PRE-XVII CONGRESO ARGENTINO de Vialidad y Tránsito

8º EXPOVIAL ARGENTINA

expo 2014 vial Argentina

3 AL 6 DE NOVIEMBRE 2014

HOTEL PANAMERICANO - Buenos Aires, Argentina

Control of Pre-Mature Cracking

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TEXAS A&M UNIVERSITY

Texas Transportation Institute
Texas A&M University System

X CONGRESO INTERNACIONAL ITS

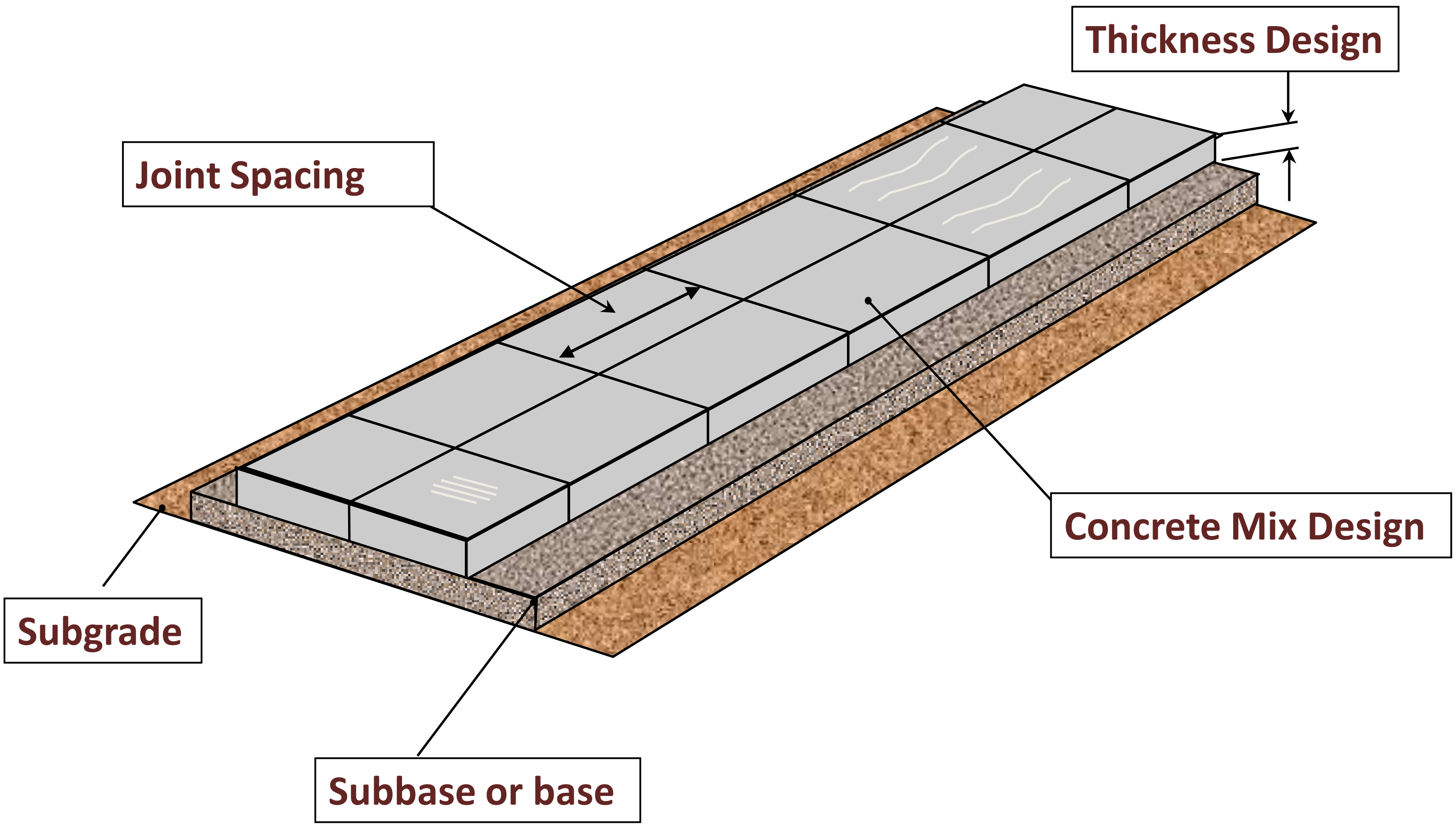
X SIMPOSIO DEL ASFALTO

II SEMINARIO INTERNACIONAL DE PAVIMENTOS DE HORMIGÓN

Discussion

- ✓ Design
- ✓ Materials
- ✓ Construction

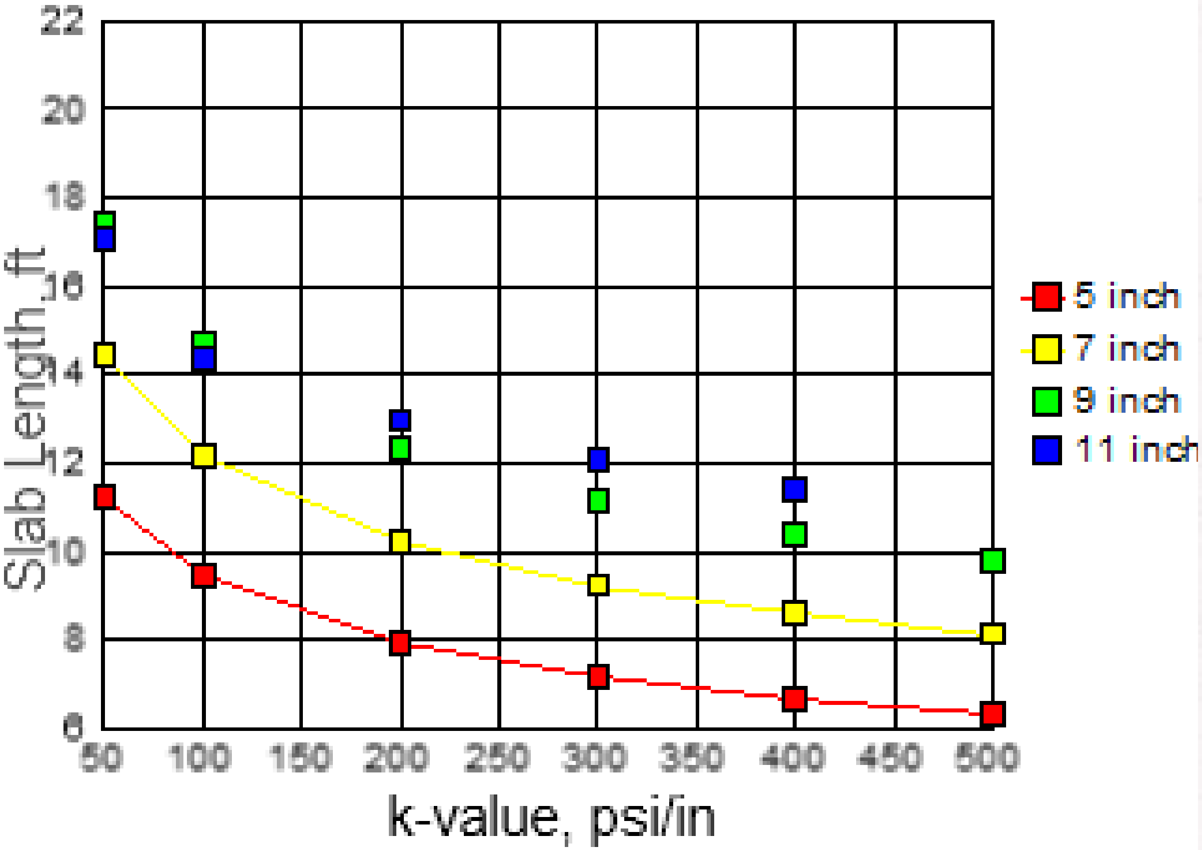
Jointed Plain Concrete Pavements (JPCP): Design Features

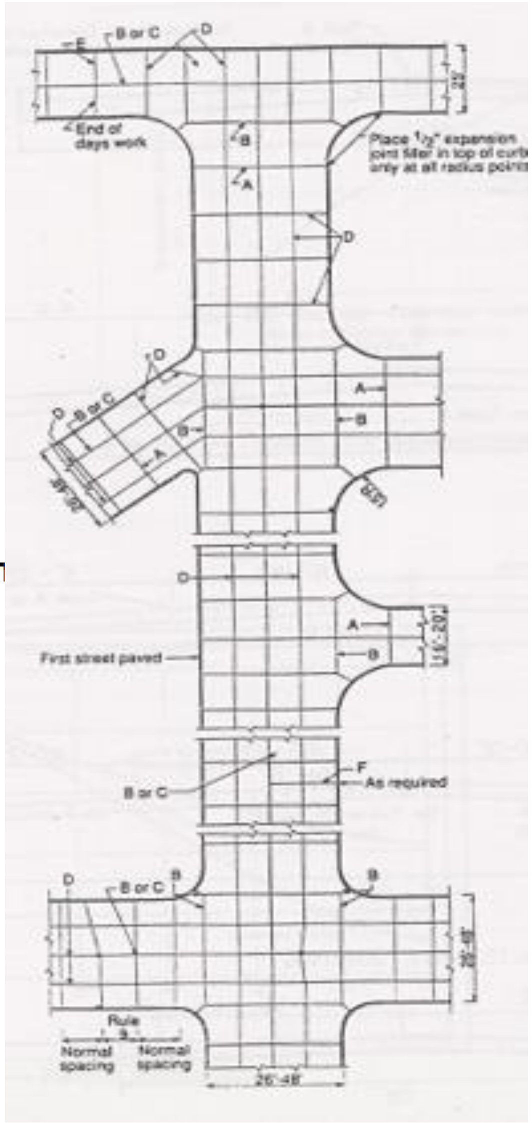


Crack Control Factors

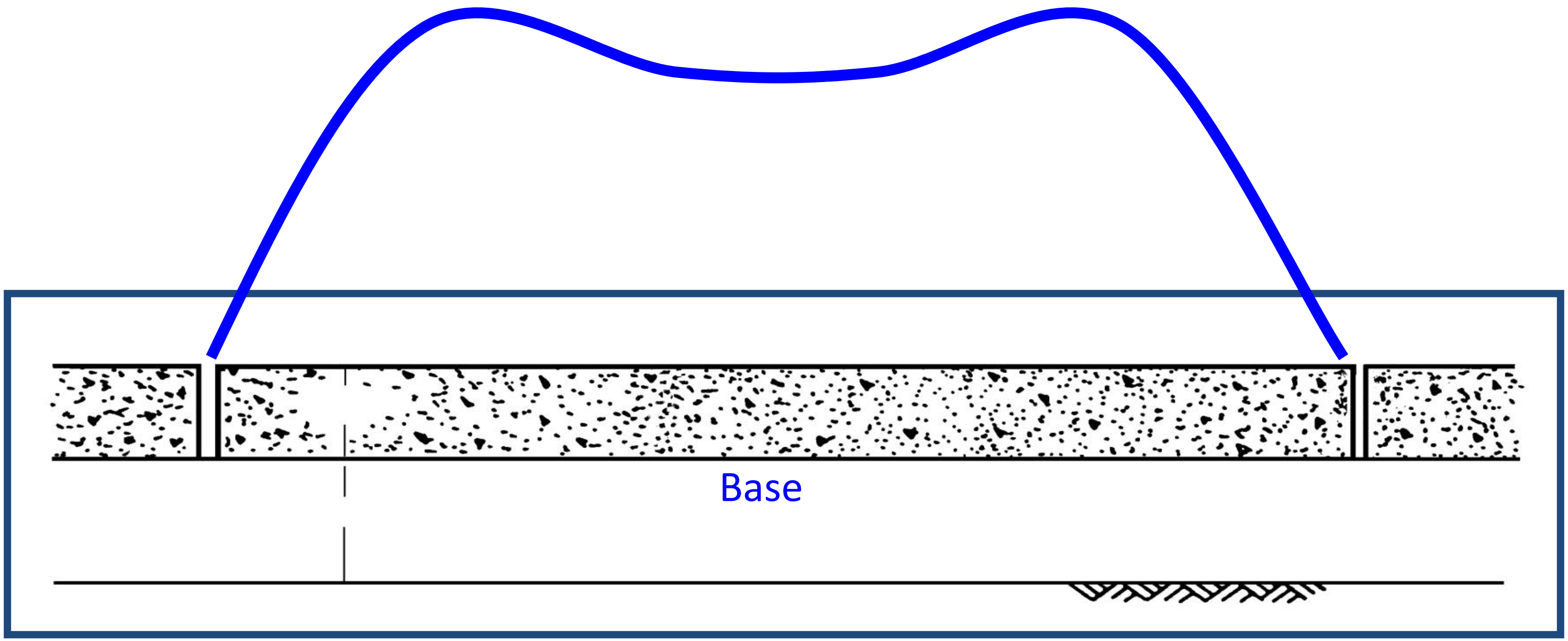
- Design
  - Jointing Patterns
  - Base Support
  - Depth and Timing of Cut
- Materials
  - Mixture Proportions (Set Gradient)
  - Bond
- Construction
  - Weather Conditions (wind, solar, etc.)
    - Method of Curing

Jointing Requirements (ACI 325.32)



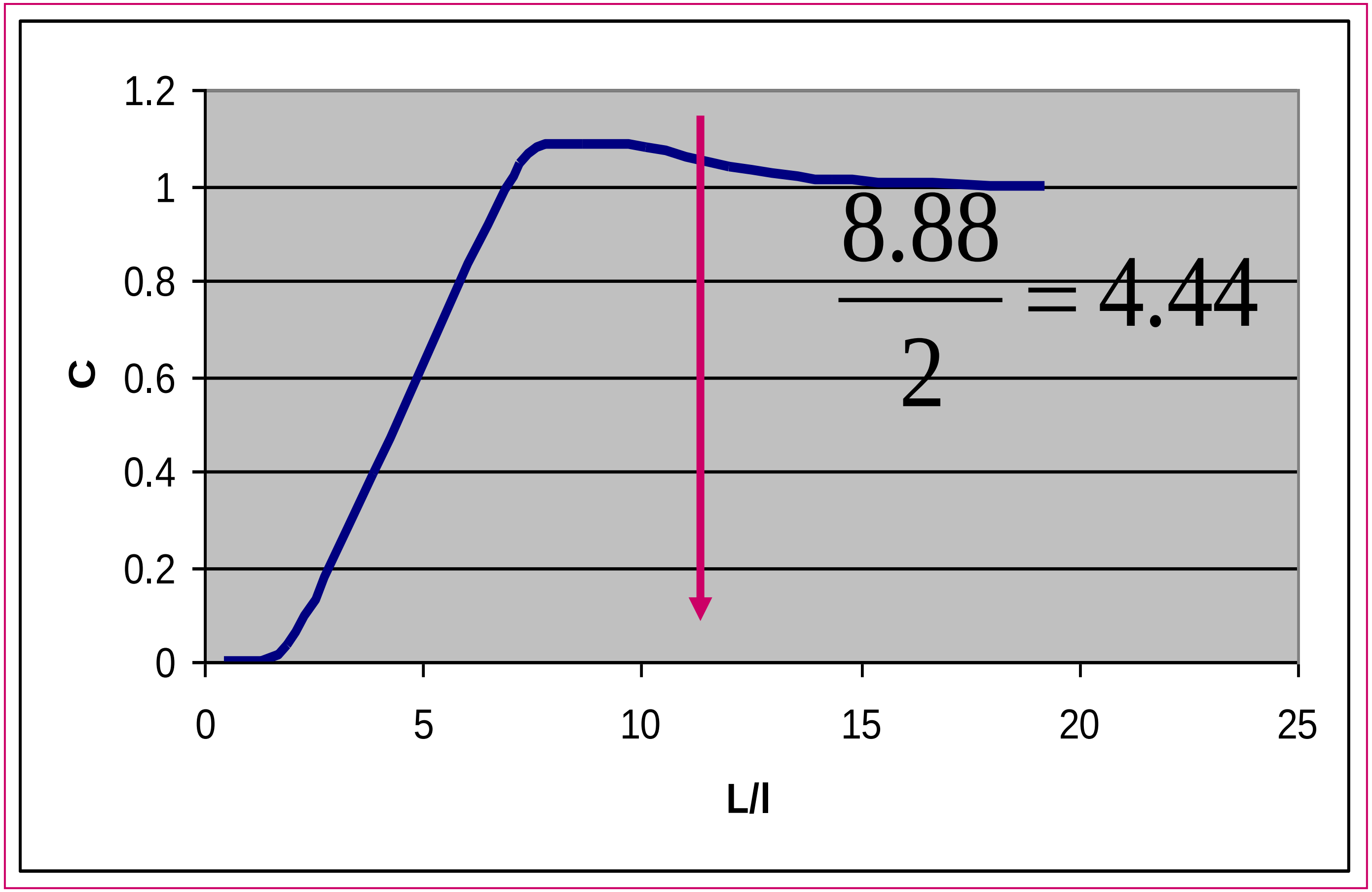


Early Stress Patterns



Maximum Jointing Limits

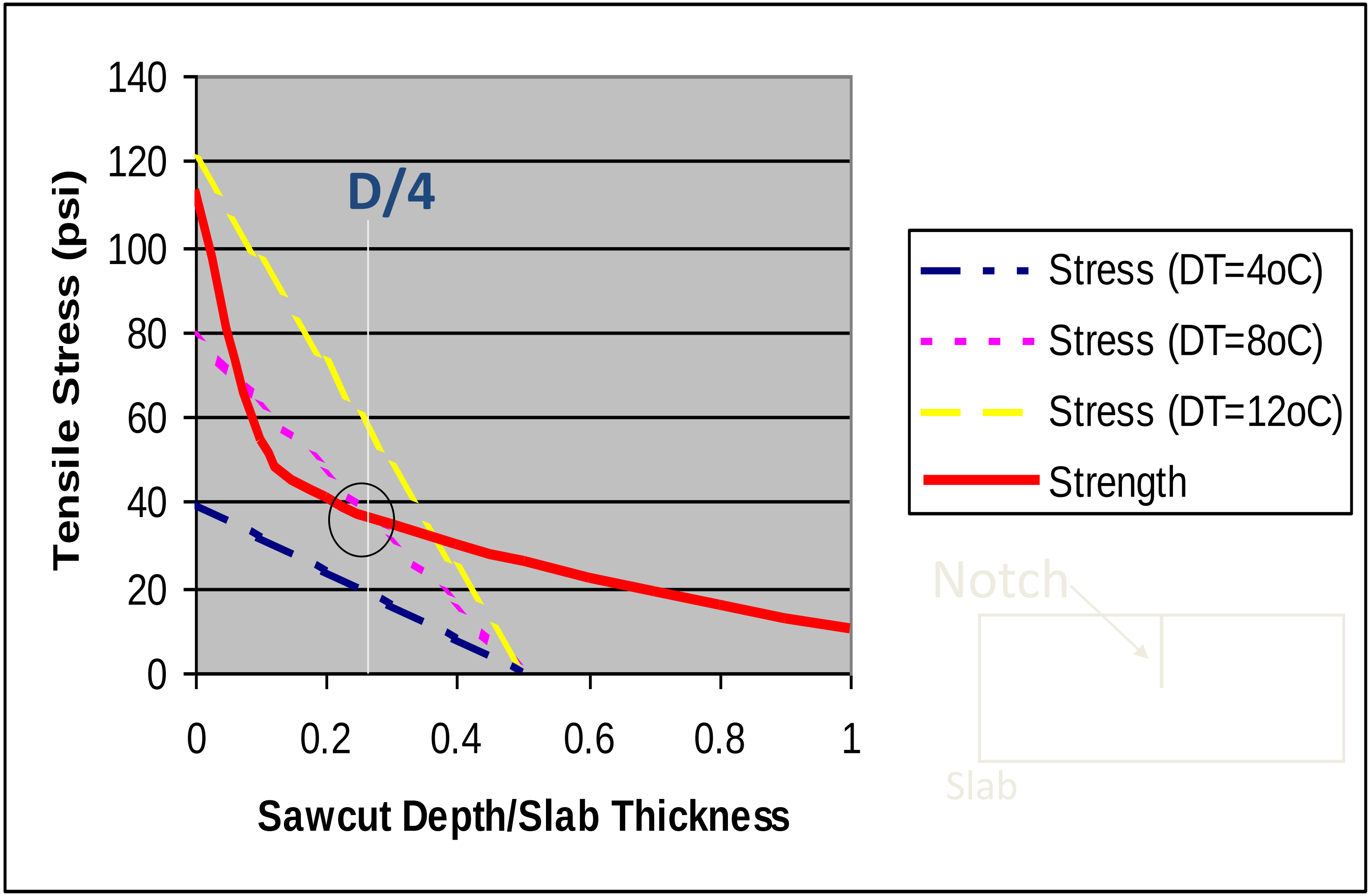
$$C = 1 - \frac{2\cos\lambda\cosh\lambda(\tan\lambda + \tanh\lambda)}{\sin 2\lambda + \sinh 2\lambda}$$



$$\frac{8.88}{2} = 4.44$$

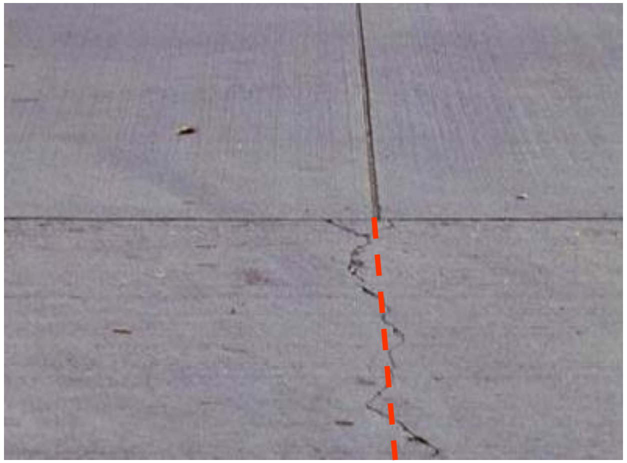
Sawcut Timing and Depth

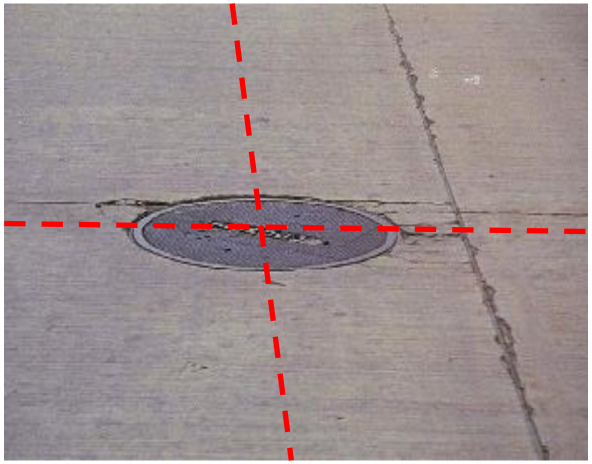
Optimum Sawcut Depth



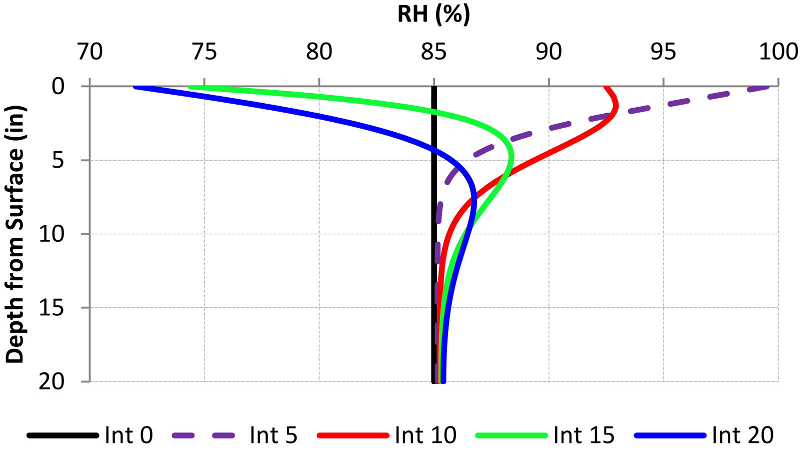
Good Practice!

Bad Practice!

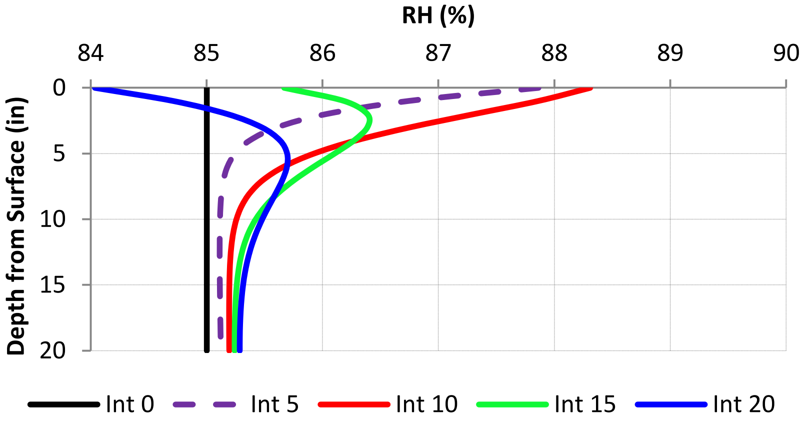




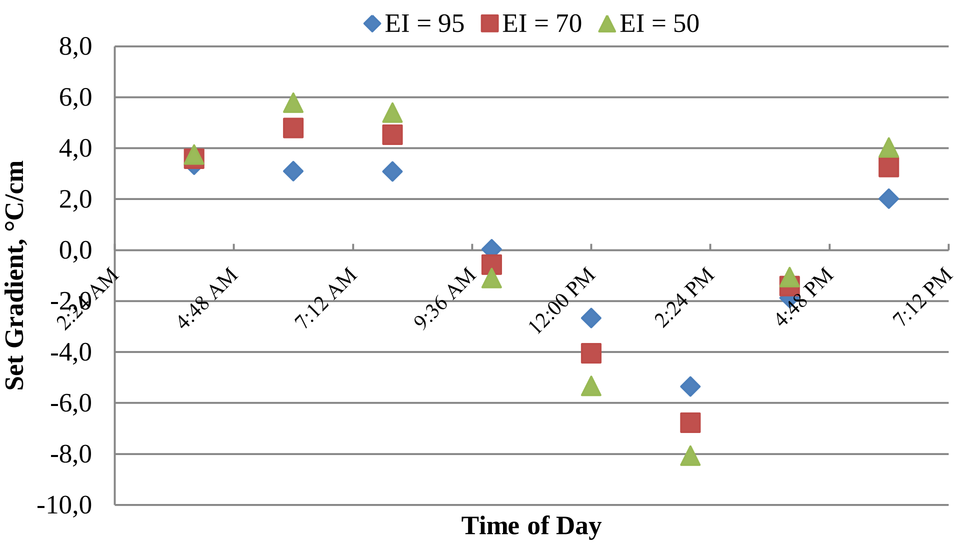
Set Gradient



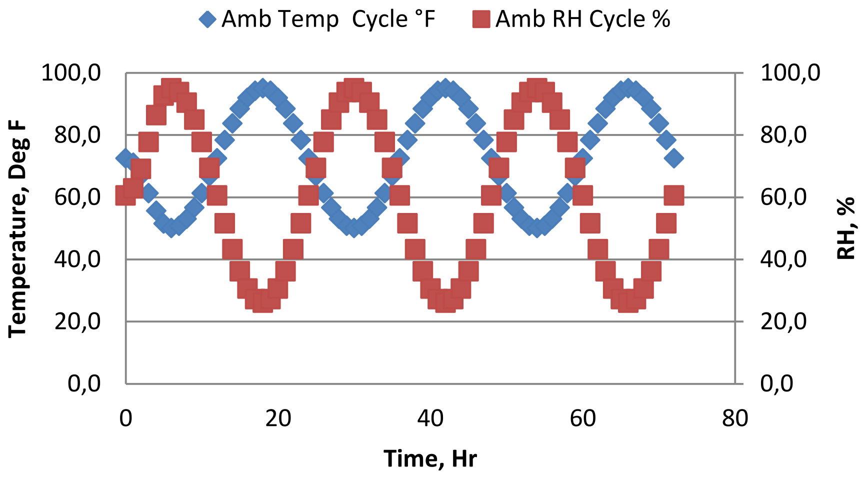
No Curing

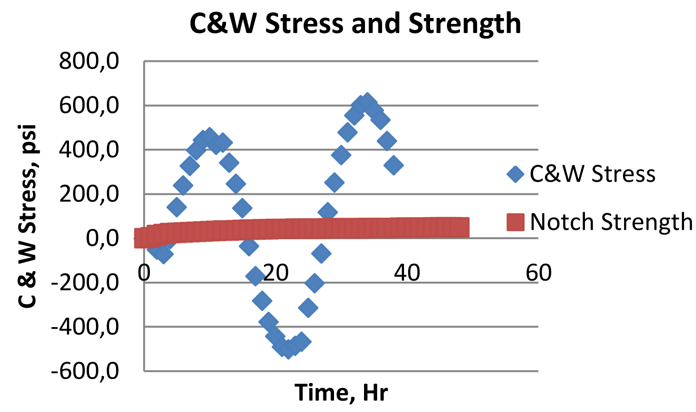


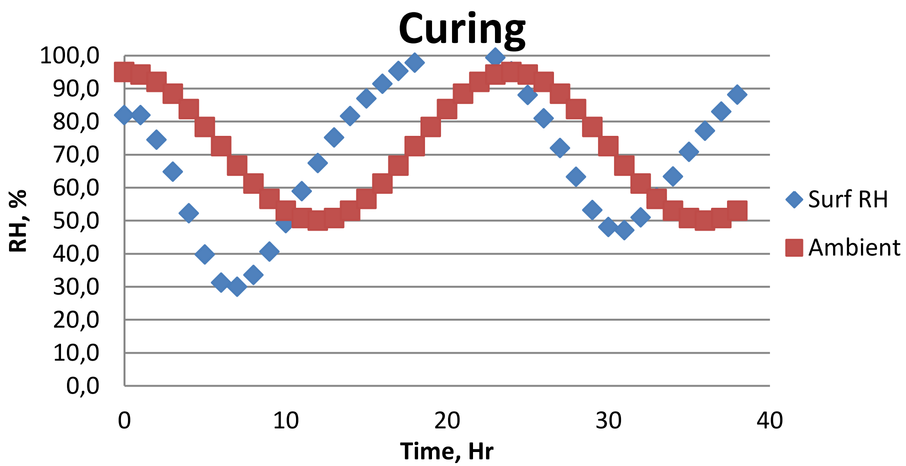
Curing

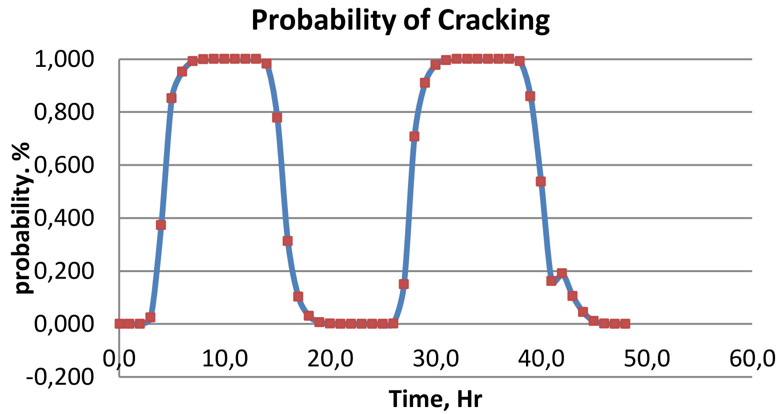


Climatic Analysis

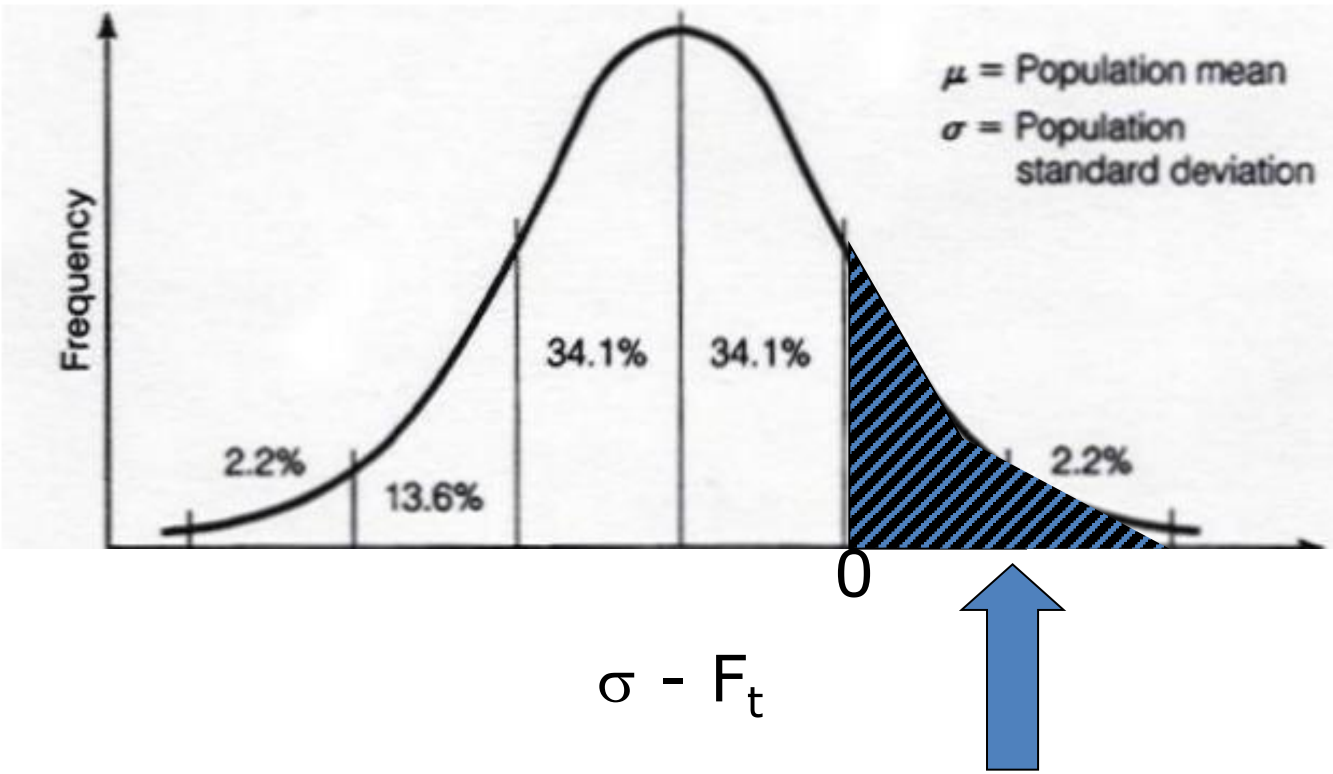






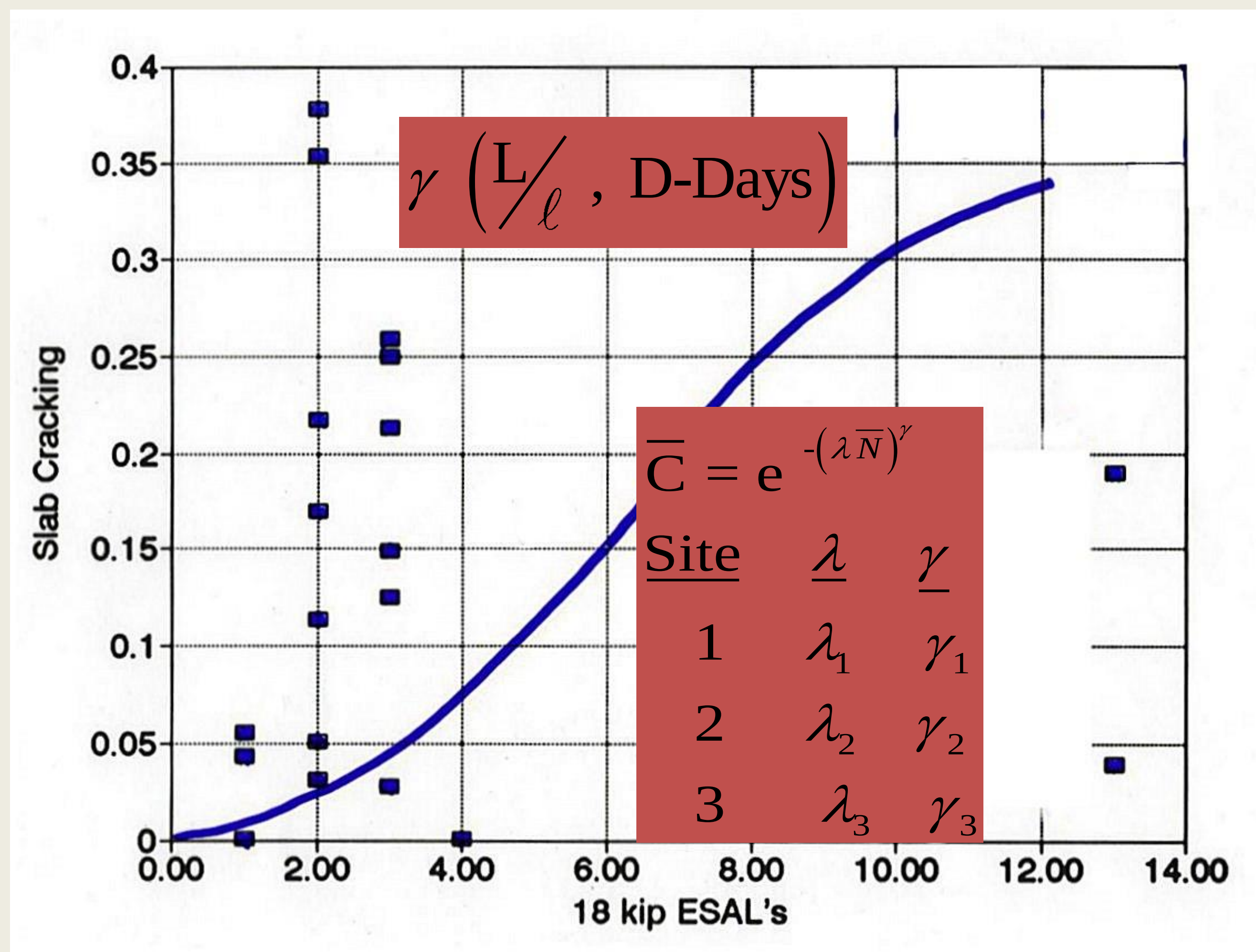


Cracking Probability



Where Stress – Strength > 0 Prob of Cracking

Field Performance

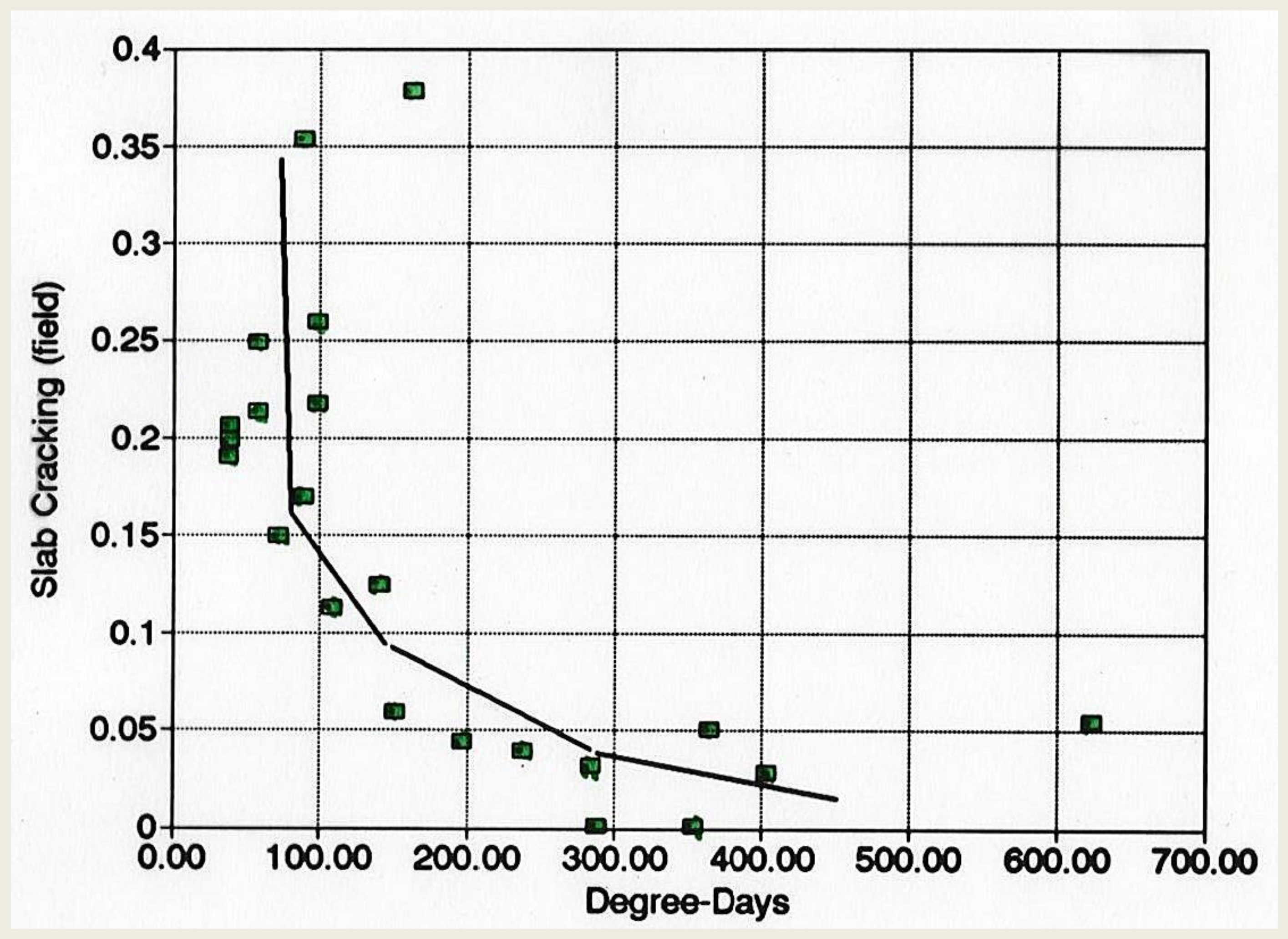


ICPA

Pavement Type	Thickness	(Summer 86) % Cracked	(Spring 87) % Cracked	(Fall/Winter 87) % Cracked	Measured Range of Temperature(°F)* Air	Surface
Carlyle, Ill:						
40' Jointed	9.5"	100	100	100	77/97	92/97
	8.5"	87	87	98	82**	89**
	7.5"	86	86	100	75/81	84/90
20' Hinge Joint						
Design A1	8.5"	0	0	0	82**	89**
Design A2	8.5"	0	0	0	82**	89**
Design B	8.5"	0	0	0	82**	89**
20' Jointed	9.5"	0	0	0	77/97	92/97
	8.5"	5	5	5	93**	110**
	7.5"	0	0	5	80/97	103/115
Freeport, Ill:						
40' Jointed	10"	0	9	12	57/74 79/83	74/79 81/88
20' Jointed	10"	0	0	0		
15' Jointed	10"	0	0	0		

* During paving construction
** Estimated average

Performance vs. Climatic Conditions



TTI: 0-1244

TEXAS TRANSPORTATION INSTITUTE

Influence of Coarse Aggregate in Portland Cement Concrete on Spalling of Concrete Pavements

Research Report 1244-11

Cooperative Research Program

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

TEXAS DEPARTMENT OF TRANSPORTATION

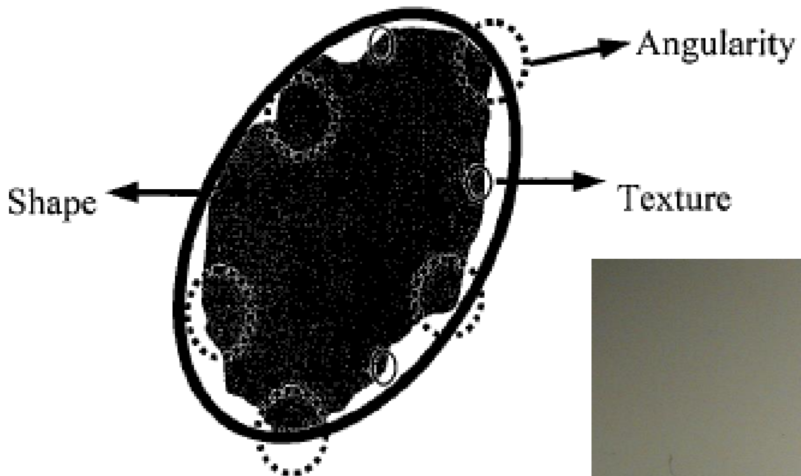
in cooperation with the
Federal Highway Administration and
Texas Department of Transportation

Aspects of Bond

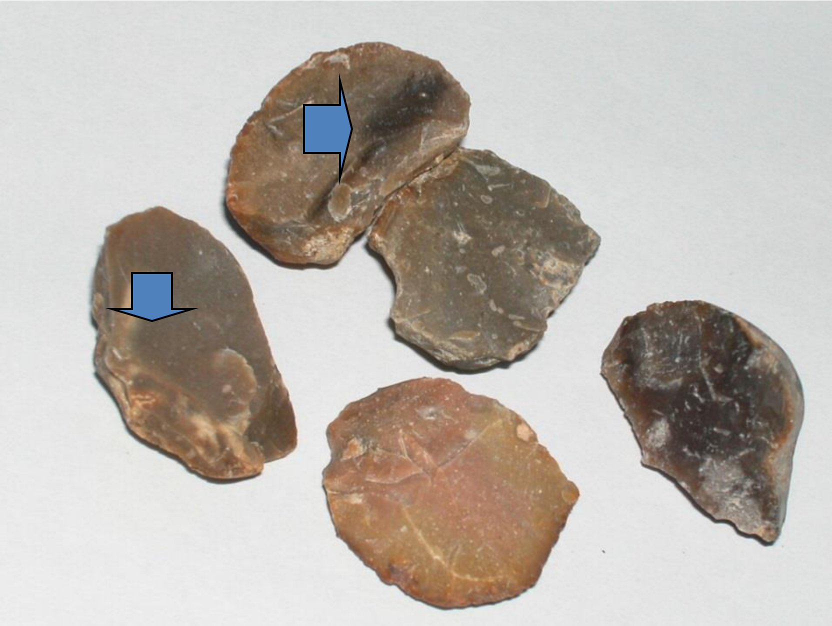
1. Mechanical interlock - texture, angularity
2. Chemical interaction – surface free energy, chemical reaction
3. Nature and thickness of ITZ
   - CH layer (duplex film)
   - Porosity
4. Fracture toughness – measure of bond

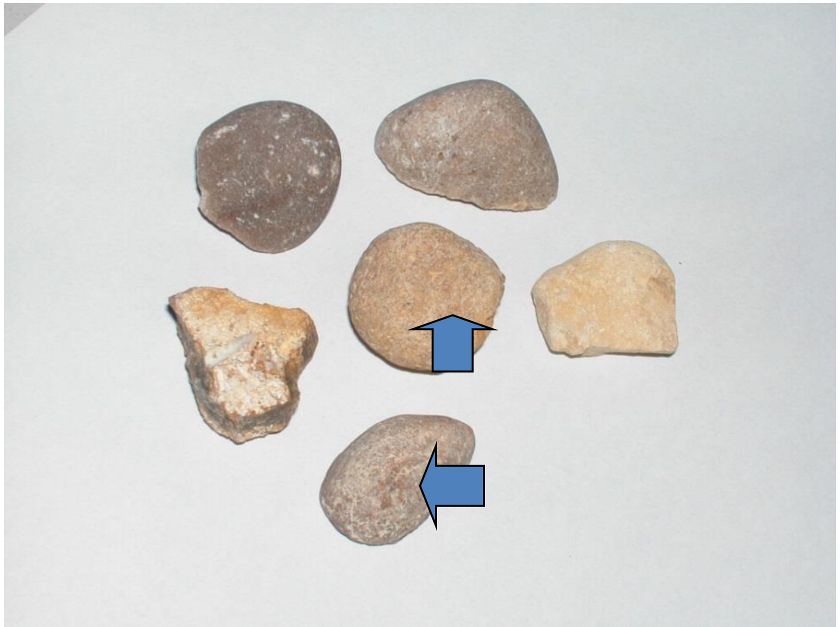
W/cm, SCMs (e.g.,fly ash)

Measuring Aggregate Shape and Texture



Crushed Gravel with mostly Chert Particles

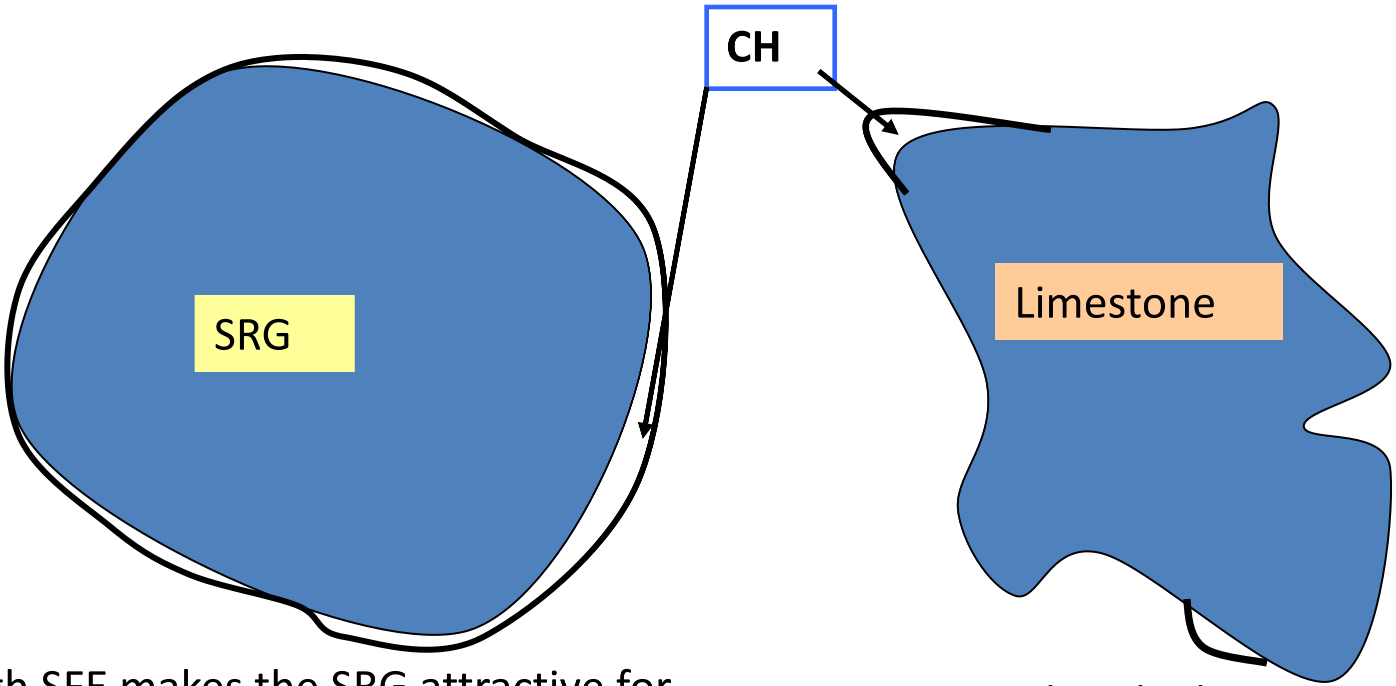




Smooth crushed faces

More texture in Natural gravel than crushed

Role of SFE on Deposition of CH at the Interface



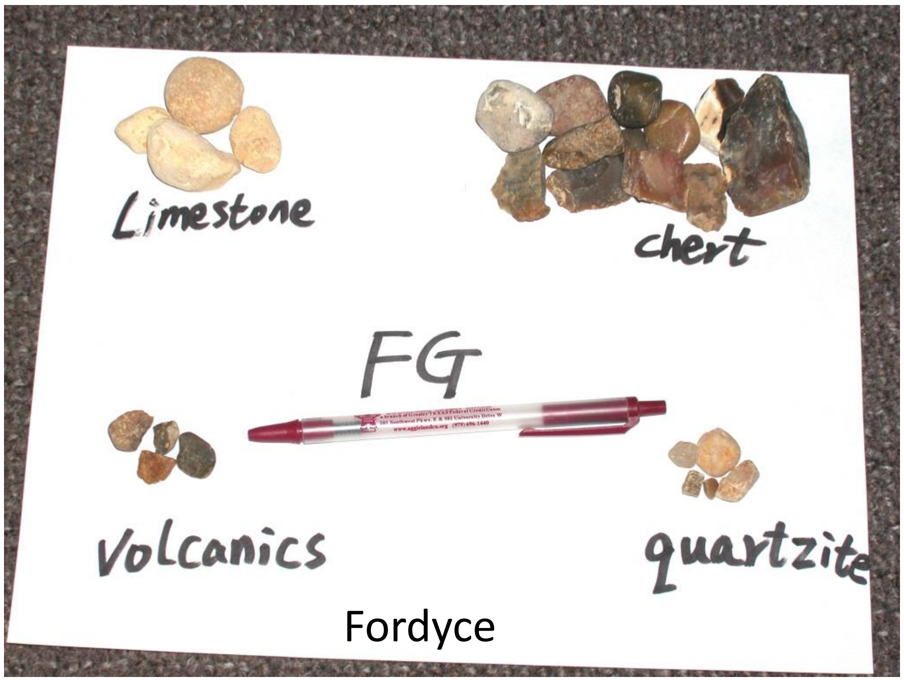
The high SFE makes the SRG attractive for CH to be deposited

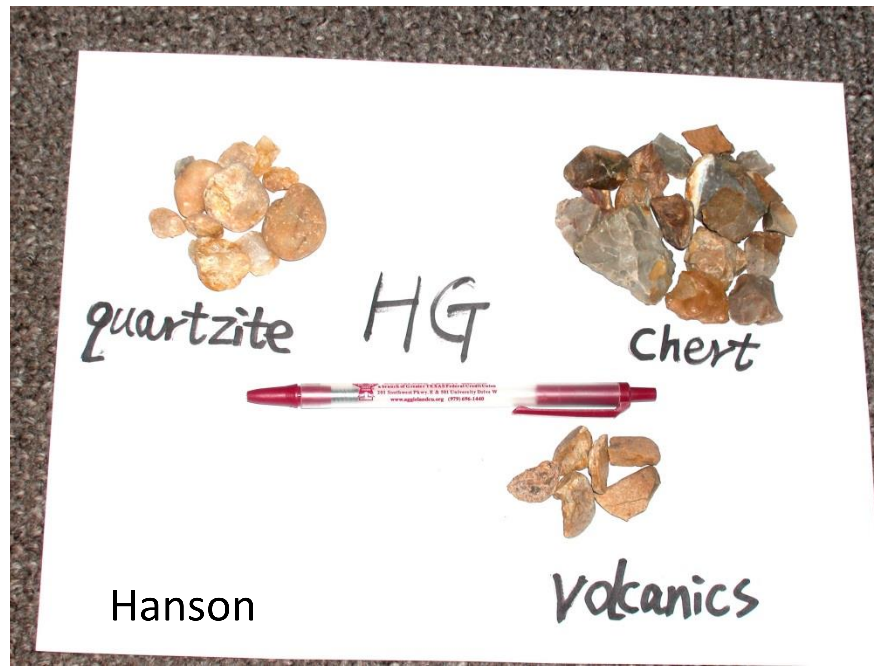
Lower SFE makes the limestone surface less attractive for CH to be deposited

Gravel vs. Limestone

	Gravel	Limestone
Mechanical interlock	Poor (smooth / low texture)	Good (high texture)
Chemical Interaction	None	Reactive interface
SFE x SSA	High (e.g., 271 MJ/g)	Relatively low (e.g., 200 MJ/g)
Nature of ITZ (CH layer, porosity)	More CH; More porous	
Fracture toughness (bond strength)	Low	High

Fordyce vs. Hanson Gravel





	Chert	Quartzite	Limestone	Volcanics
Hanson	68.38	24.21	-	6.25
Fordyce	67.26	08.03	21.29	3.42

Quartzite Fragments

Quartz = 32 erg/cm^2

Gravel = 357 erg / cm^2

Remedial Measures

1. Improve bond strength by manipulating the ITZ

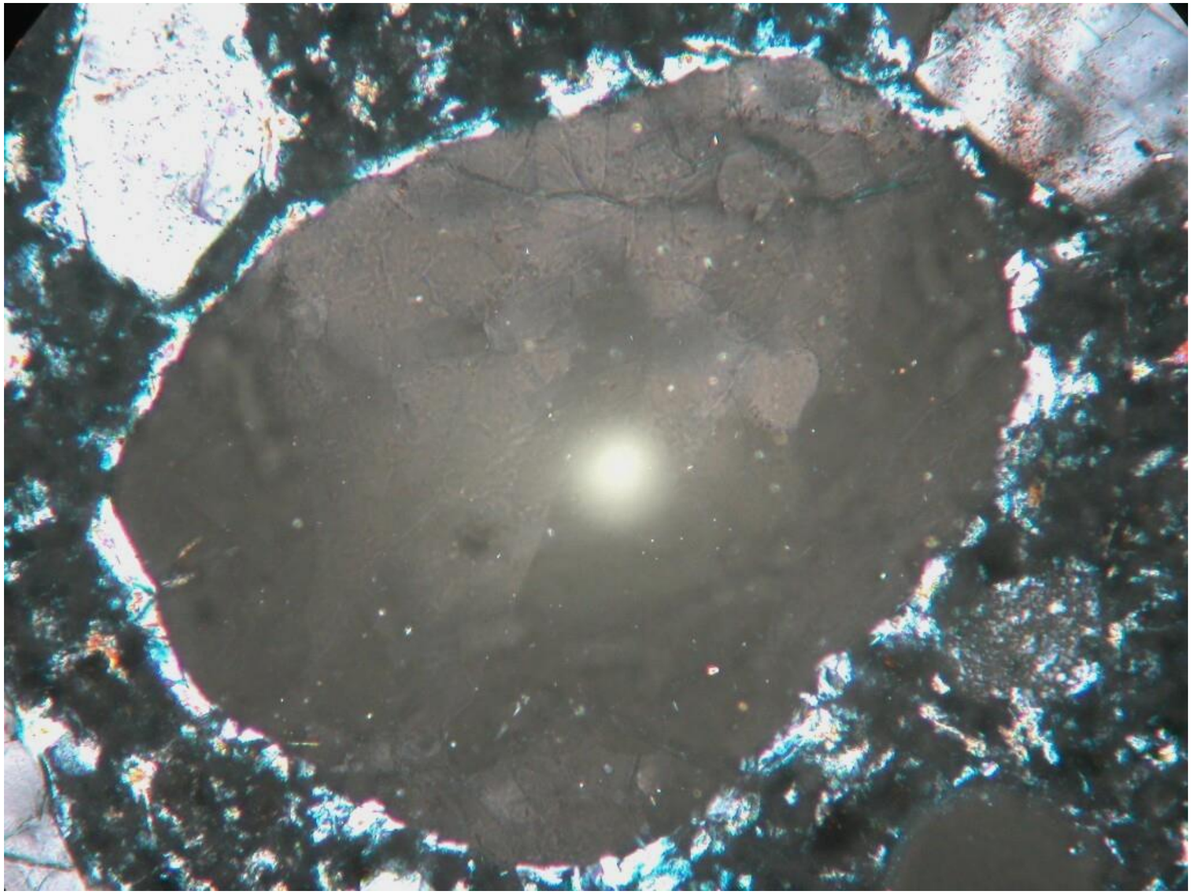
- Low w/cm ratio
- Dense graded aggregate / aggregate blending
- Use of UF FA
- Modification of order of batching

2. Improve curing to reduce the shrinkage stress due to evaporation

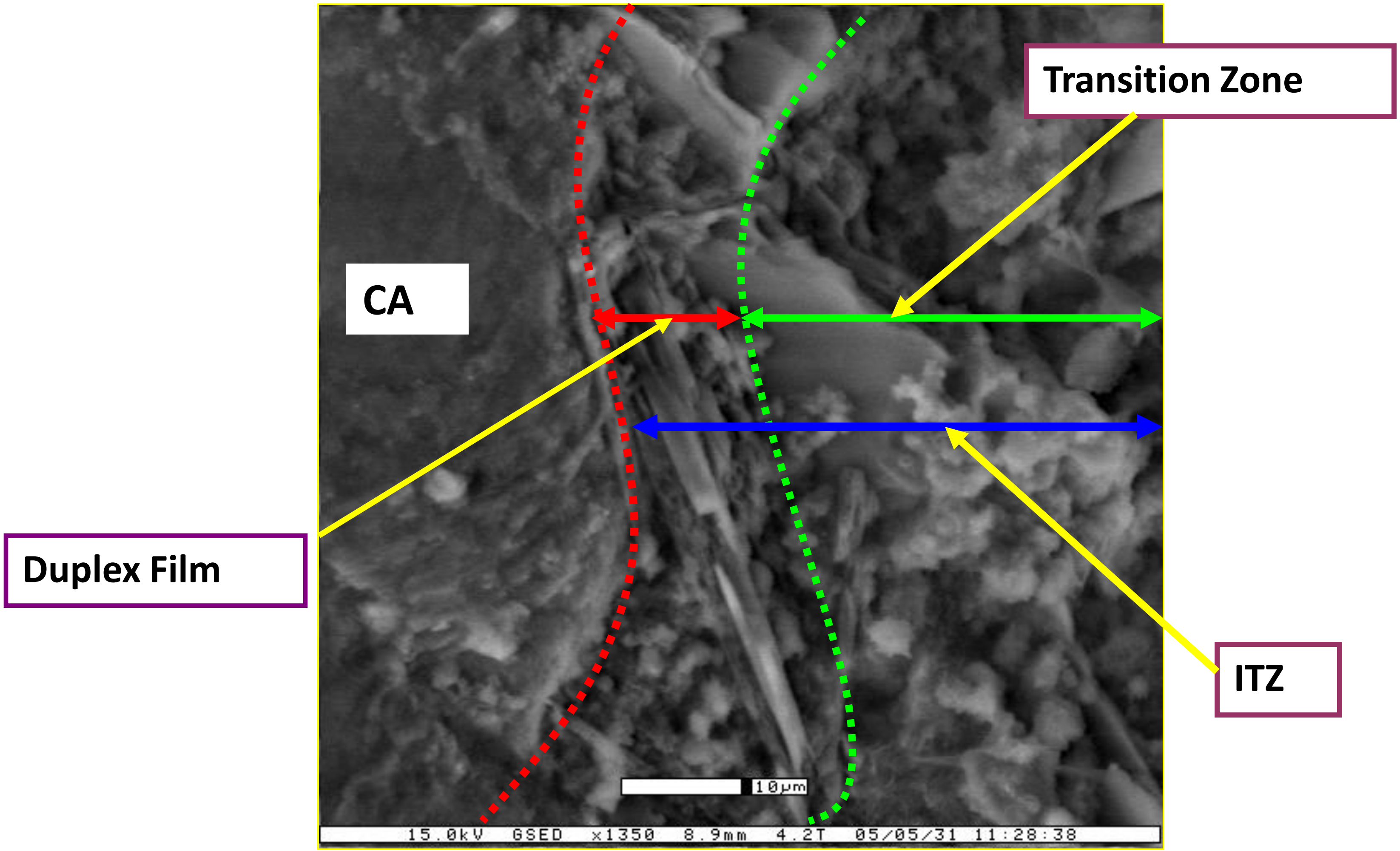
3. Induced crack pattern

Concrete with W/C – 0.54-0.58

No Fly Ash

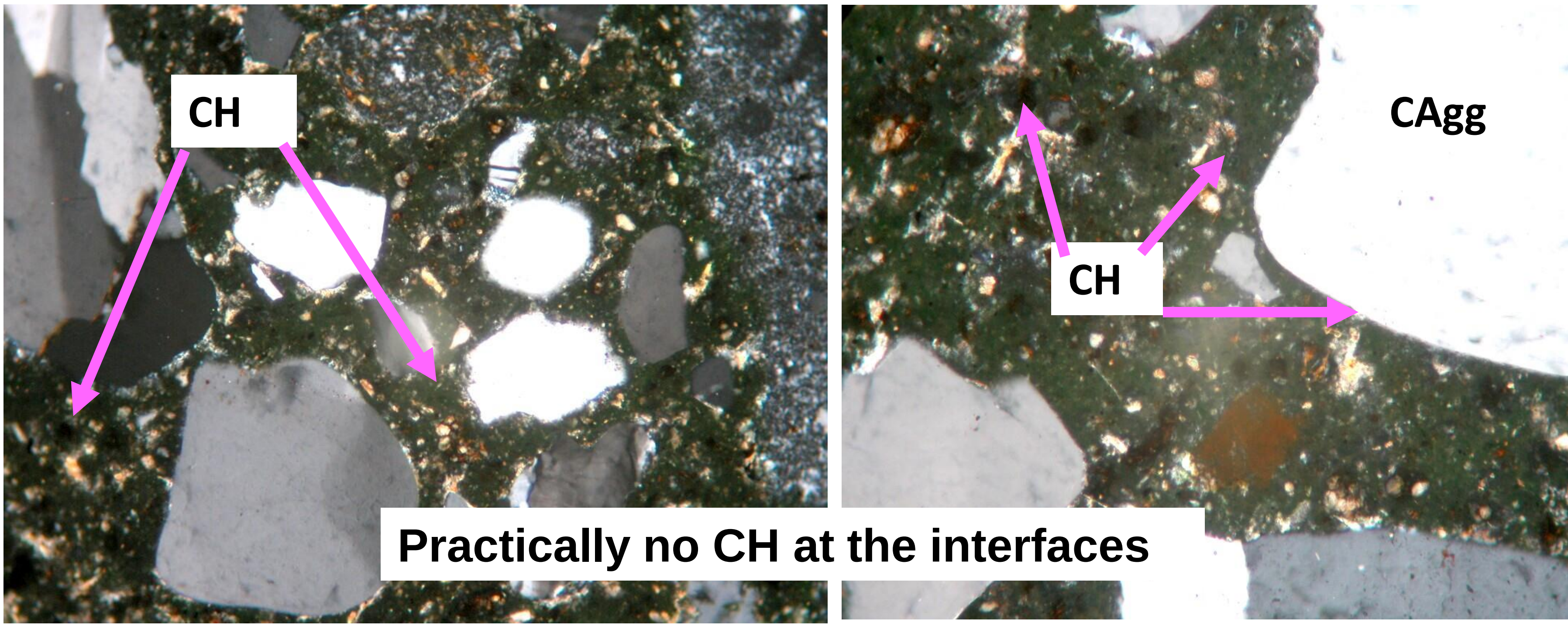


Interfacial Transition Zone



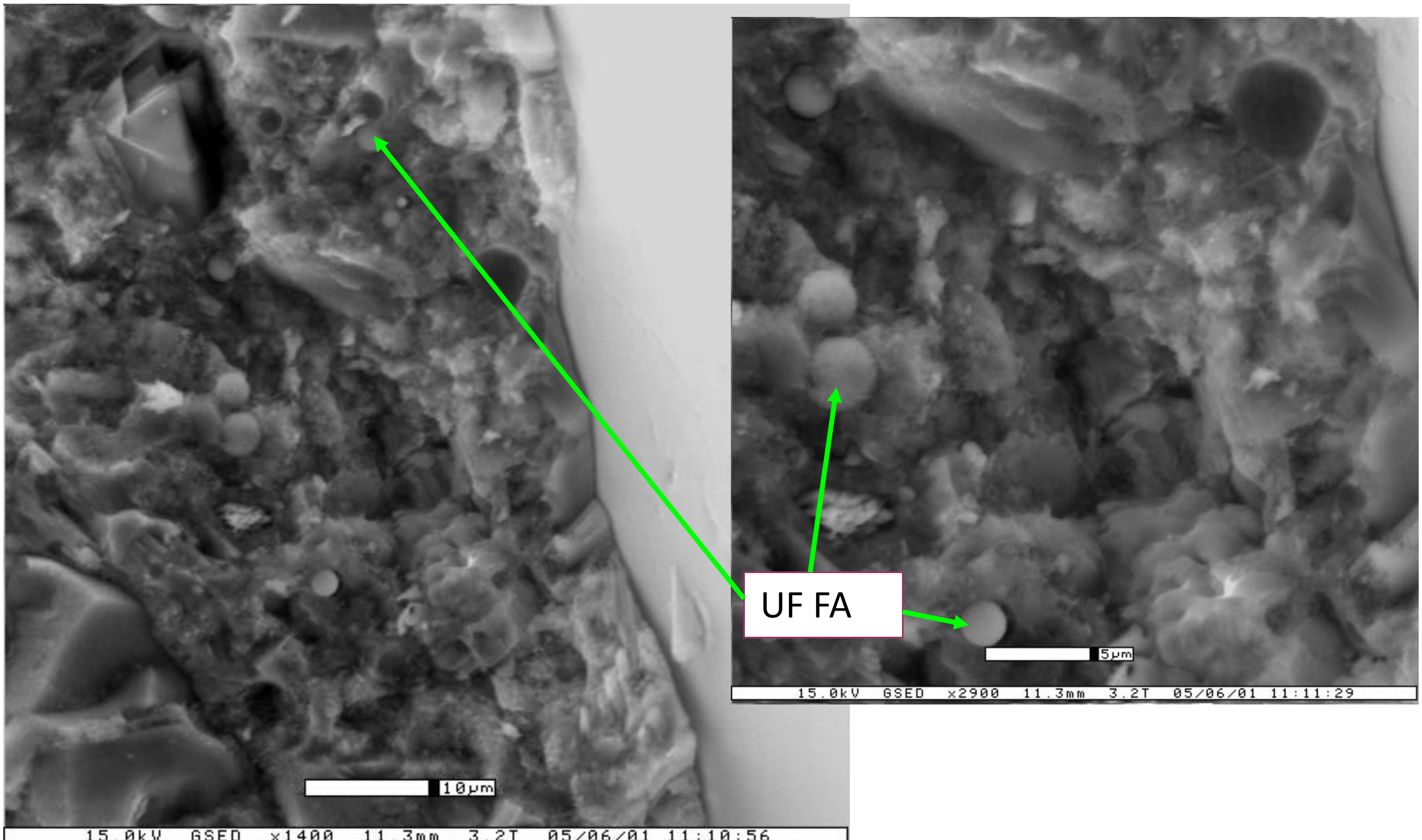
ITZ Microstructures

20% UFFA, w/cm = 0.40, CC, SRG (H)



ITZ of SRG concrete (ESEM)

(UFFA 8%, w/cm = 0.40, Mat Curing)



Use of Dense Gradation

Fordyce natural gravel
w/cm=0.4
% of fly ash = 25% (10% ultra-fine + 15% Class F)
Moisture Curing

Tests	CF	CAF	IAF	7 Day - MOR	Slump (in.)
1	5.5	0.555	0.14	540.0	1.00
2	6	0.555	0.14	633.8	1.25
3	6	0.495	0.18	589.6	2.00

Modification in Batching Order

Constituents	Charging sequence and mixing time (seconds)													
	0	10	20	30	40	50	60	70	80	90	100	110	120	130
CA 1 (1.5″) + CA 2 (3/8″)														
Water (50%)														
Water (rest 50%)														
FA+Cement +Ash+Admix.														
Total Mixing time														

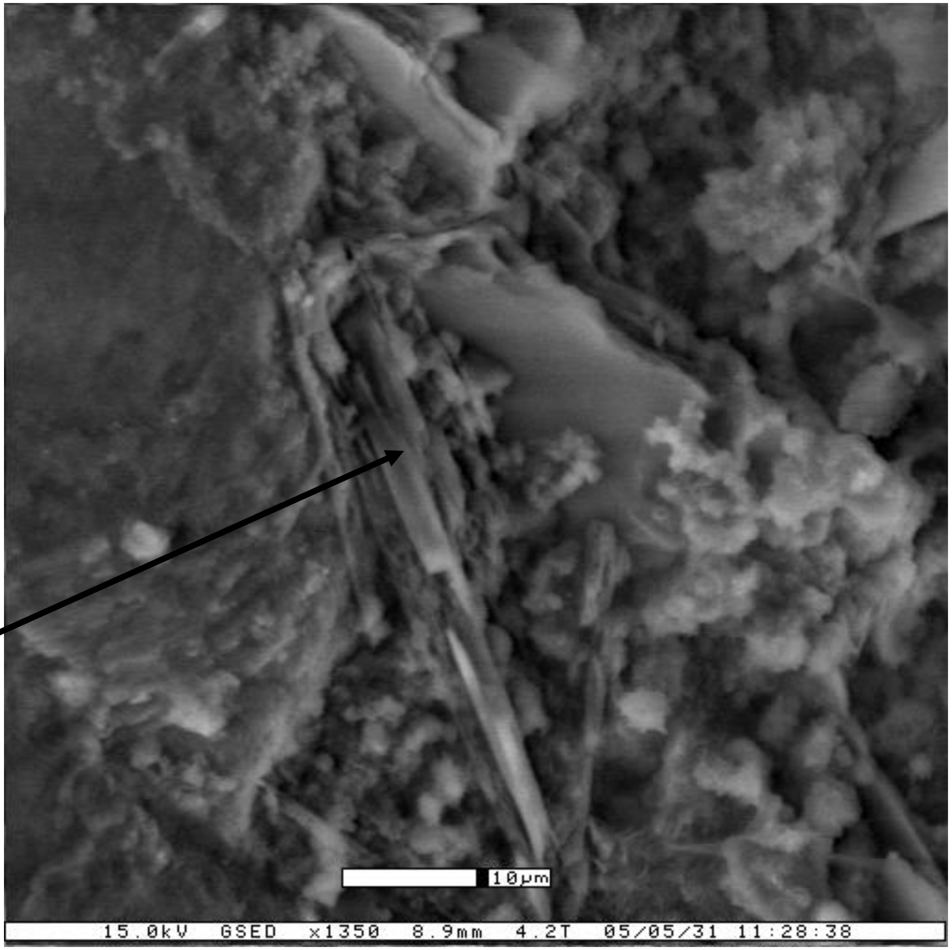
CA1 – SRG (Fordyce), CA2 – Pea Gravel (Fordyce), FA – Fine Aggregate (Fordyce)

Modified Mixing Cycles: Observation

- Good workability, placement and finishability
- No edge sloughing
- No build up (caking), dry-packing and dry ball formation
- Increase of mixing time (~ 50 sec.)

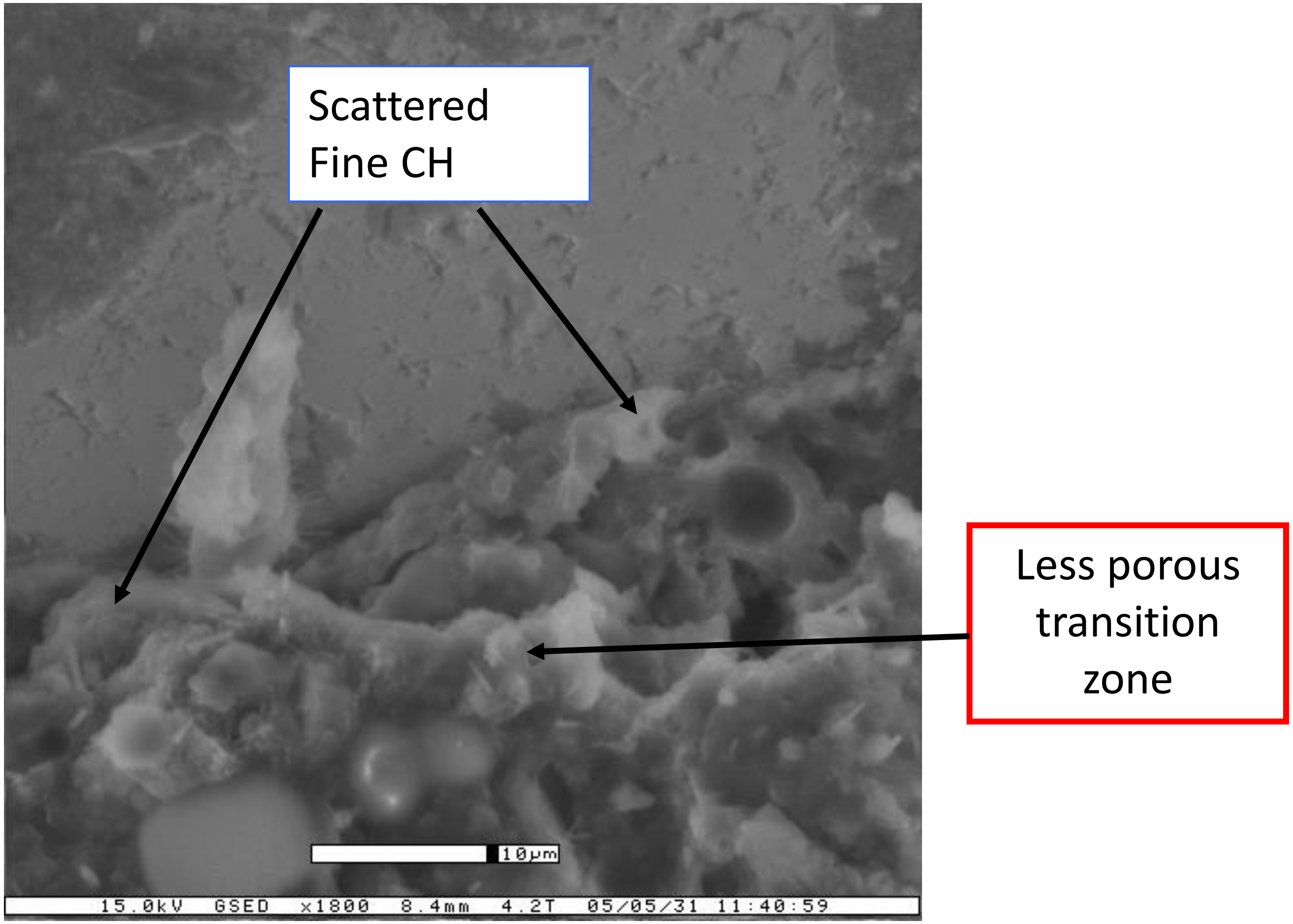
Mixing Cycles	Slump (inch)	Split Tensile (psi)
Conventional	0.5	321.15
Modified	No slump	341.84

ITZ of Conventional Mixing Cycles



Well developed, coarse CH

ITZ of Modified Mixing Cycles



Impact of Remedial Measures

Measures	Construction	Performance	Cost
Use of UFFA 8 to 10%	Extra Bin Needed	Densification/pozzolanic Reduces CH/Incr strength	+$10/yd
Low w/cm	No affect on constr	Reduces CH/Incr strength	Minimal
Dense Grading	Extra Bin Needed for IA (-3/8// + #4) Pea Gravel	Increases strength Lowers shrinkage stress	Will depend on availability
Modified batching cycles	Increase of mixing time + 50 sec	Reduces CH/Incr strength	Minimal
Induced crack pattern	3-4 hours after placement	Reduces Stress	+$2/yd (at a 6 ft interval)
Improved Curing	Applying 2nd CC layer after 4-5 hr Increase in Labor	Reduces Stress	

Not all Gravels are alike!!

Present Curing Standards

- ASTM C 156
  - Focus on water retention
  - Specifically
    - Limited to fixed test conditions & application rate
    - Difficult to interpret for field application
- Adaptation to Field Conditions?
  - What constitutes quality curing---***Is water loss early a bad thing or not?***
  - New curing technologies: lithium, post treatments
  - Multiple applications

A Direct Approach

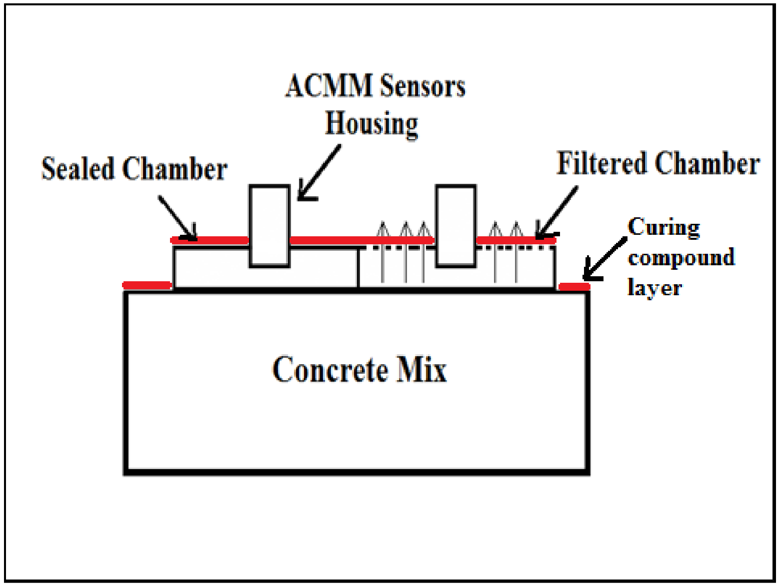
- Laboratory/Field Test for Evaluating Curing Compound
  - Relative humidity (RH) measurement
  - Moisture loss measurement
  - Concrete surface abrasion test
- Propose an Evaluation Index
- Relate Index to Performance

Dew Point Temperature Measurement

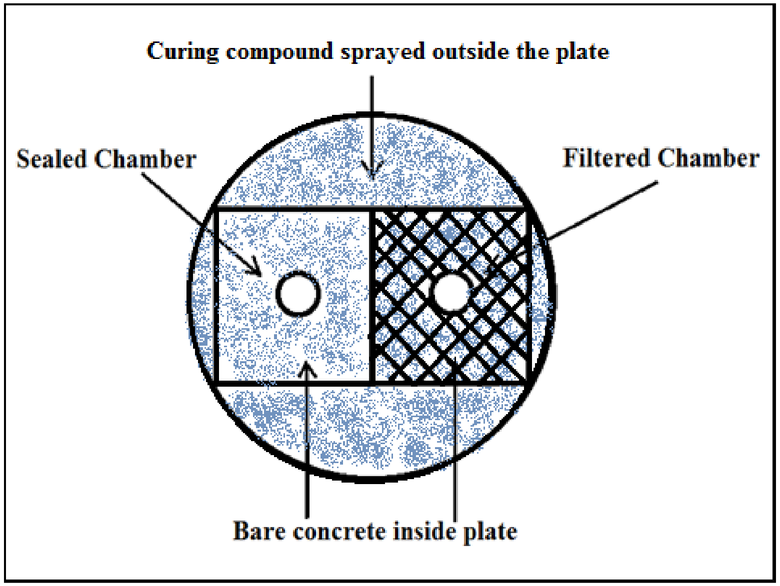
- ACMM device to collect RH data
  - RH data
  - Ambient temperature
  - Wind speed
  - Solar radiation

Two Sampling Chambers

- Sealed chamber
  - Collect RH data near perfect curing conditions
- Filtered chamber
  - Collect RH data just below the concrete curing surface



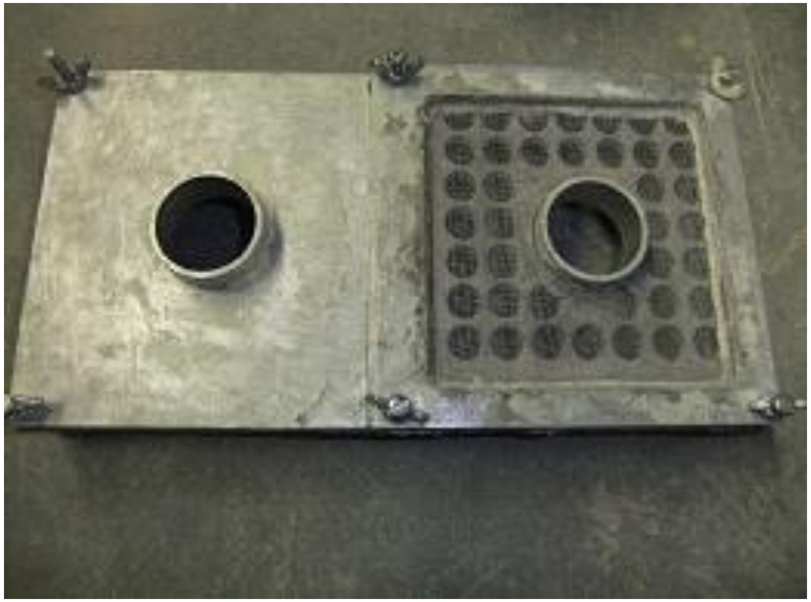
Side View



Top View

Filtered DP Measurement

- Screen is place over a plate for the filter chamber
- Thin mortar layer on the screen
- Curing compound is applied on the mortar

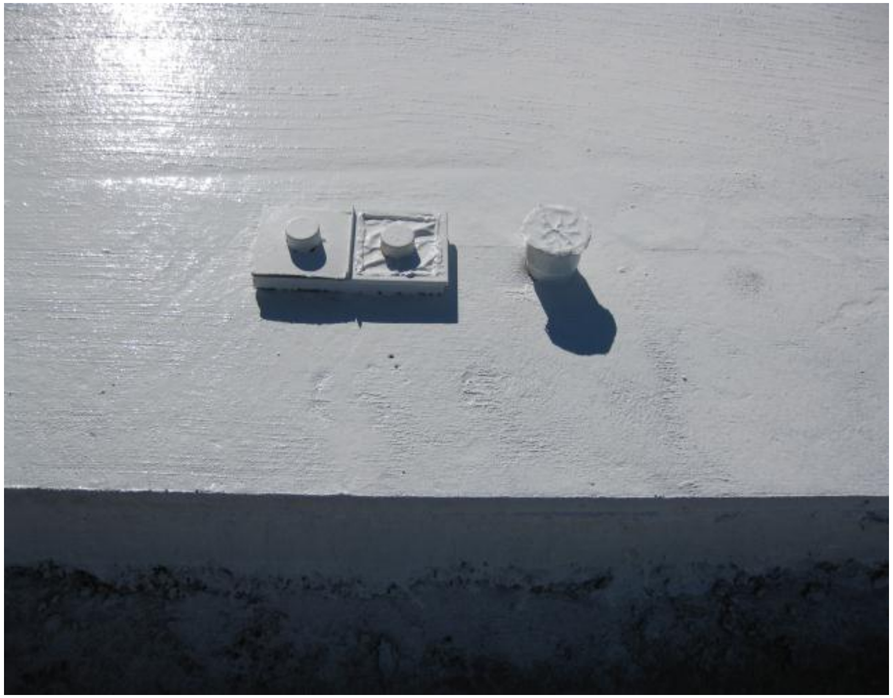


Laboratory Measurement

- After placing curing compound , place the ACMM device on the housings in the plate

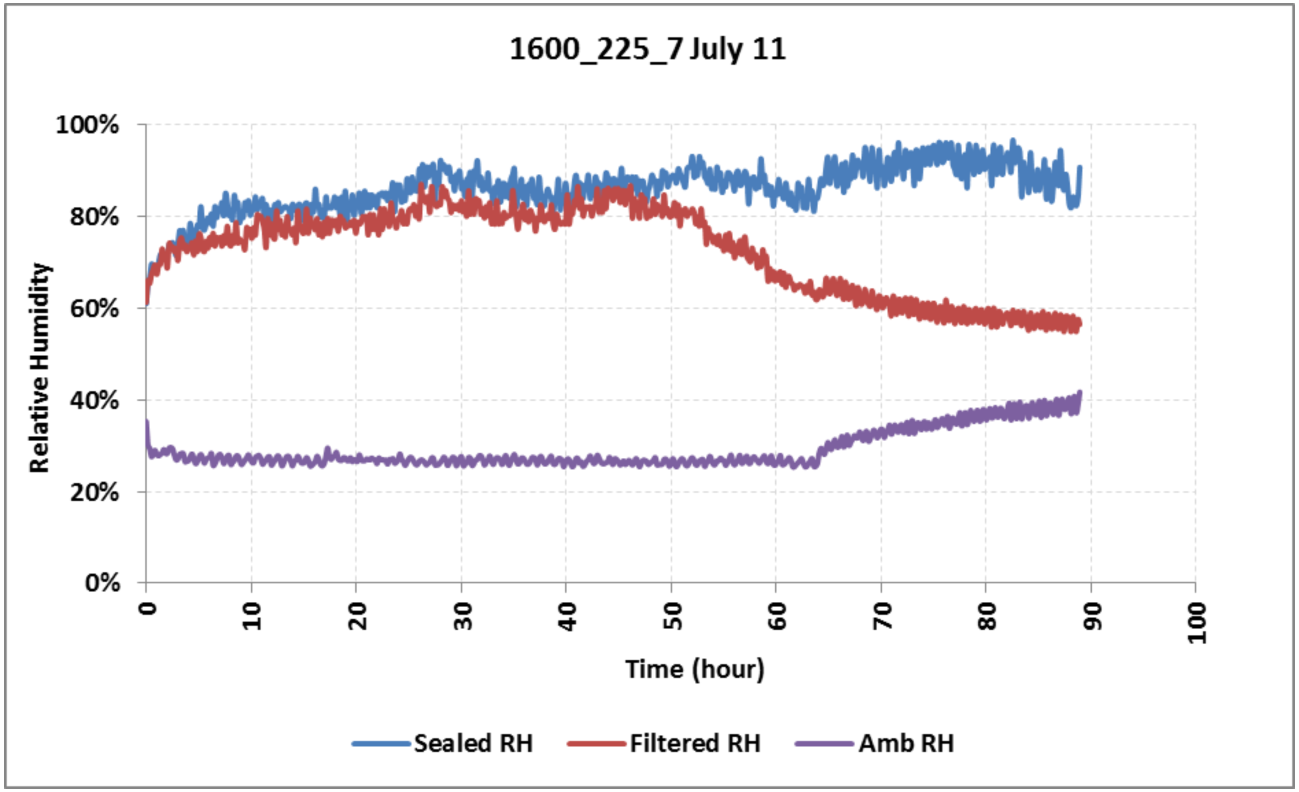
Field RH Measurement

- Same procedure is applicable for field condition to collect RH data



Example RH Measurements

- Curing compound 1600
- 225 ft^2/gal application rate



Evaluation Index (EI)

- Equivalent Age (t) of Concrete

$$\beta_H = \left[1 + (7.5 - 7.5H)^4\right]^{-1}$$

$$t_i = \beta_H \bullet \sum_0^t \frac{(T - T_o)}{T_{rm} - T_0} \times \Delta t = \frac{1}{1 + (7.5 - 7.5 \times RH)^4} \sum_0^t \frac{(T - T_o)}{T_{rm} - T_0} \times \Delta t$$

where

β_H	= the moisture modification factor
RH	= the humidity of concrete
t_i	= equivalent age of concrete
i	= sealed, filtered, and ambient conditions
T	= the average temperature of the concrete during time interval Δt
T_0	= the datum temperature with a value of -10 ºC
T_{rm}	= room temperature 21ºC

Evaluation Index (EI)

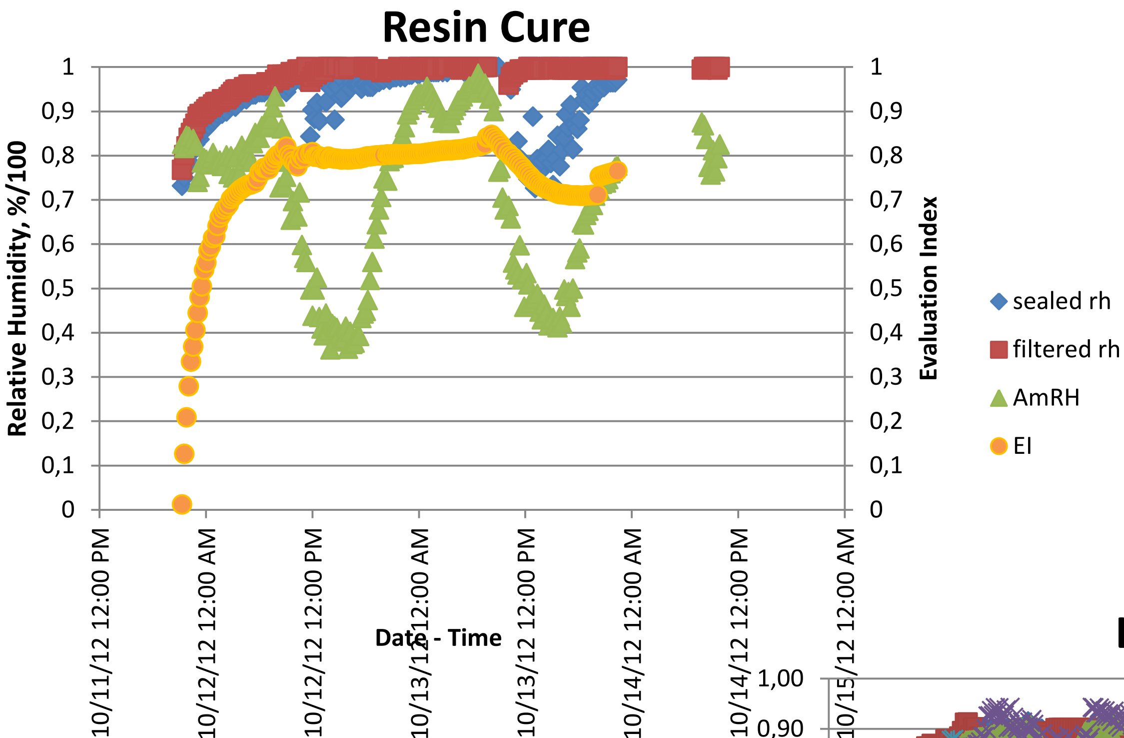
- EI is defined as:

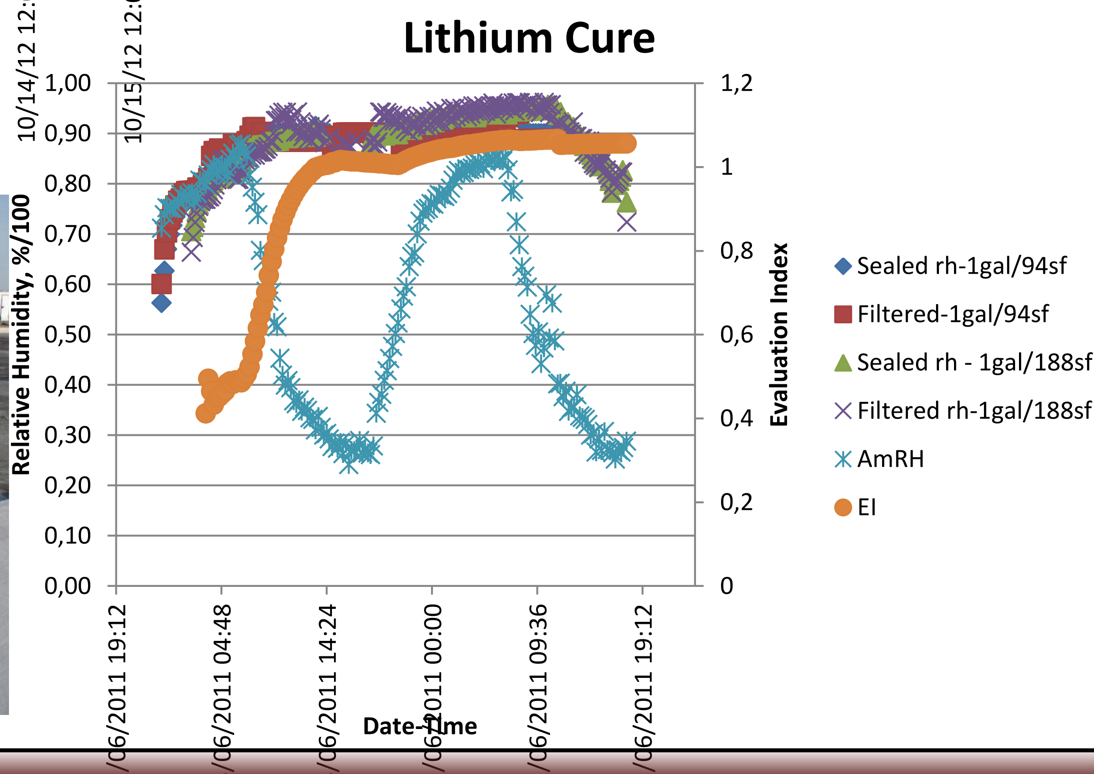
$$EI = \frac{t_f - t_a}{t_s - t_a}$$

where

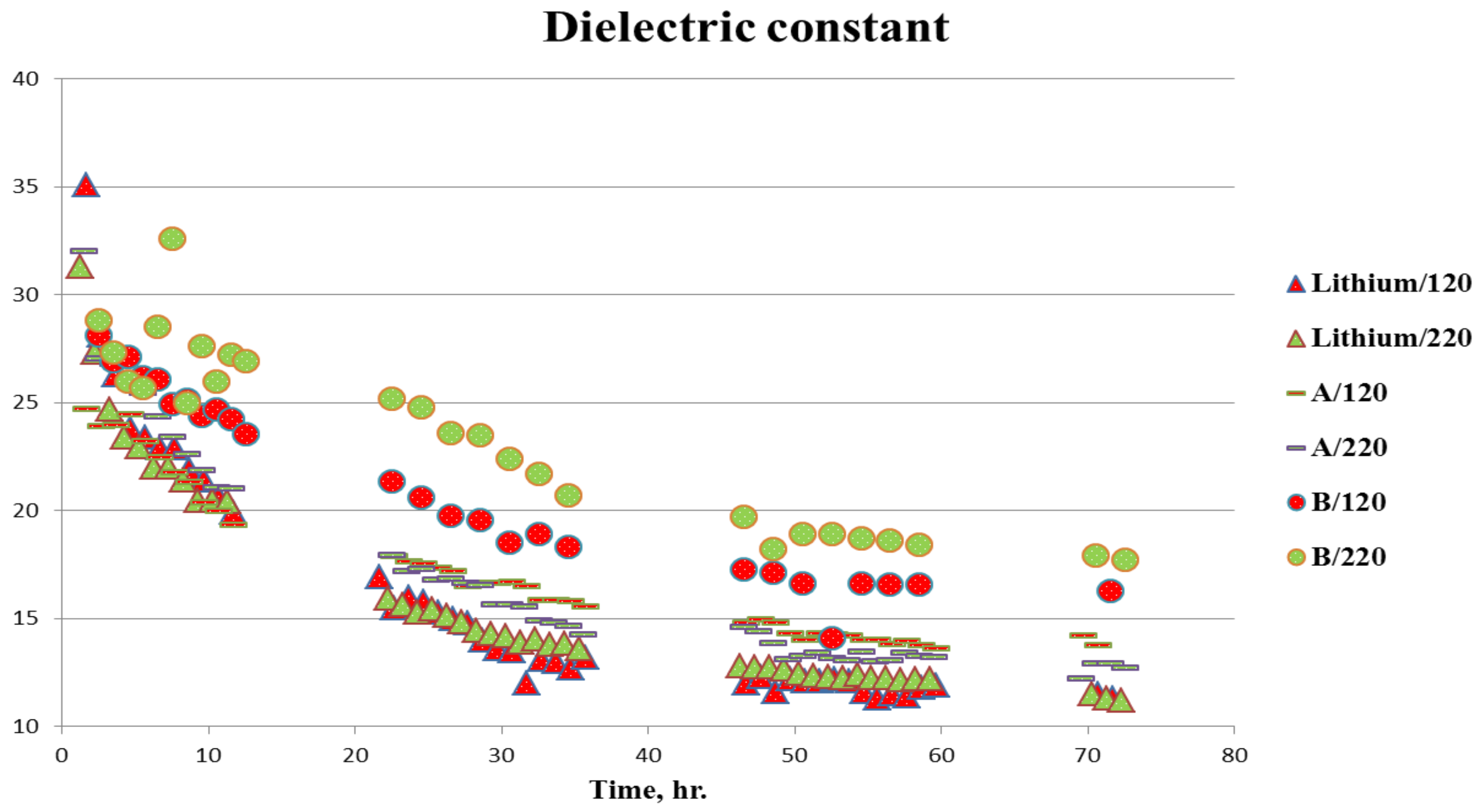
t_f = the equivalent age of the filtered curing condition
t_s = the equivalent age of the sealed curing condition
t_a = the equivalent age of the ambient curing condition

Field Monitoring





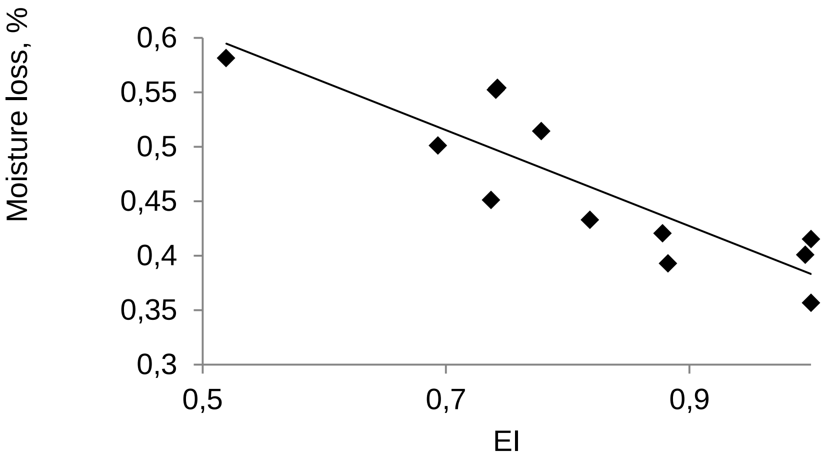
Percometer

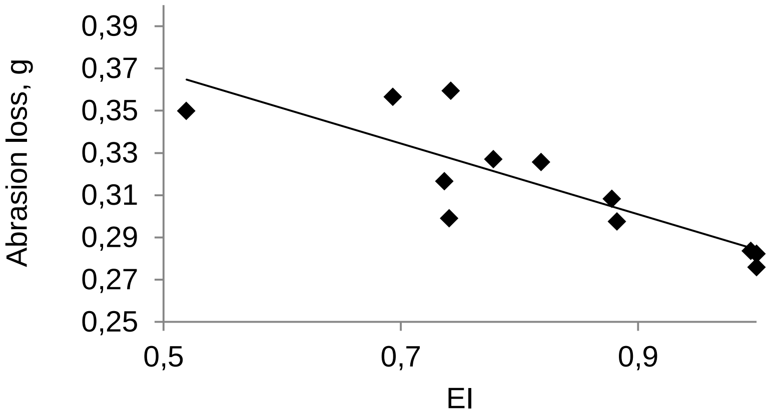


Circle----- **Curing compound B**
Line------ **Curing compound A**
Triangle---- **Lithium**

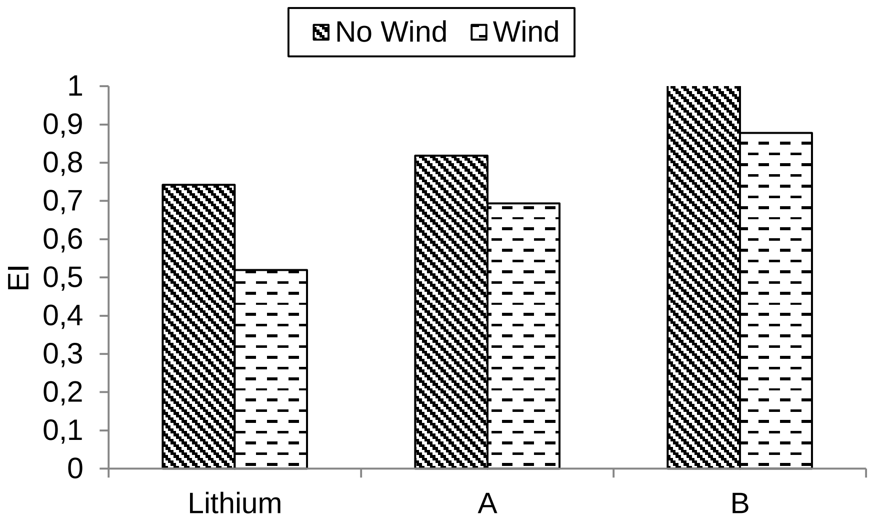
Red----120 AR
Green ----220 AR

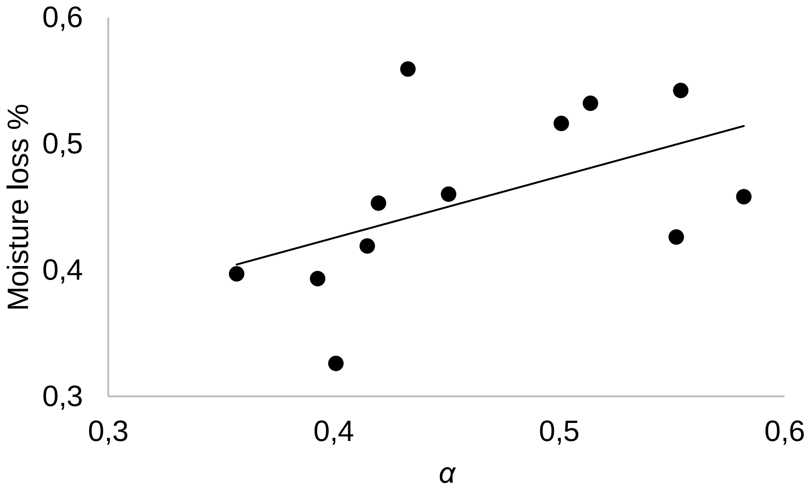
Moisture and Strength Correlations





EI and Dielectric Correlations



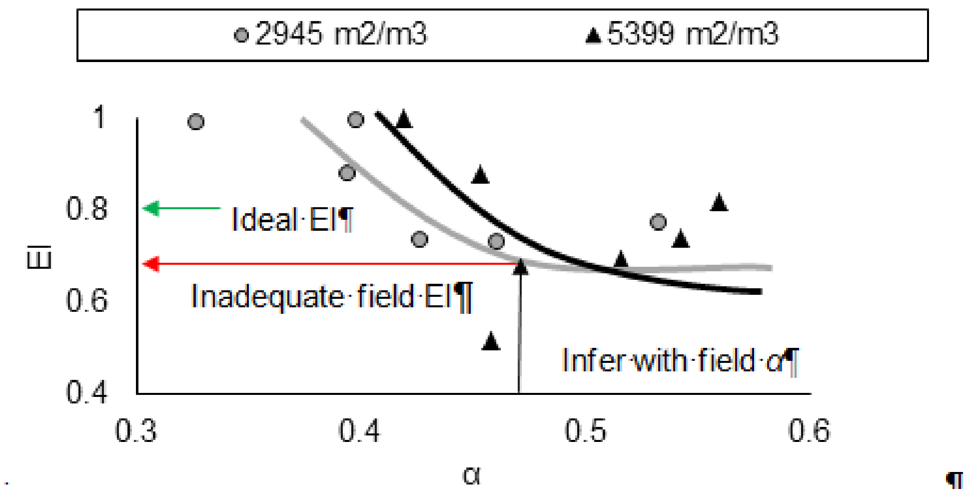


What and How to Spec Curing?

- Equipment Control
  - Rate of application
  - Pressure/rate of travel
  - Bar height
- Specification & Evaluation?
  - ASTM 309
  - Monitor application amount
  - Monitor quality
- New Methods and Materials?
- Contractor Incentive?

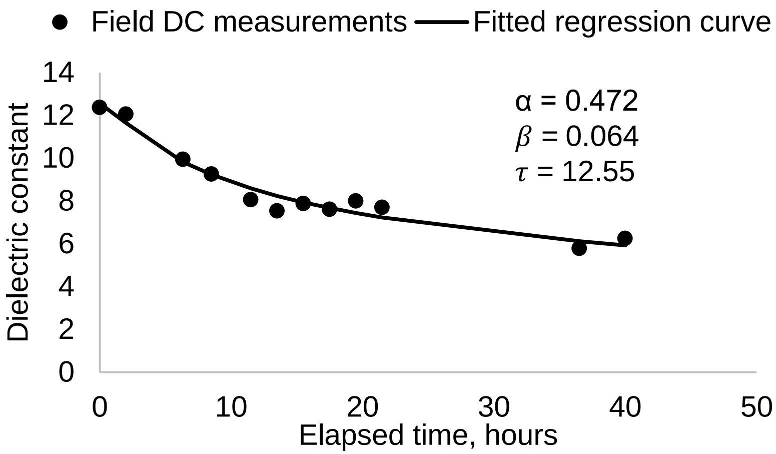
How to Manage Curing Effectiveness

- Laboratory Testing – Standard
  - EI
  - For a range of rates



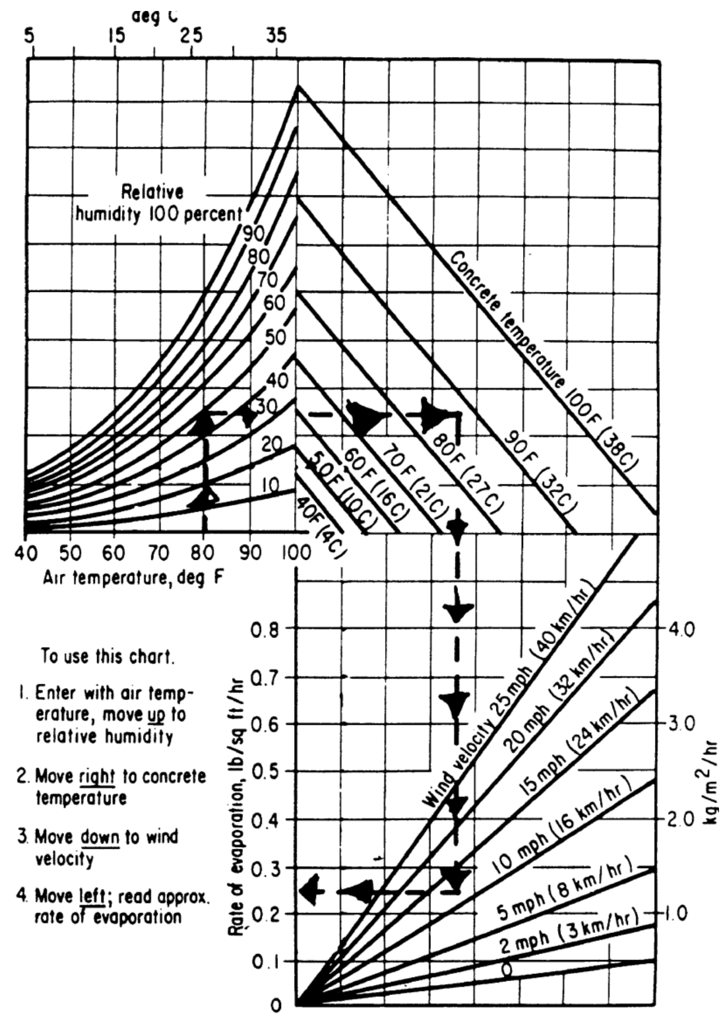
How to Manage Curing Effectiveness

- Field Measurement – for a given rate
  - Check over a wide areas



Factors-ACI 305R

- Potential for Evaporation
  - Wind speed
  - Temperature
  - Relative Humidity
- Rate of Application
- Effectiveness EI
  - Laboratory Based
  - Field Calibrated



Curing Inspection

- Lab
  - EI, α, and Rate of Application Curve
- Field
  - Dielectric vs. Time Curve
  - EI – inferred from α
    - For a Given Rate of Application

Conclusions

- Design, Materials, and Construction Factors Affect Crack Control
- Gravelly Materials Attract a Water Film - CH
  - Attraction varies with quartzite content
- Low w/c, Modified Batching and Improved Curing Practices are Viable Solutions

Conclusions

- Curing quality has a significant role on concrete pavement performance
- A new approach is needed to better account for field conditions
- Improving curing quality will required a concerted effort