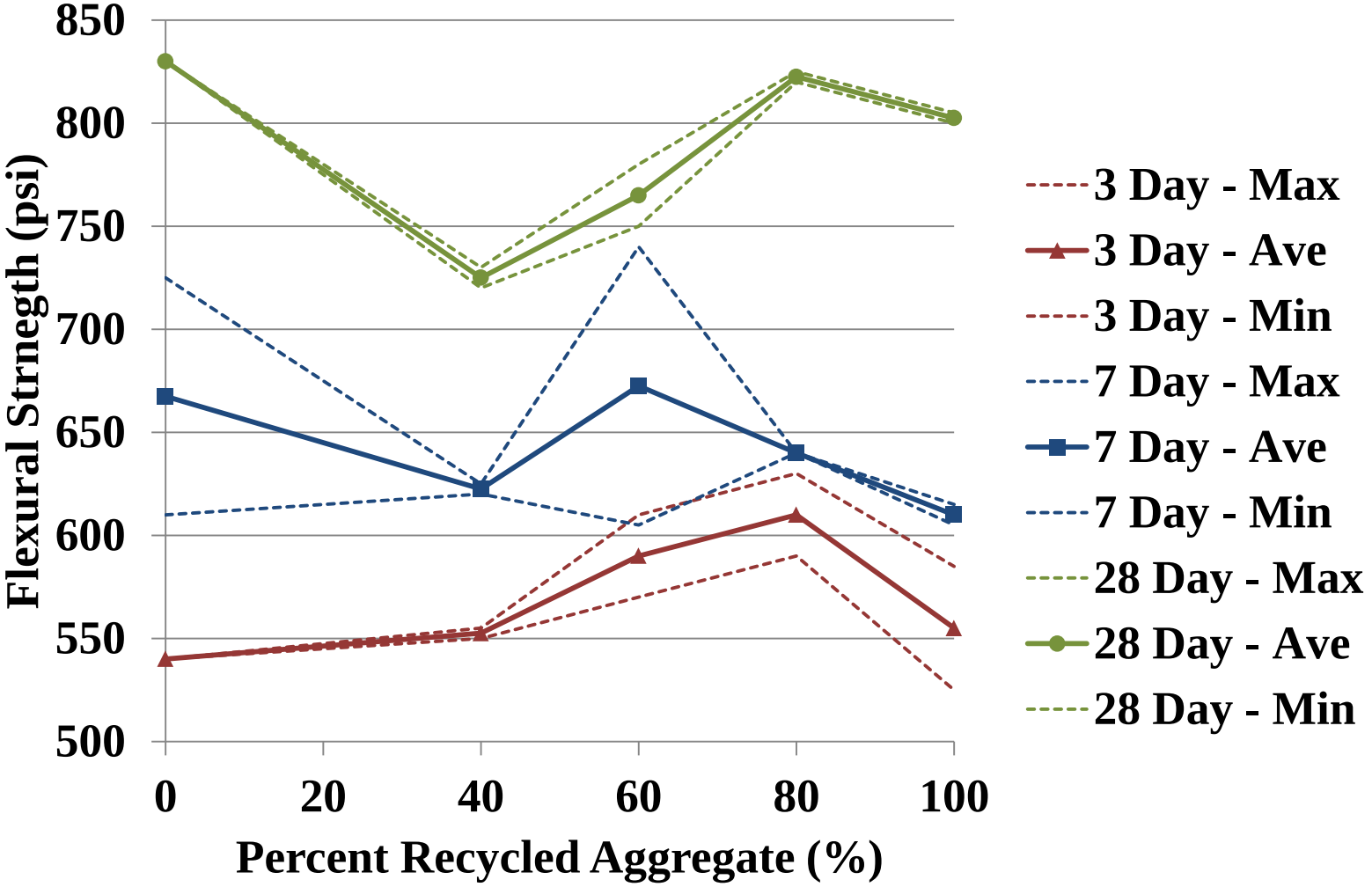
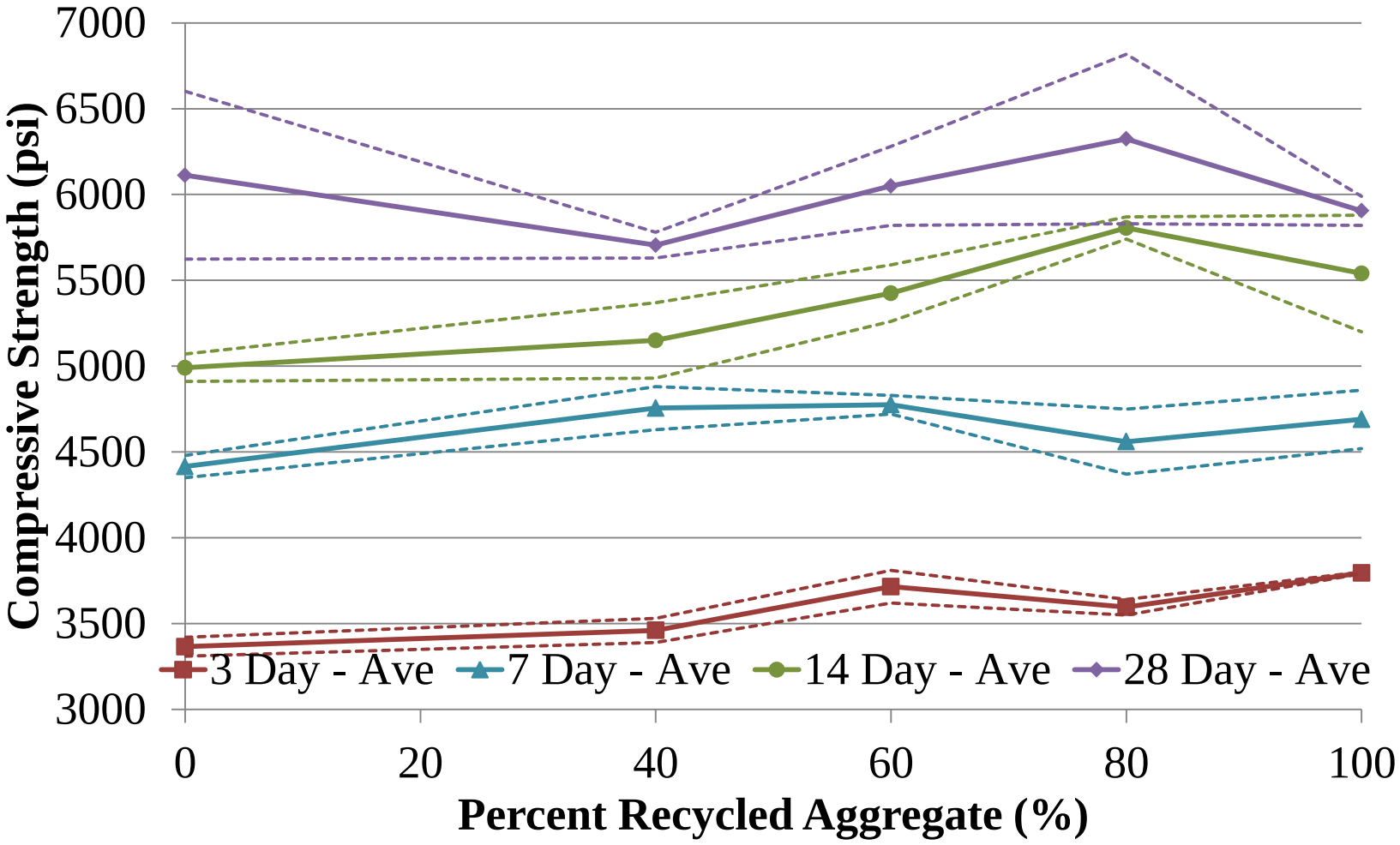
40
60
80
100
100-HS
80-HS
100-M


RAPID CHLORIDE VS. SURFACE RESISTIVITY
Rapid Chloride (Coulombs)
700
600
500
400
300
200
100
0
35
55
75
95
115
Surface Resistivity (kilohm-cm)
y = 15923x^-0.916
R² = 0.7297

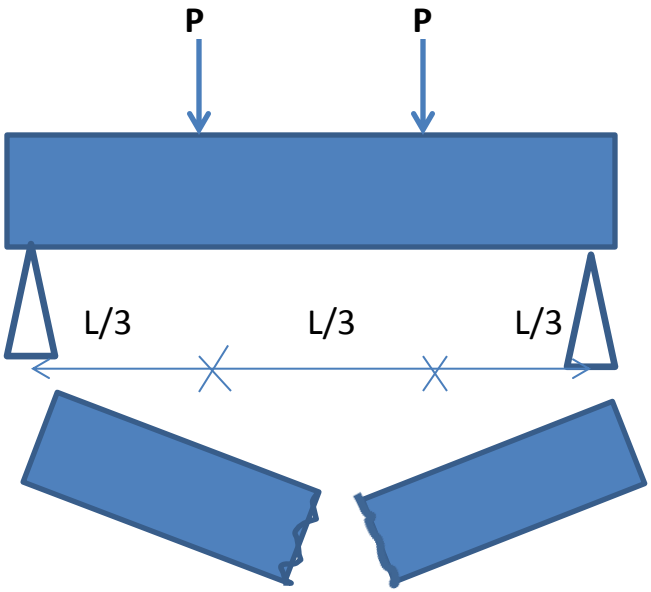
FLEXURAL STRENGTH PROPERTIES



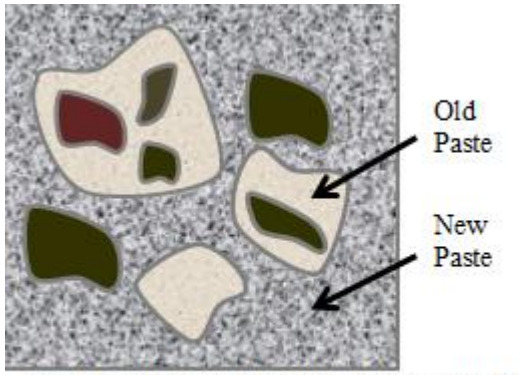
COMPRESSIVE STRENGTH PROPERTIES



AGGREGATE CRACKED FACE ANALYSIS



b) Fractured face of beam



Total Number of Effective Aggregate: 5
Total Number of Virgin Aggregate: 6

FRACTURED FACE EVALUATION

OBSERVED
# of Fractured RCA
# of Fractured Aggregate

COMPUTED
Aggregate Avoidance index

FRACTURED FACE EVALUATION

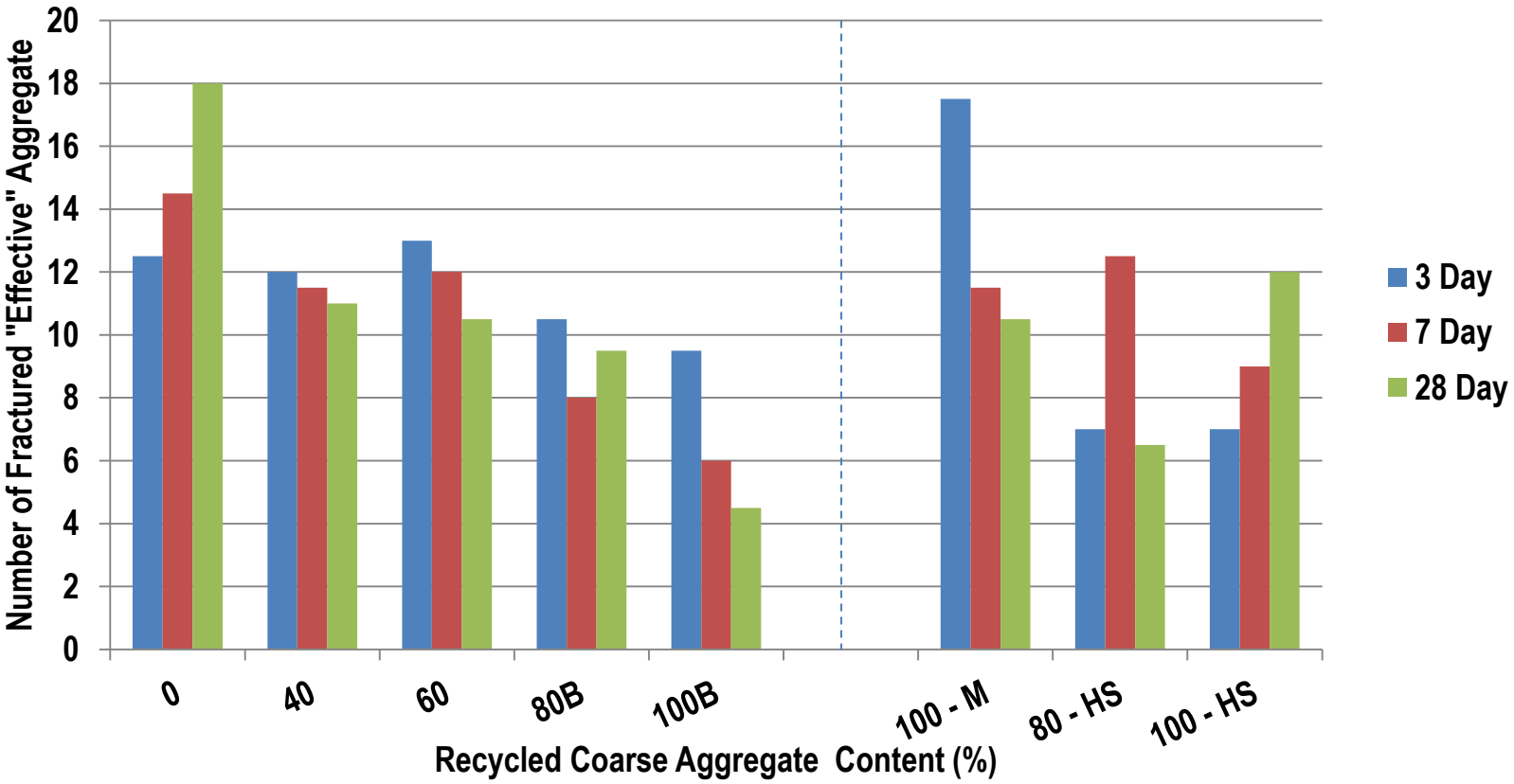
OBSERVED
# of Fractured RCA
# of Fractured Aggregate

COMPUTED
Aggregate Avoidance index

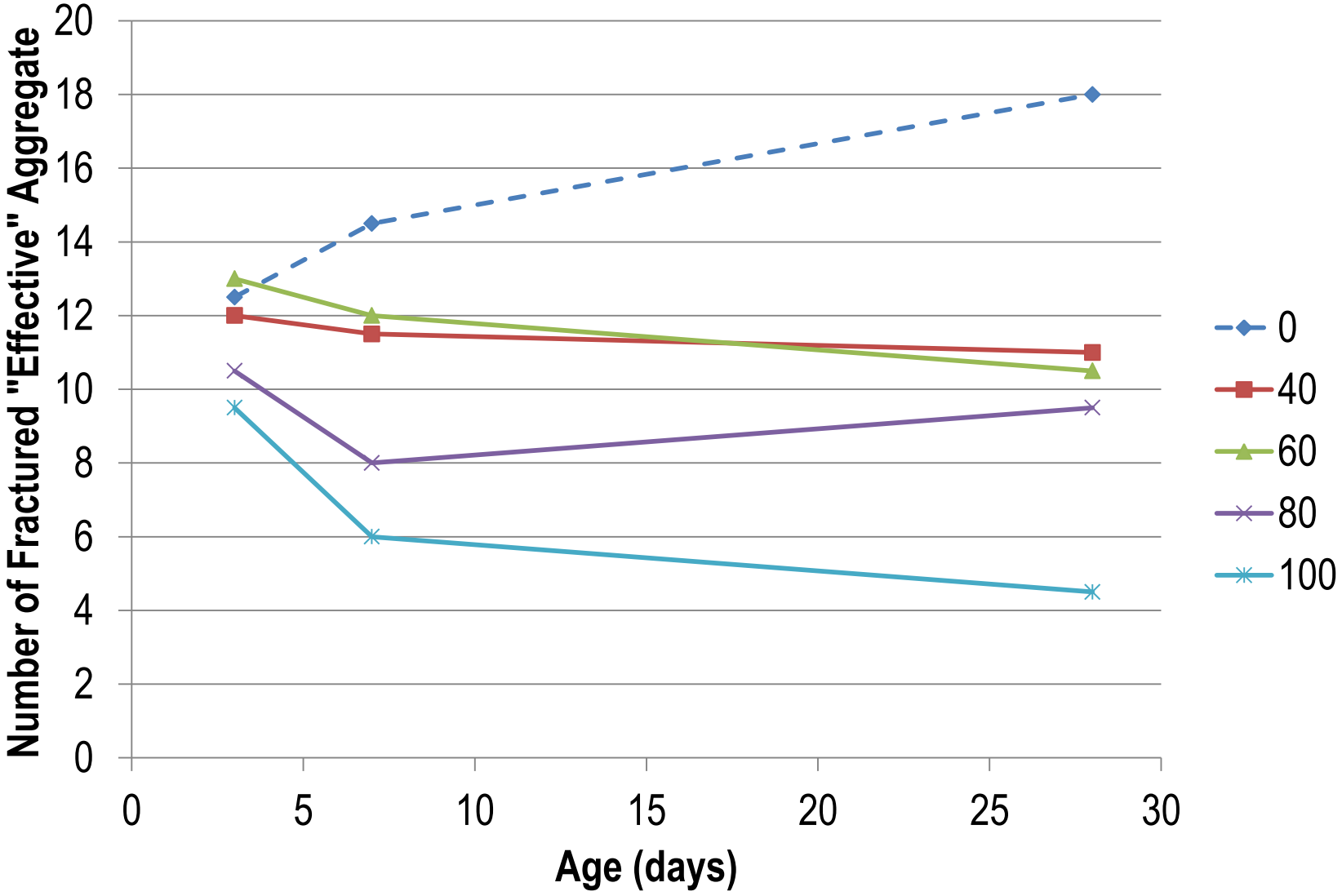
INTERIM OBSERVATION

- Apparently no statistically Significant difference b/w Mechanical Properties RAC Vs NO RAC
- Recycled aggregate 2 lift paving can be more cost effective than traditional (virgin aggregate concrete) monolithic layer.
- RAC $\geq$ 50% Appeared to Optimize Mech. Properties. MnROAD sustainable concrete cell
- Observed Cracked Beam Face Anomaly
- Investigate Cracked Face More Closely: Is there Enhancement of ITZ?
  - Count cracked aggregate face
  - Develop a systematic evaluation method

BEAM FACE FRACTURED AGGREGATE COUNT



Counted Fractured Aggregates



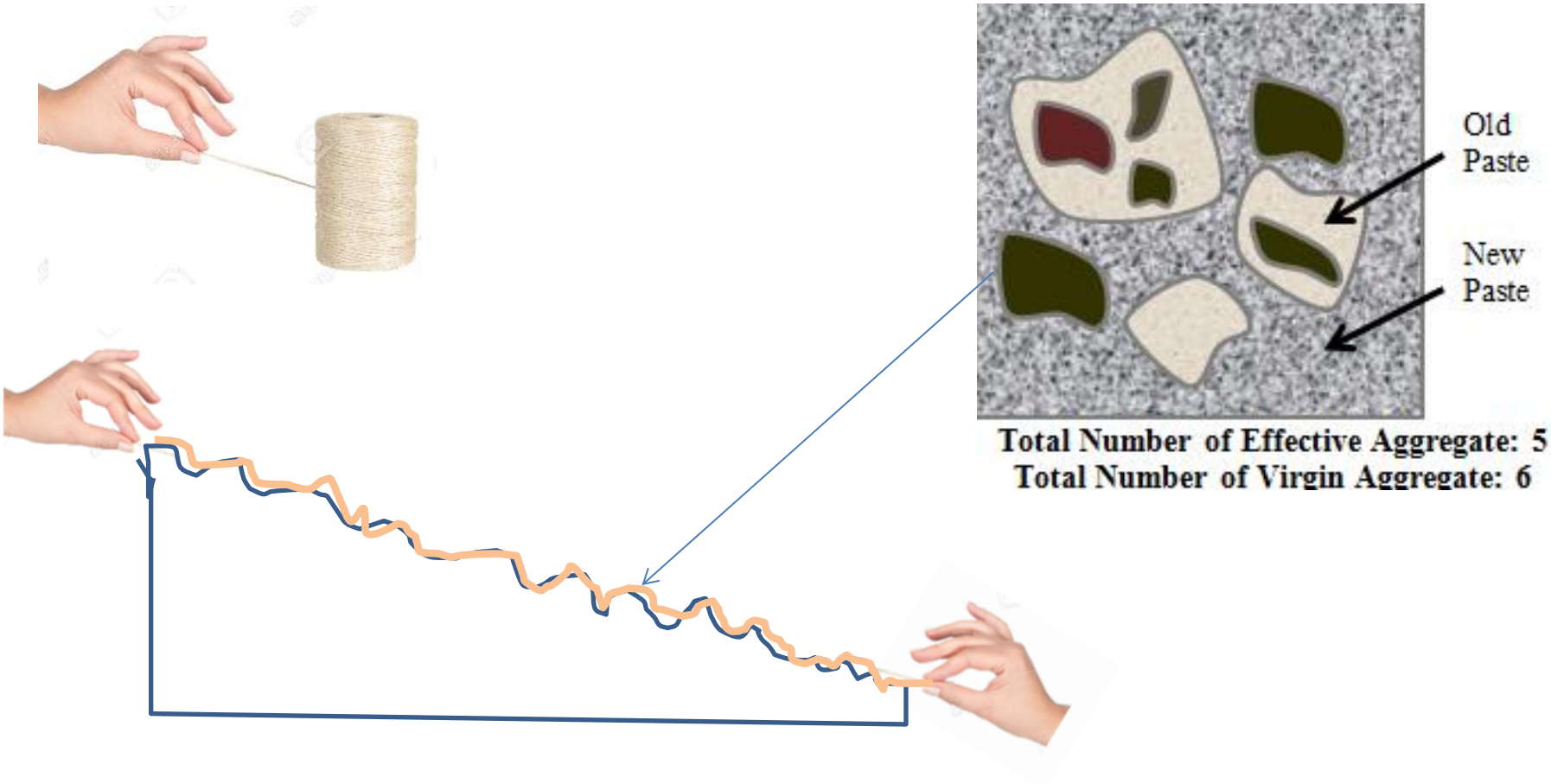
The Aggregate Avoidance Concept

- Remove the Human factor

<u>Lemmae</u>:

- Aggregate is avoided during early age cracking
- Aggregate is avoided when cracking occurs and the aggregate is of high quality.
- Aggregate is avoided when zone around the aggregate is enhanced thus protecting the aggregate
- AAI ~ More Tortuous Path

Conceptualization of Aggregate Avoidance Index

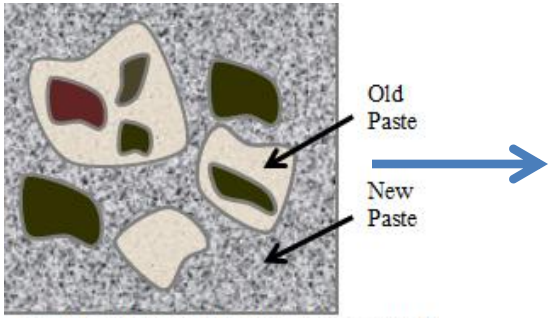


Thread Length

Displacement

$$(\mathrm{AAI}) = \frac{\text{Thread Length}}{\text{Displacement}}$$

Conceptualization of Aggregate Avoidance Index



Total Number of Effective Aggregate: 5
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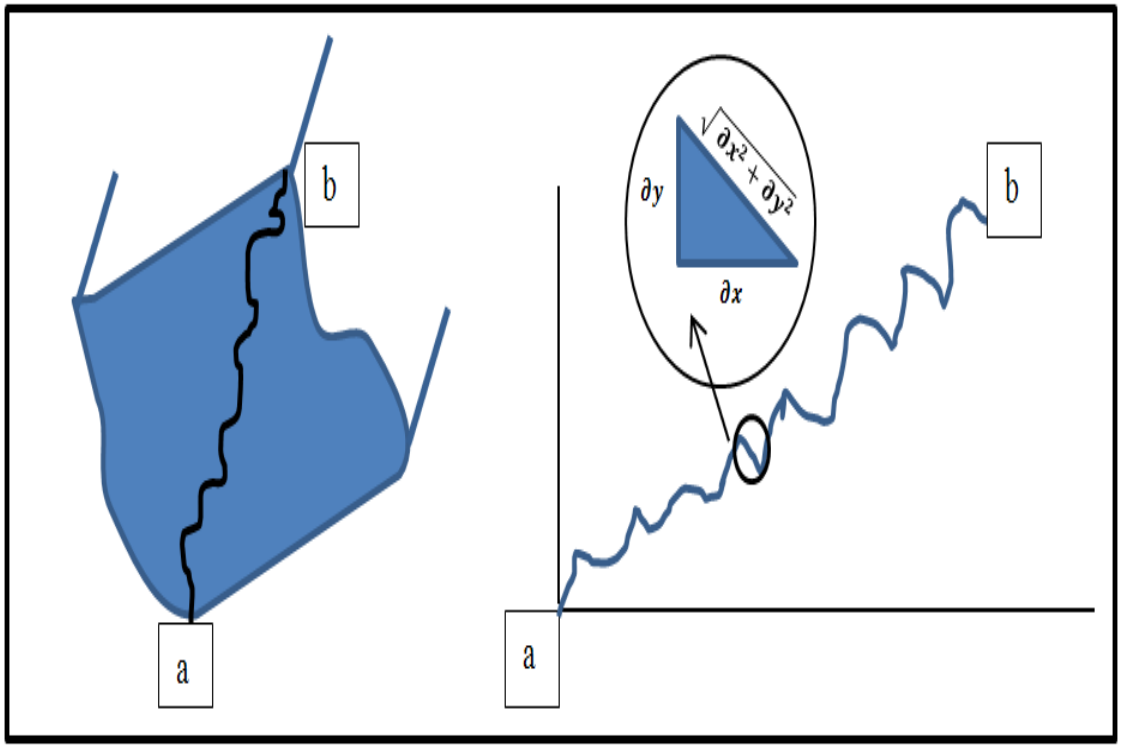
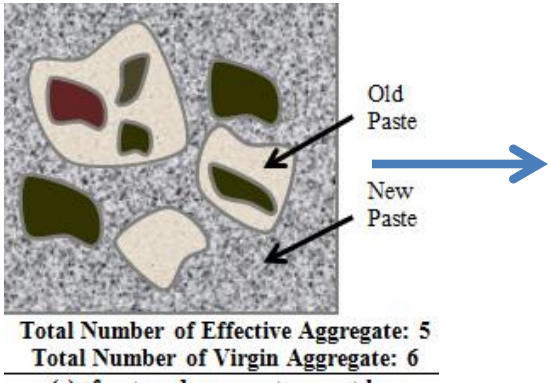


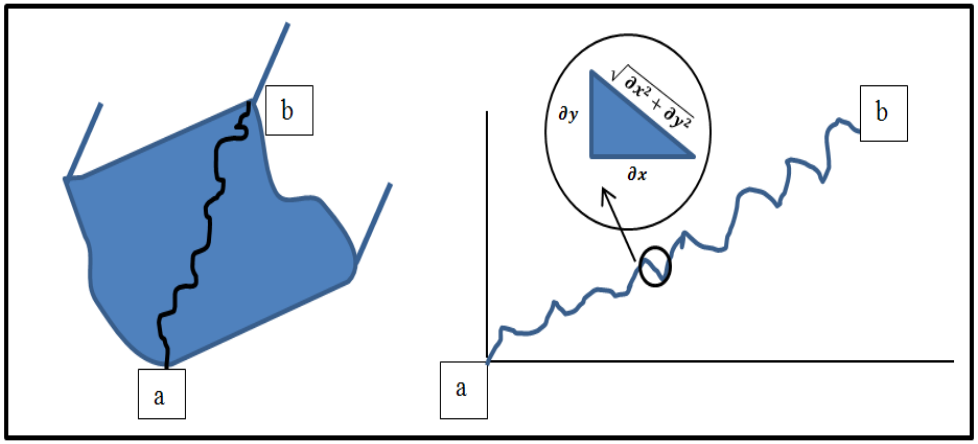
$$\text{Aggregate avioidance index (AAI)} = \frac{\text{length of fracture line}}{\text{absolute displacement}}$$

Length of element ds = $\sqrt{(\partial x)^2 + (\partial y)^2} = \left((\partial x)^2\left(1 + \left(\frac{\partial y}{\partial x}\right)^2\right)\right)^{\frac{1}{2}}$

$$\text{AAI} = \frac{1}{b-a}\int_a^b \left((1 + \left(\frac{\partial y}{\partial x}\right)^2\right)^{\frac{1}{2}} (\partial x)$$

Conceptualization of Aggregate Avoidance Index





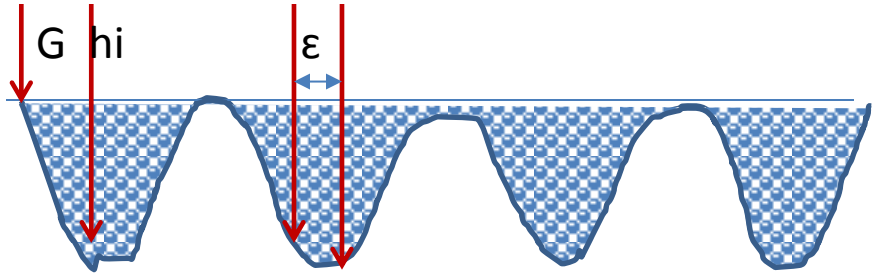
$$\text{Aggregate avioidance index (AAI)} = \frac{\text{length of fracture line}}{\text{absolute displacement}}$$

Length of element ds = $\sqrt{(\partial x)^2 + (\partial y)^2} = \left((\partial x)^2\left(1 + \left(\frac{\partial y}{\partial x}\right)^2\right)\right)^{\frac{1}{2}}$

$$\text{AAI} = \frac{1}{b-a}\sum_{a}^{b} \left((1 + (slope)^2)^{\frac{1}{2}}(step\ size)\right)$$

$$\textbf{Aggregate avioidance index (AAI)} = \frac{\textbf{length of fracture } \boldsymbol{line}}{\textbf{absolute displacement}}$$

What About Average Texture Depth?

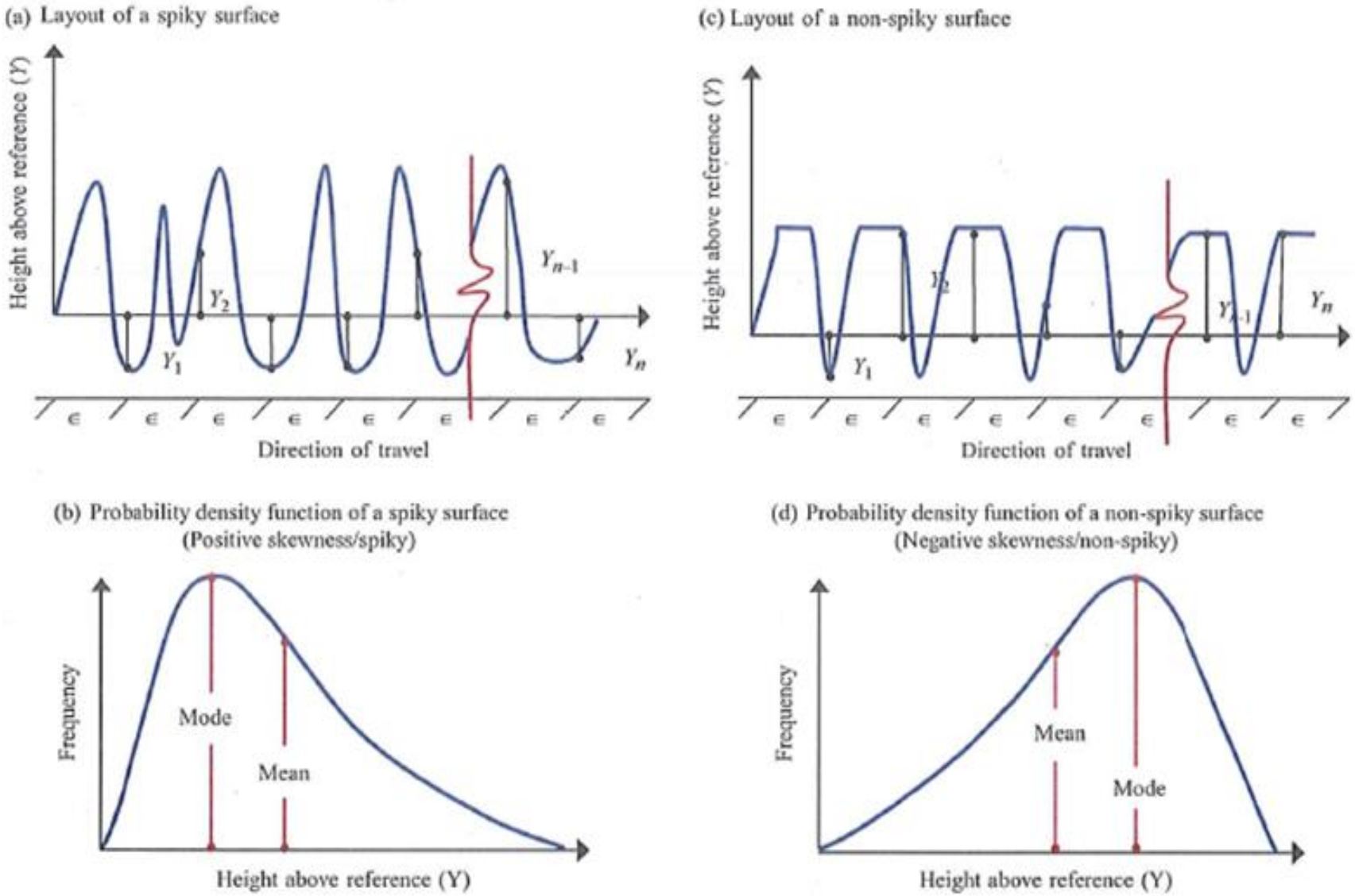


$$\text{MPD} = \sum_{i=1}^{n} \frac{(h_i - G)\varepsilon}{n}$$

$$\text{AAI} = \frac{\sum_{i=1}^{n}\left(\left(h_i - h_{(i-1)}\right)^2 + \varepsilon^2\right)^{0.5}}{n\varepsilon}$$

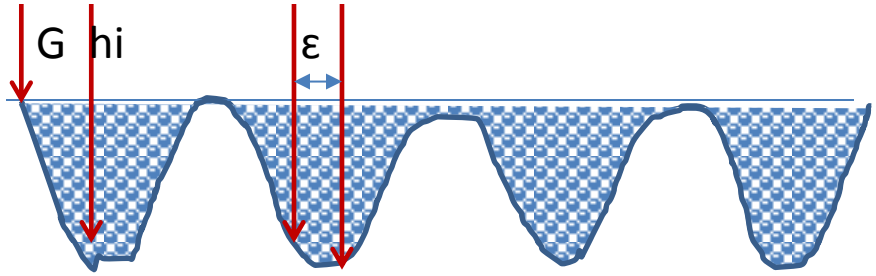
AAI is a better indicator of undulations within macro texture.

What About Skewness??



Layout graphs and probability density function graphs [Izevbekhai 2012]

What About Pointedness / Kurtosis



Macro Kurtosis = $\frac{n(n+1)}{(n-1)(n-2)(n-3)} \sum_{i=1}^{n} \left(\frac{\boldsymbol{h_i} - \bar{\boldsymbol{h}}}{\boldsymbol{s}}\right)^4 - \frac{3\,(n-1)^2}{(n-2)(n-3)}$

where

Y = depth measured from reference

N = Sample size

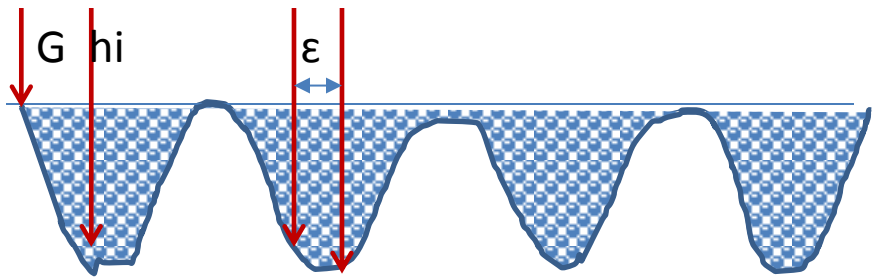
S = Sample standard deviation

$$\textbf{AAI} = \frac{\sum_{i=1}^{n}\left(\left(h_i - h_{(i-1)}\right)^2 + \varepsilon^2\right)^{0.5}}{n\varepsilon}$$

If "ε" is small compared to a typical wavelength

AAI is a better indicator than Kurtosis of undulations within fractured face macro texture.

What About Skewness



Skewness = $\frac{\sum_{i=1}^{n}(h_i-\overline{h})^3}{(n-1)S^3}$

where

h = depth measured from reference

n= Sample size

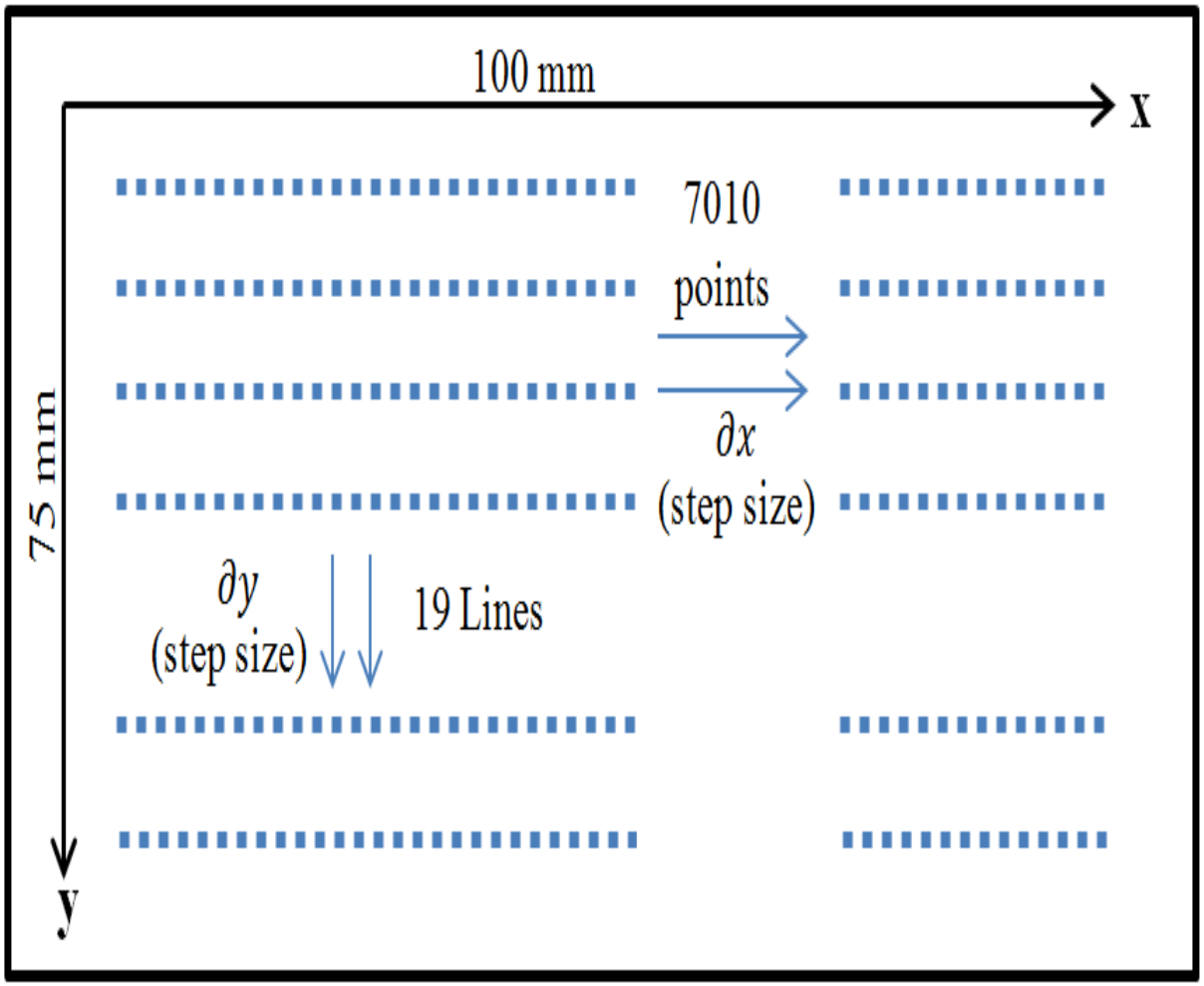
S = Sample standard deviation

AAI=$\frac{\sum_{i=1}^{n}\left(\left(h_i-h_{(i-1)}\right)^2+\varepsilon^2\right)^{0.5}}{n\varepsilon}$

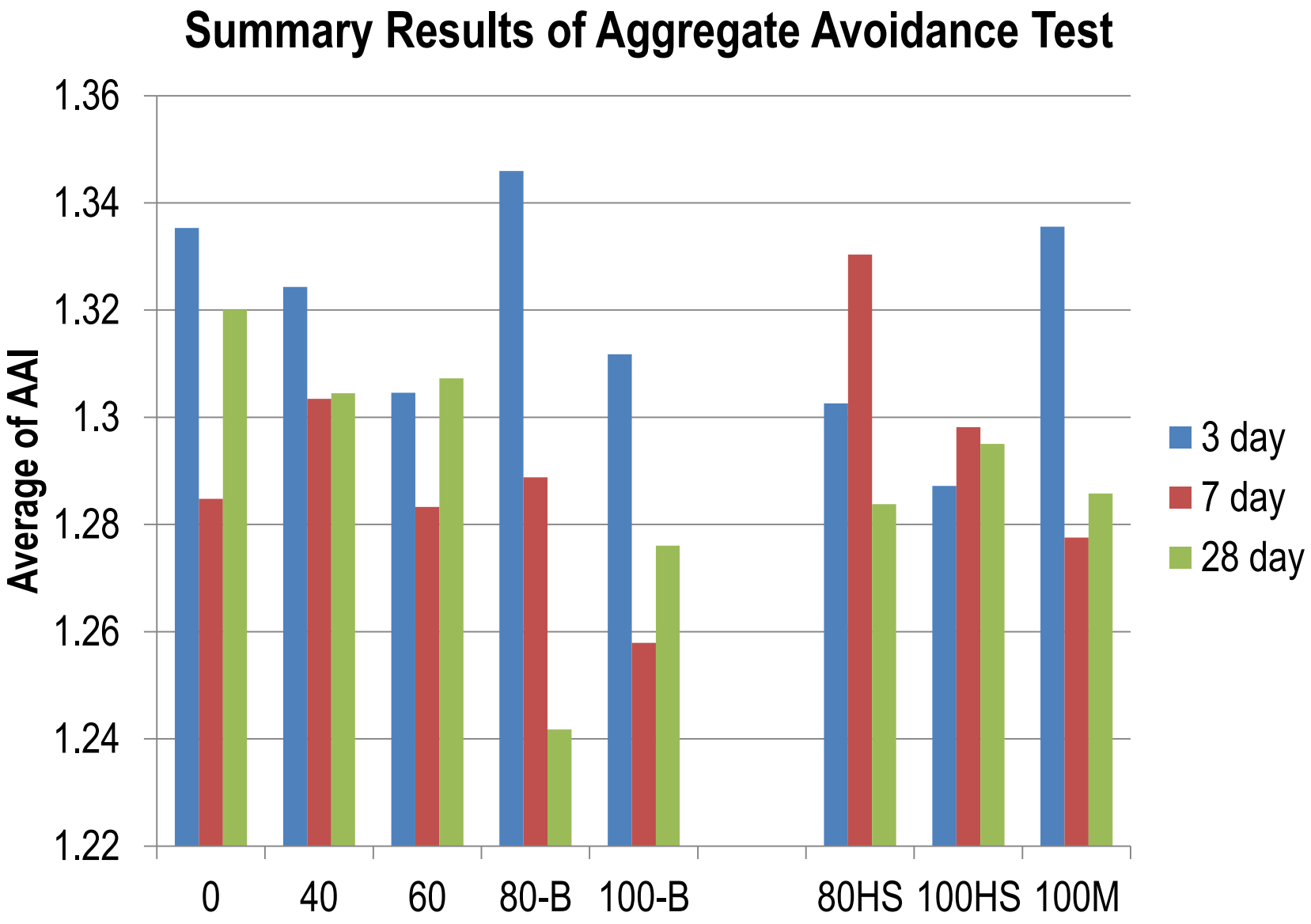
If "ε" is small compared to a typical wavelength

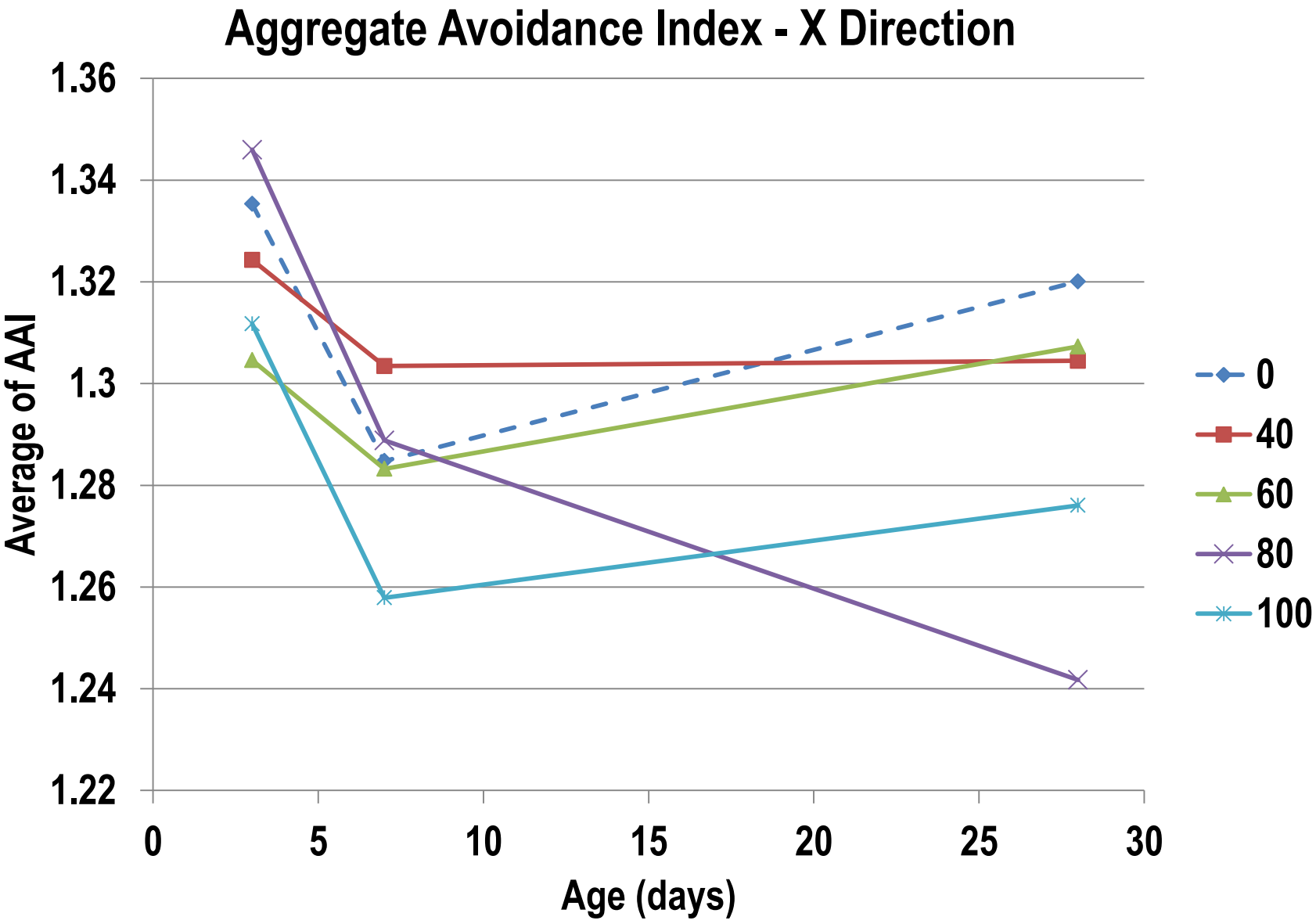
AAI is a better indicator than skewness or Kurtosis of undulations within macro texture.

MEASUREMENT OF UNEVENNESS OF FRACTURED FACE



MEASUREMENT OF UNEVENNESS OF FRACTURED FACE


Summary Results of Aggregate Avoidance Test
Average of AAI
1.36
1.34
1.32
1.3
1.28
1.26
1.24
1.22
0
40
60
80-B
100-B
80HS
100HS
100M
3 day
7 day
28 day


Aggregate Avoidance Index - X Direction
Average of AAI
1.36
1.34
1.32
1.3
1.28
1.26
1.24
1.22
0
5
10
15
20
25
30
Age (days)
0
40
60
80
100

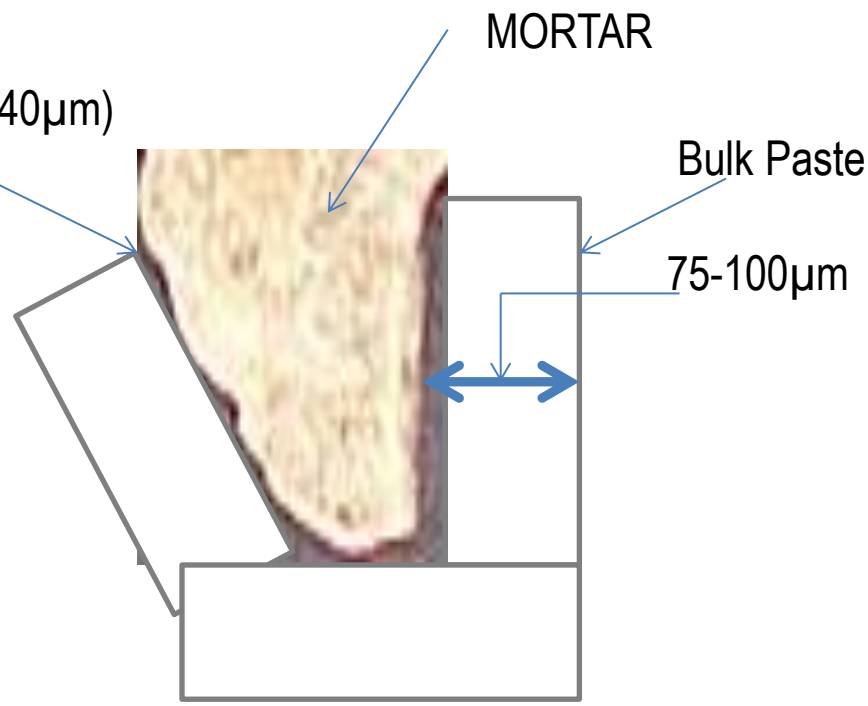
INTERFACIAL TRANSITION ZONE ENHANCEMENT

$$logE_c = V_p logE_p + V_a logE_a + V_i logE_i \quad (Mindess\ Young\ \&\ Darwin\ 2003)$$

where subscript "I" refers to ITZ "a" to aggregate and "p" to paste

Where quantity "V" refers to volume and "E" to Elastic Modulus

Thus $E_c = E_p^{vp} E_a^{Va} E_i^{V_i}$



Excess Bleed water; Low CSH; High CH & High Ettrignite

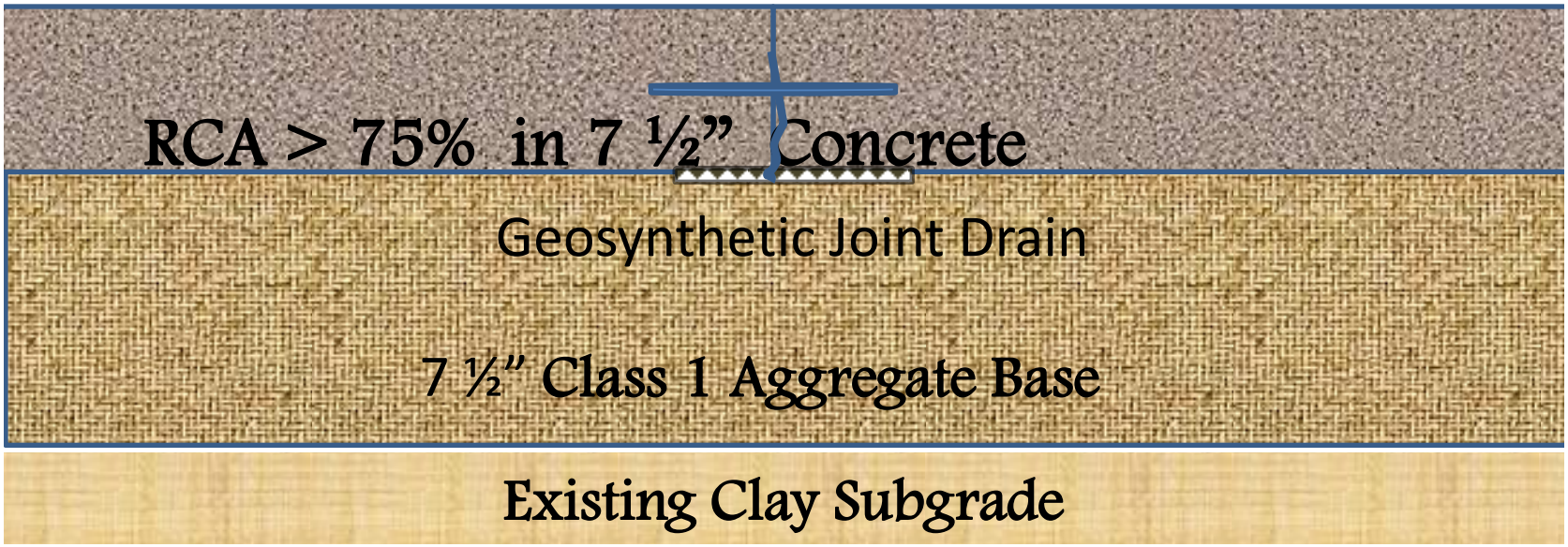
Cracking occurs 10-20µm in the ITZ

More sustainable to enhance ITZ

RECYCLED AGGREGATE CONCRETE INITIATIVES

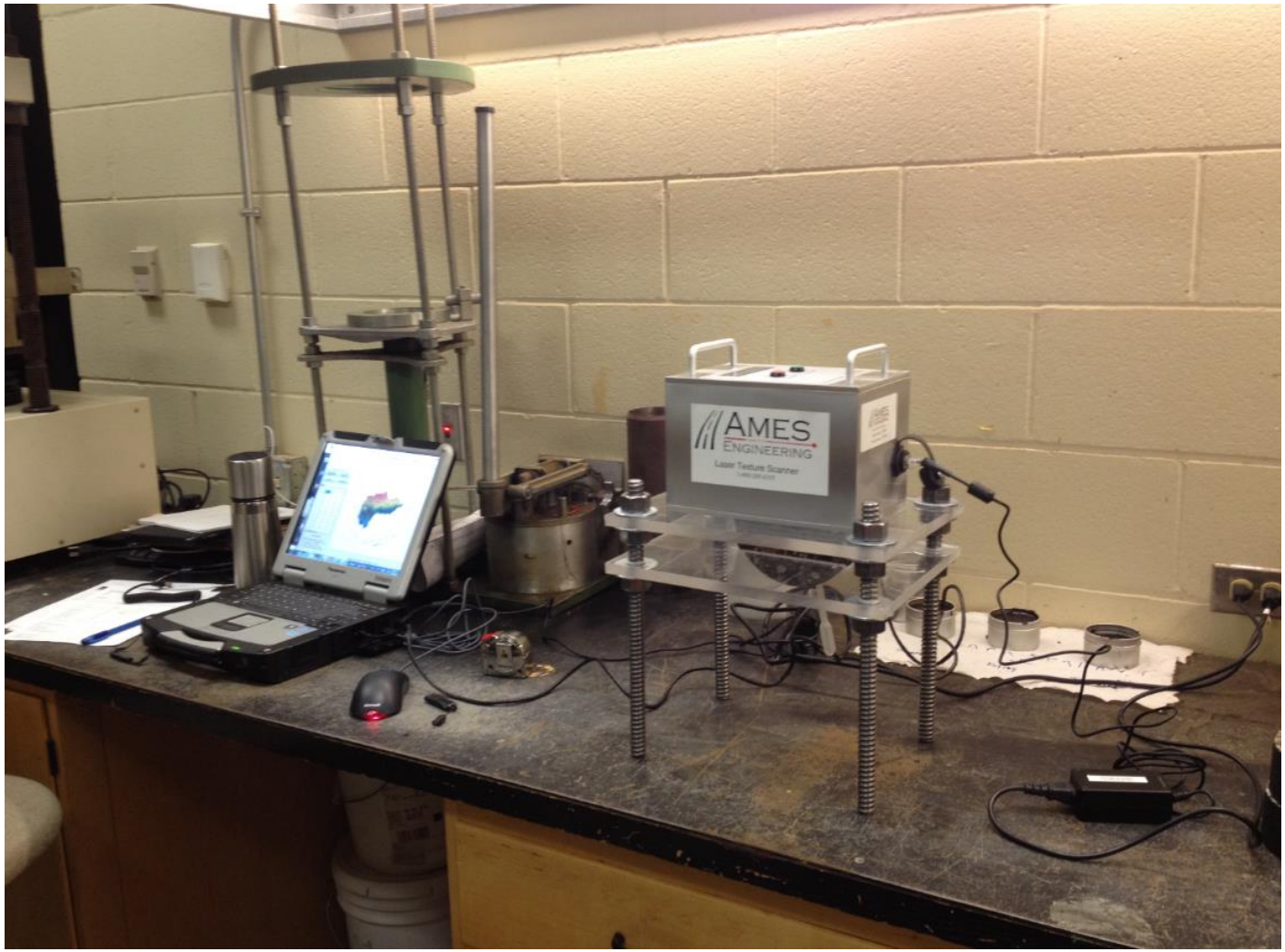
- Sustainable Concrete Cell MnROAD 2013 Construction
- Pre-Construction In House Research
  - Rheological,
  - Mechanical
  - Fracture and Durability Properties
- Economy of Scale

Monitoring Contract: MnDOT/ Minnesota State University

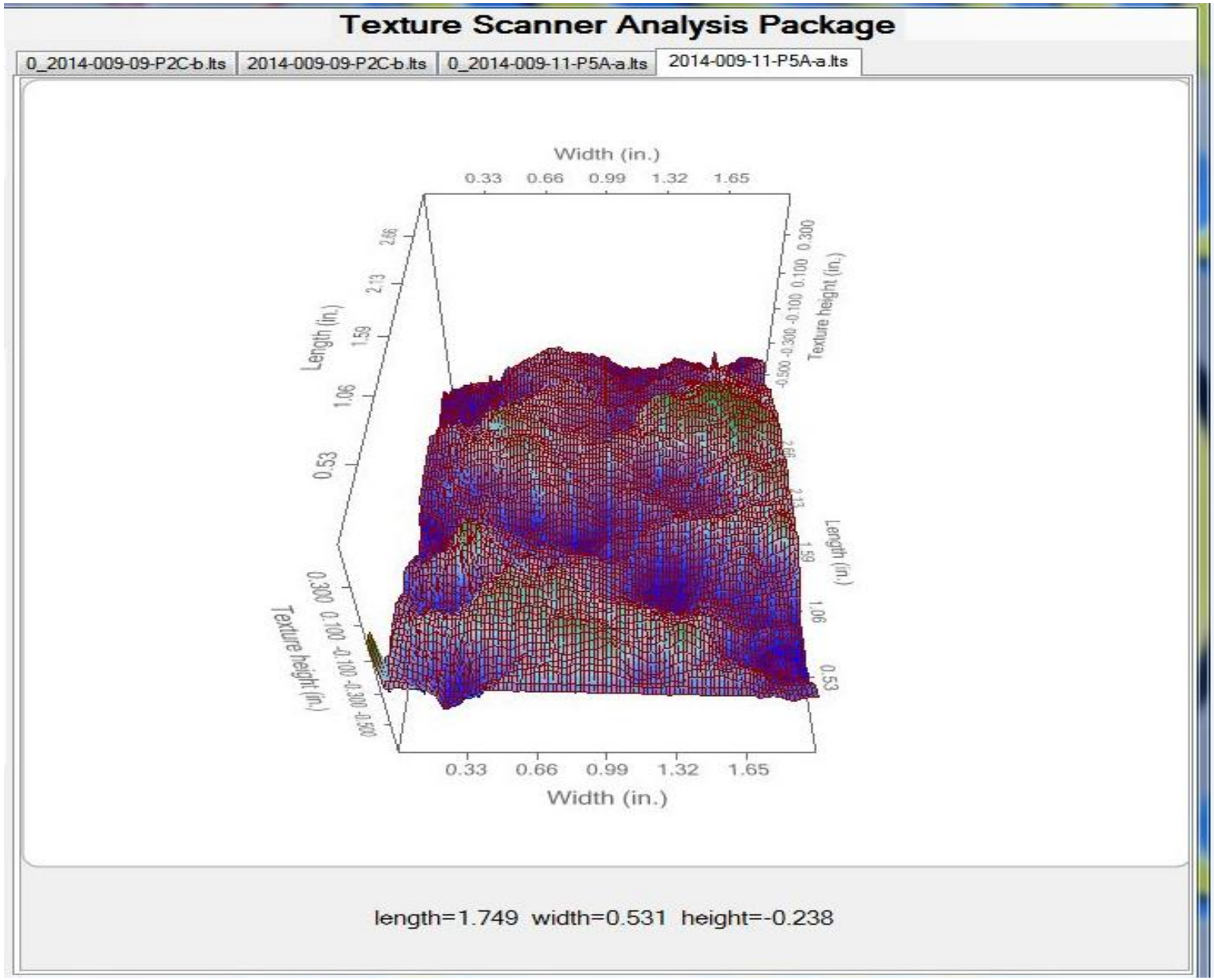


Proposed MnROAD Cells 613 & 713

ASPHALT SCANNING PROCESS



ASPHALT SCAN OUTPUT GRAPHICS



AGGREGATE AVOIDANCE QUACKERY

AGGREGATE AVOIDANCE EXPLAINS ALL PAVEMENT PROBLEMS

CONCLUSION

- Use of Recycled Concrete Aggregate is a cost effective Sustainable solution.
- Comparable to Non RAC in Flexure, Comp, Durability, Permeability
- Enhancement of ITZ has been quantified.
- Aggregate Avoidance Index has been demonstrated as a viable quantity as Proxy for Evaluating ITZ in RAC Concrete
- Does not absolve practitioners of due diligence: Absorption, w/c ratio non synergistic admixtures.
- Long-term Evaluation Optimal Design 75% RAC Continues at MnROAD.
- Valid Application in Asphalt

Suggested Light Reading

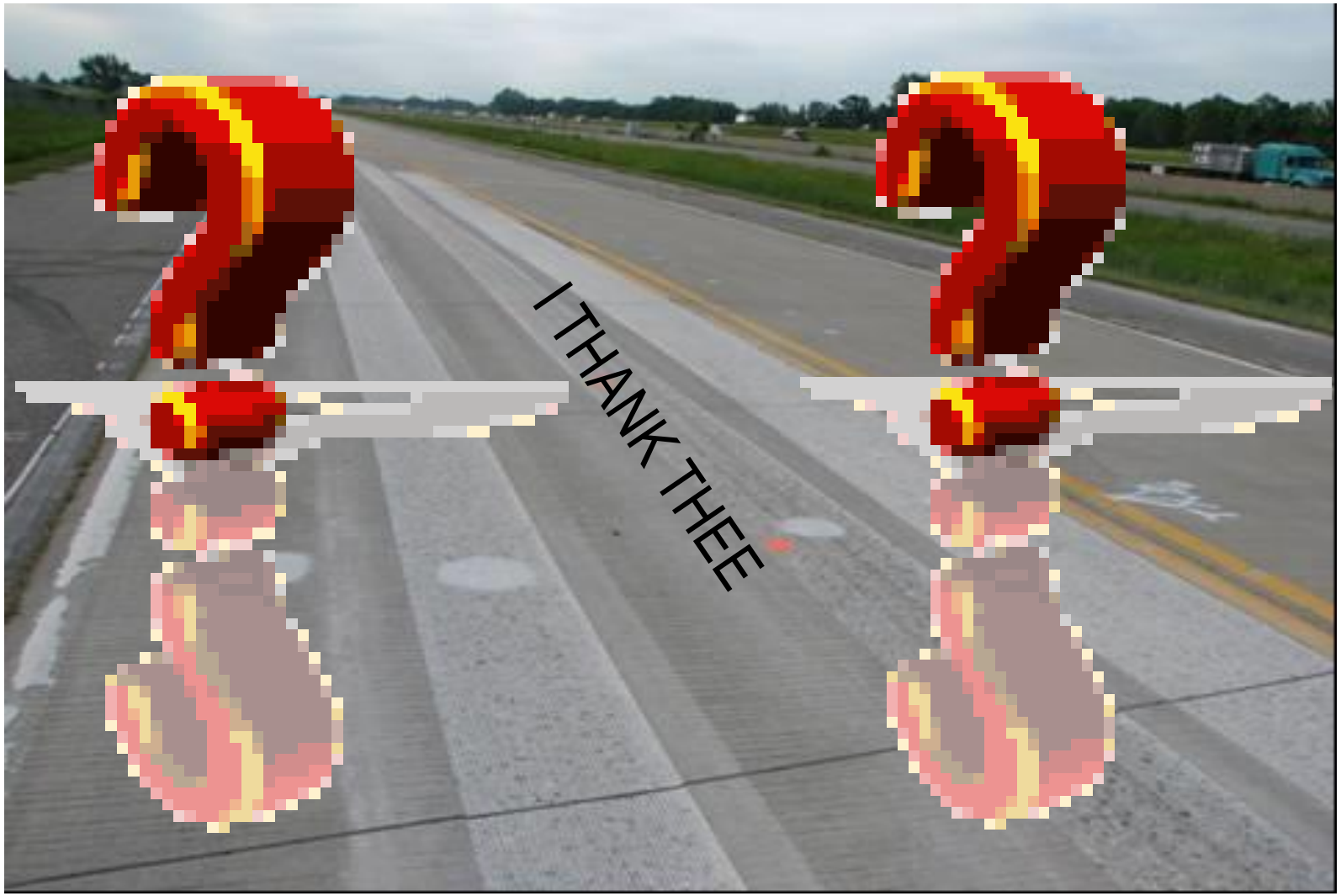
Akkari A.K., Izevbekhai B.I., Olson S.C. (2014)

Development of Aggregate Avoidance Index for Evaluating Recycled Aggregate Concrete TRR 2441, pp. 53–61

URL : http://trrjournalonline.trb.org/doi/abs/10.3141/2441-08

Accessed 7/01/2015

Acknowledgements

- Alexandra Akkari & Steve Olson Co-authors
- MnDOT Concrete Lab
- Dave Baker & MnDOT Aggregate Lab
- Andrew Lutaya (Currently Metro Area Manager)
- Trenton Pray (SWPP)

QUESTIONS