Lightweight Aggregate and Internally Curing to Mitigate Bridge Deck Cracking

Presented By:

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AUBURN UNIVERSITY

Presentation Objectives

- Evaluate the effect of lightweight aggregate and internal curing on the development of autogenous stress, thermal stresses and the cracking tendency of lightweight aggregate concrete.

Outline

- Cracking Mechanisms
- Testing Equipment
- Experimental Work
- Results
- Conclusions

Cracking Mechanisms

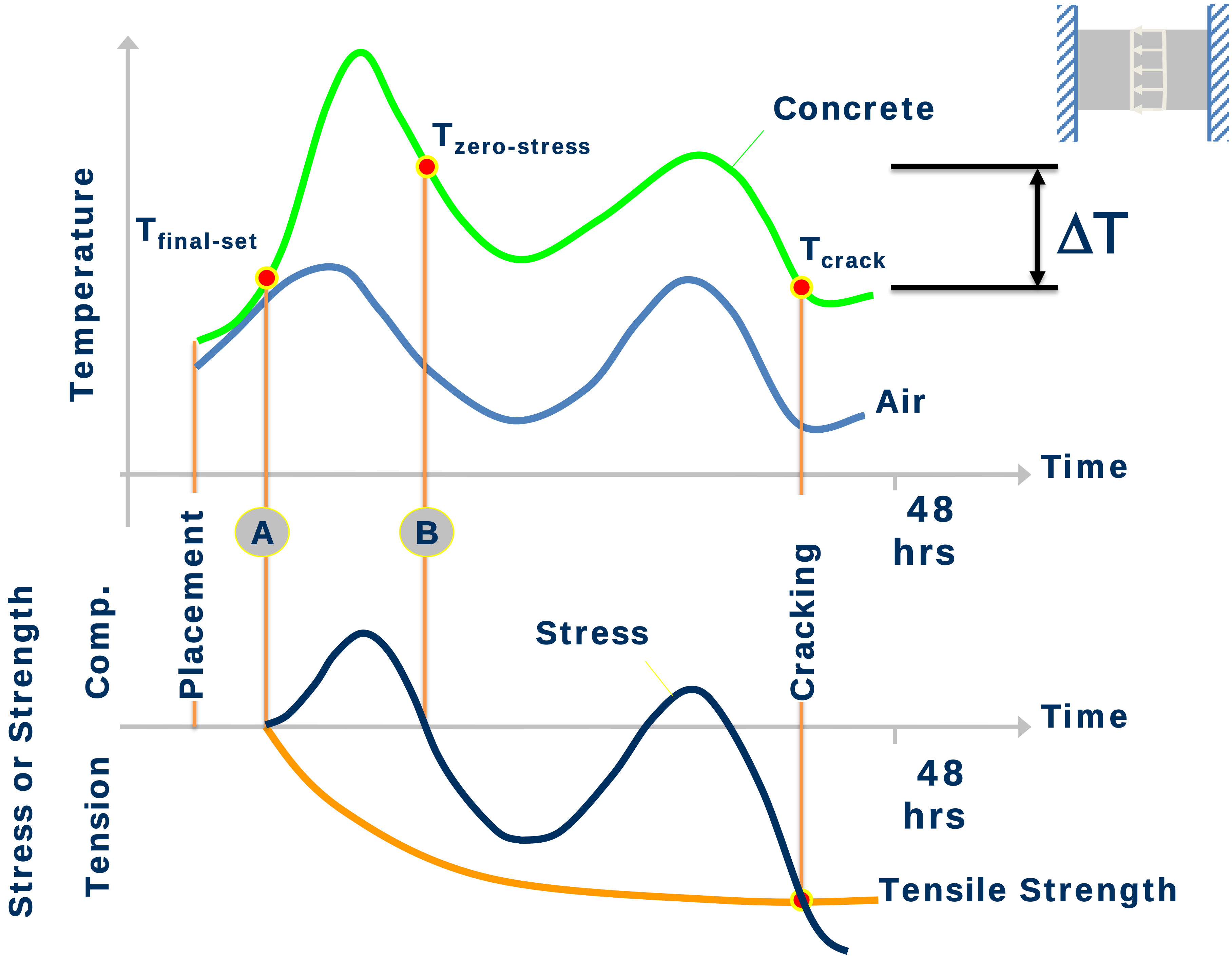
Why Does Concrete Crack?

Restraint + Volume Change = Stress

Cracking Occurs When Tensile Stress Exceeds Tensile Capacity

Cracking Mechanisms

- Early-Age Volume Change Occurs Because
  - Thermal effects
    - Temperature changes due to hydration
    - Coefficient of thermal expansion
  - Decrease of internal relative humidity
    - Drying due to atmospheric conditions
    - Self desiccation (autogenous shrinkage)



Temperature
T final-set
T zero-stress
Concrete
T crack
ΔT
Air
Time
48 hrs
A
B
Placement
Cracking
Stress or Strength
Comp.
Tension
Stress
Time
48 hrs
Tensile Strength

Cracking Mechanisms

- Why Use Lightweight Aggregate?
  - When batched in the pre-wetted state, LWA has internal water stored in its pores
    - This water promotes hydration $\Rightarrow$ internal curing
  - Use of saturated lightweight aggregates may reduce autogenous shrinkage

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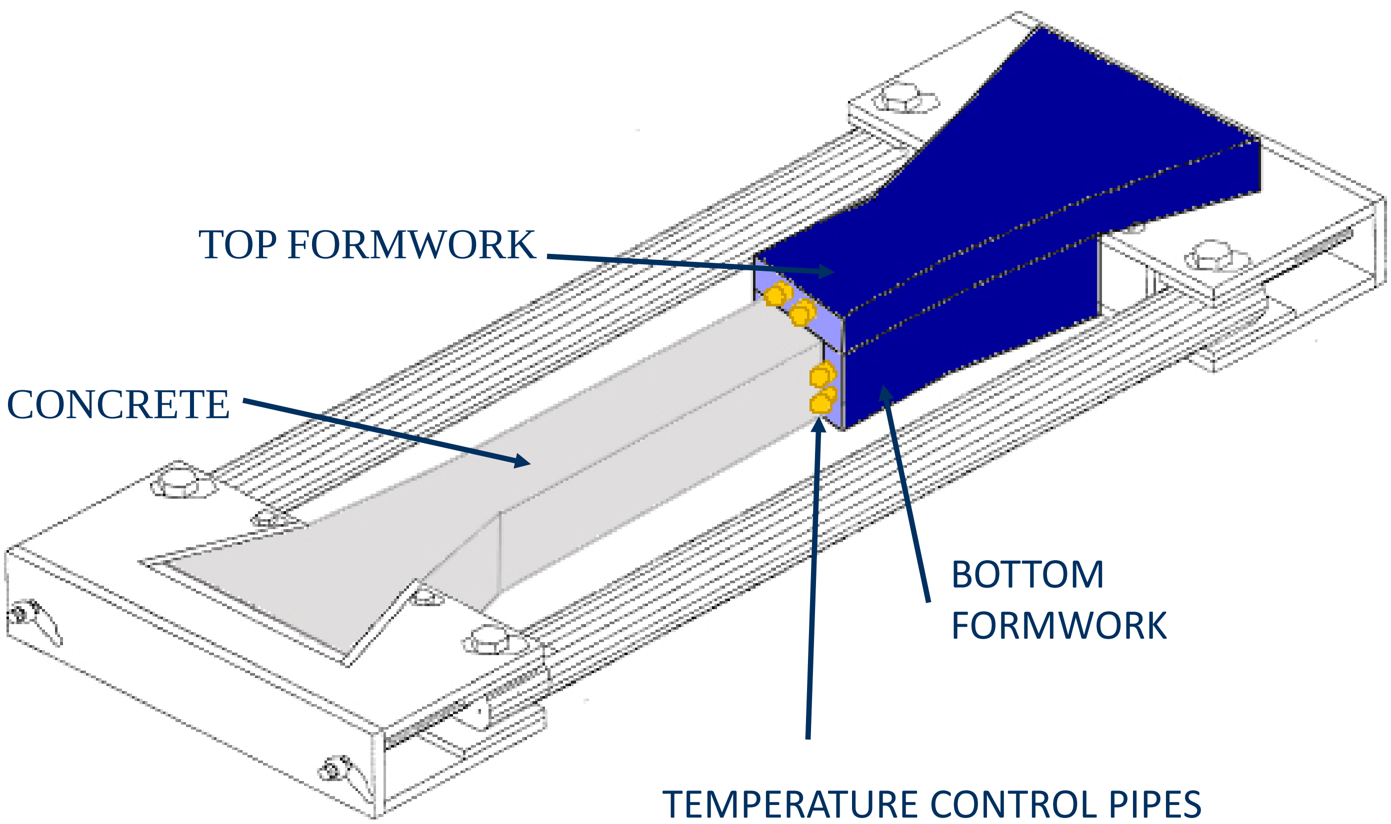
Test Equipment

Rigid Cracking Frame



Testing Equipment

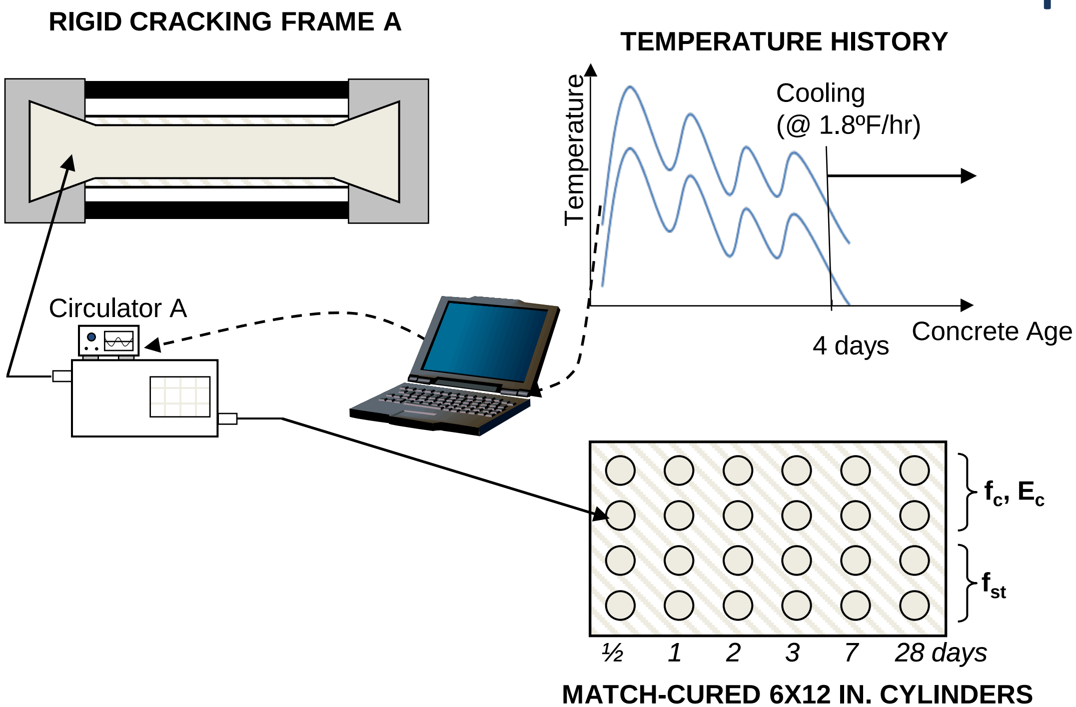
Rigid Cracking Frames

Testing Equipment

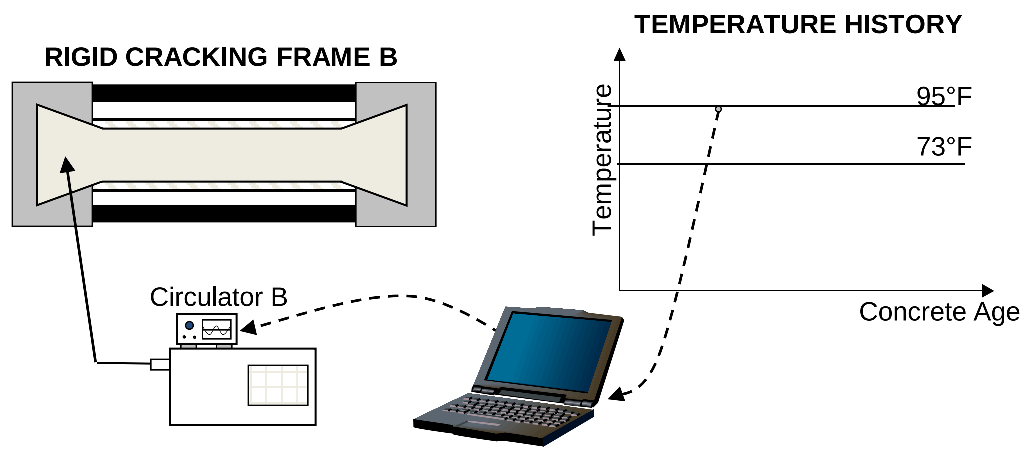
Match Cure Box

Testing Equipment

The Setup



Stress Development=
f(Thermal and Autogenous Effects)



Stress Development=
f(Autogenous Effects)

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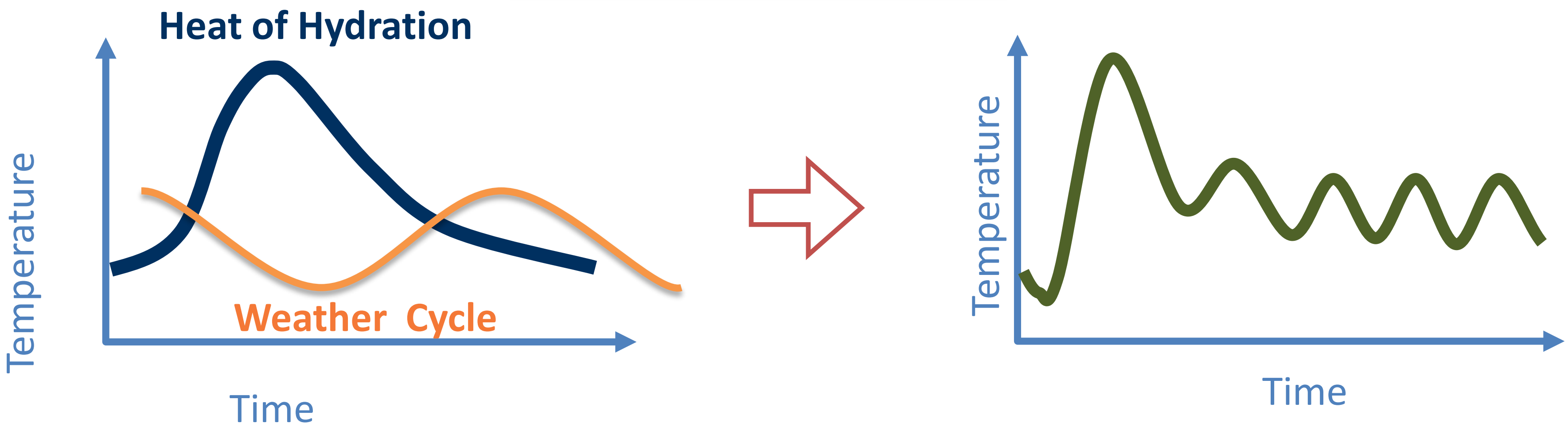
Experimental Work

In-Place Temperature Prediction Models (ConcreteWorks version 2.01)



- Cement Composition
- Effect of SCMs
- Cement Fineness
- Amount of Cement
- Chemical Admixtures
- w-cm Ratio
- Mix Temperature

- Air Temperature
- Wind Speed
- Relative Humidity
- Cloud Cover
- Solar Radiation
- Air Pressure

- Element Geometry
- Element Size
- Form Properties
- Curing Method
- Aggregate type

Experimental Work

- Each concrete mixture was tested:
  - Rigid Cracking Frame
    - Summer and Fall placement scenario
    - Isothermal 73 °F and 95 °F
  - Match Cure Box
    - Summer and Fall placement scenario
      - Compressive strength
      - Splitting tensile strength
      - Modulus of Elasticity
  - Coefficient of Thermal Expansion Testing

Experimental Work

- Mixtures tested:
  - Control mixtures (CTRL)
    - Bridge deck mixture
    - w/c = 0.42, Cement content 620 lb/yd^3
    - Slump: 3 to 5 in., Air Content: 4.5 to 6.5 %
    - Aggregates: Siliceous river gravel and natural sand
  - Internal curing mixtures (IC)
    - Same w/c, slump, air content and normalweight aggregates
    - Add Lightweight sand to achieve an equilibrium density equal to 135 pcf
  - Sand-Lightweight mixtures (SLW)
    - Same w/c, slump, air content and normalweight fine aggregates
    - Cement content 658 lb/yd^3
    - Lightweight coarse aggregate

Experimental Work

- Lightweight Aggregates

Item		Lightweight Aggregate Type				
		Slate		Clay		Shale
Supplier		Stalite		TXI		Buildex
Source		Gold Hill, NC		Frazier Park, CA		New Market, MO
Coarse Aggregate	Gradation	3/4 in. to #4		3/8 in. to #4		1/2 in. to #4
	Absorption (%)	6.4		25.5		32
	Relative Density	1.52		1.72		1.59
Fine Aggregate	Gradation	#4 to 0	#4 to 0	#4 to 0	3/8 in. to 0	#4 to 0
	Absorption (%)	9	9	19	19	19.3
	Relative Density	1.84	1.84	1.81	1.81	1.8
	Fineness Modulus	2.83	3.37	3.07	4.32	2.99

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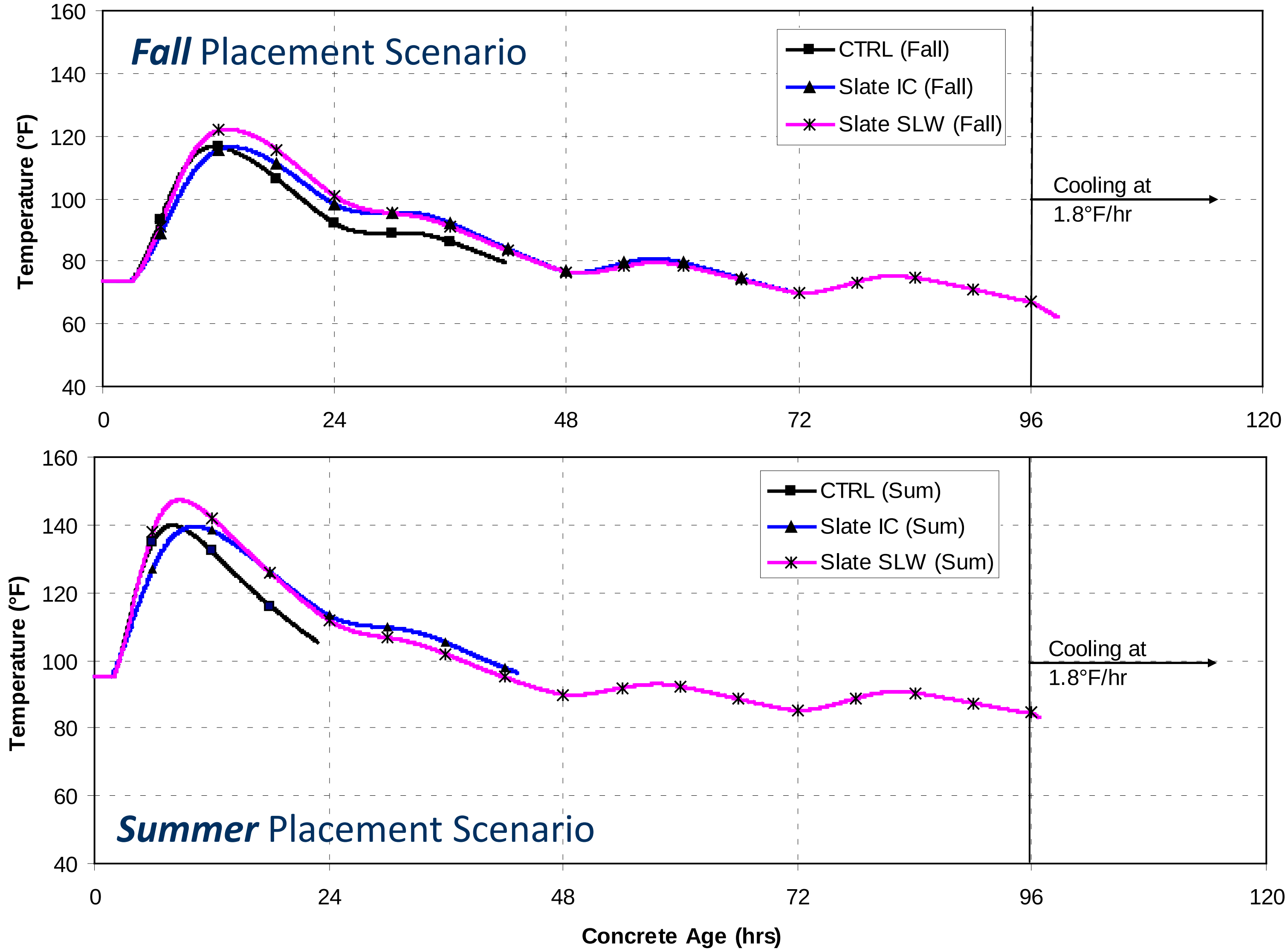
Results

Typical Mixture Proportions and Properties

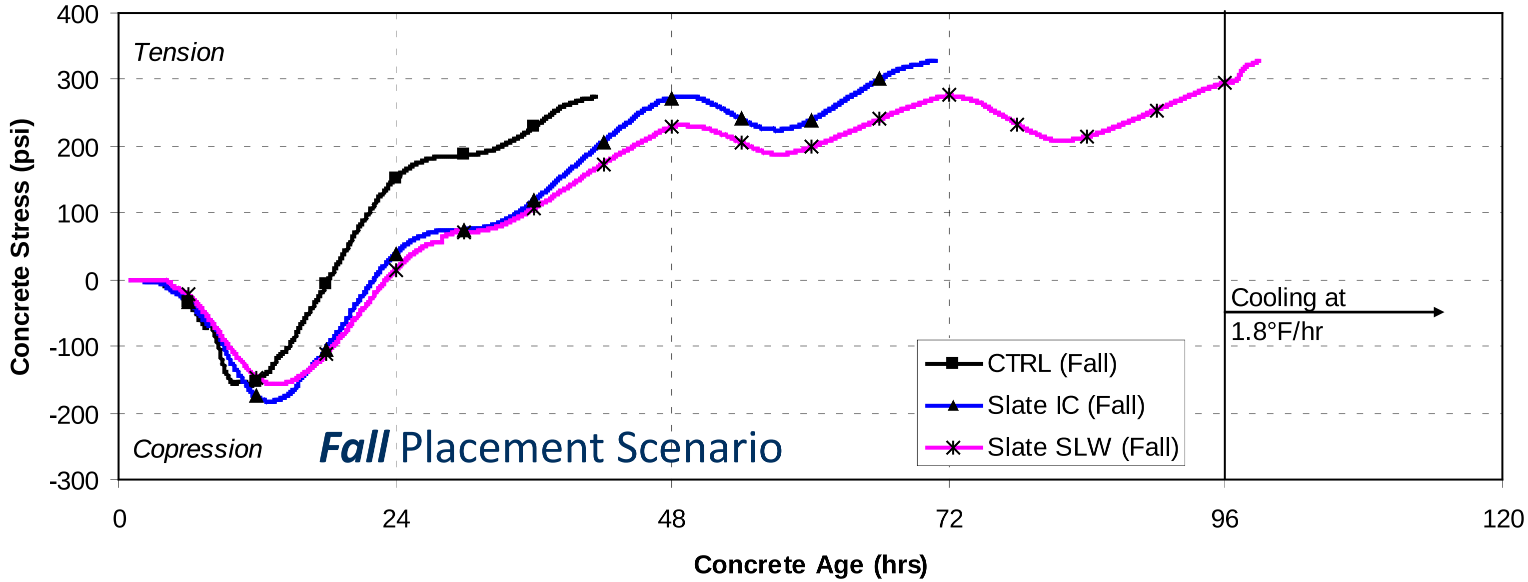
Component	CTRL	Slate IC	Slate SLW
Water	260	260	276
Cement (lb/yd^3)	620	620	658
No. 67 River Gravel SSD (lb/yd^3)	1761	1761	0
Slate Lightweight Coarse SD (lb/yd^3)	0	0	875
Natural Sand SSD (lb/yd^3)	1210	818	1381
Slate Fine Aggregate SD (lb/yd^3)	0	276	0
Air (%)	5.5	5.5	5.5
w/cm	0.42	0.42	0.42
Property			
Fresh Density (lb/ft^3)	142.6	138.3	118.2
Calculated Equilibrium Density (lb/ft^3)	140.0	135.0	113.6
Coefficient of Thermal Expansion (με/°F)	**6.2**	**5.9**	**5.1**
Thermal Diffusivity (ft^2/hr)	1.64	1.52	1.26
Internal Curing Provided Water (lb/yd^3)	0	22	51

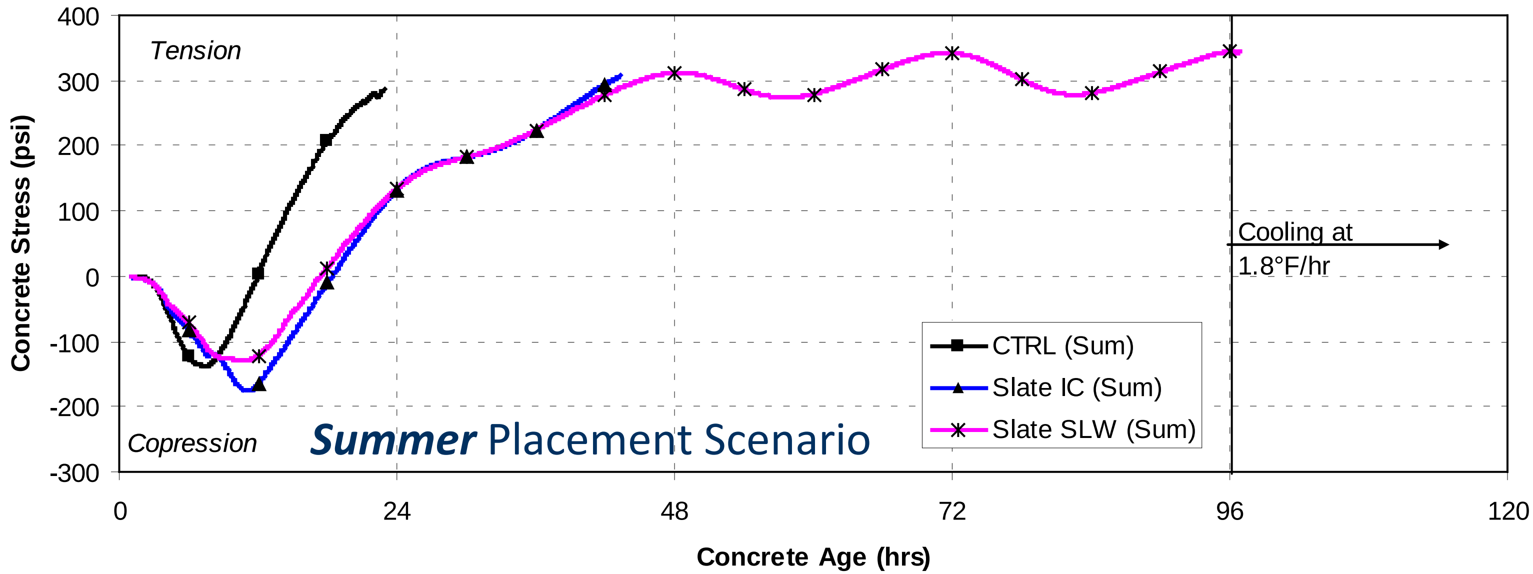
Results
Typical Temperature Modeling



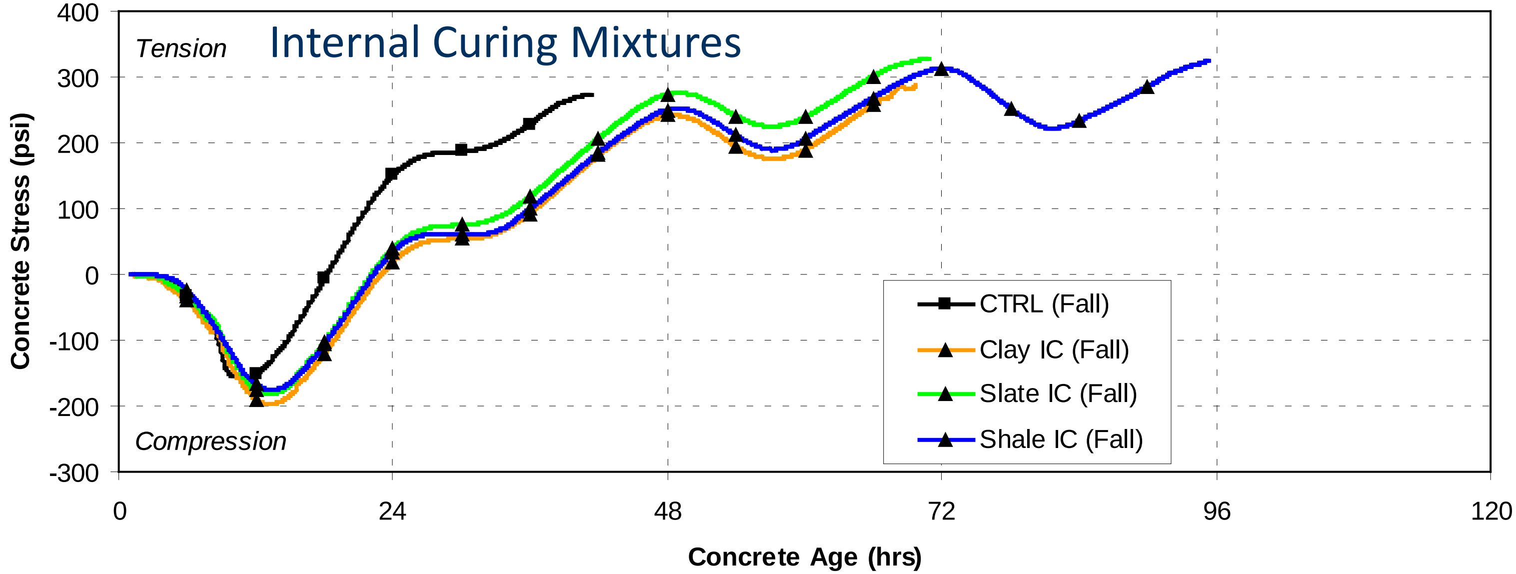
Results

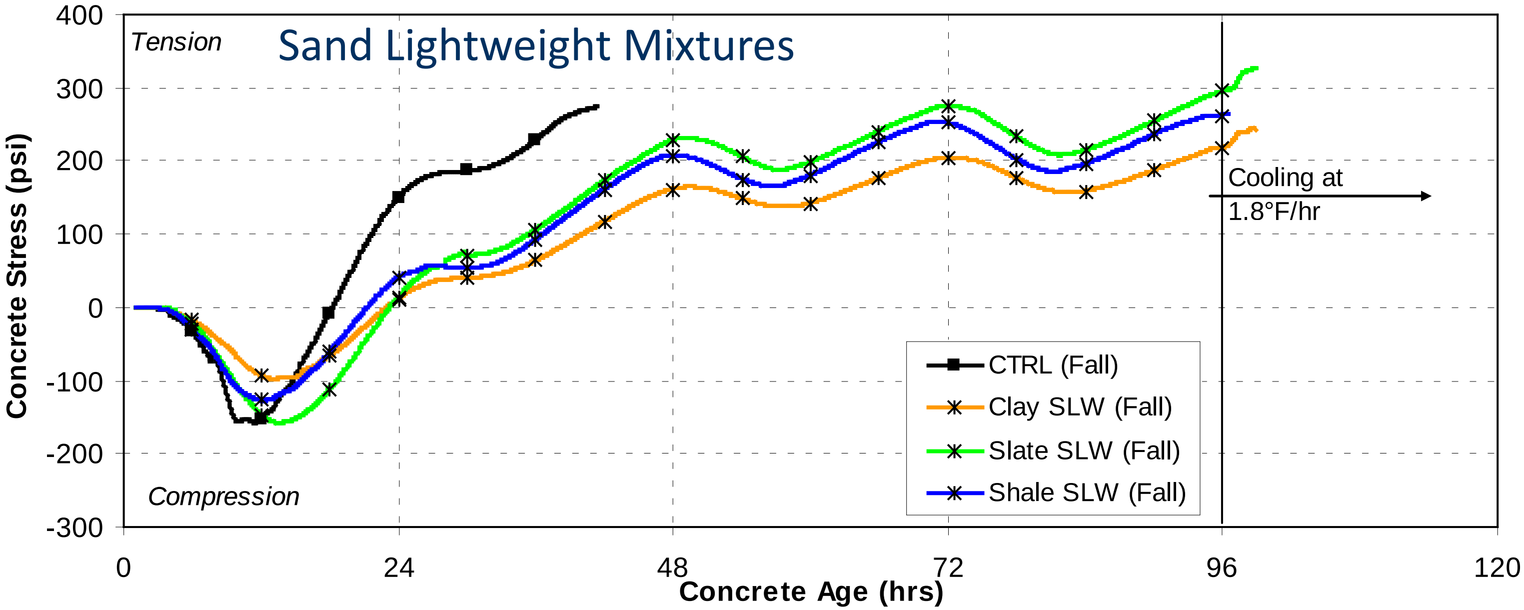
Typical Thermal Stress Development



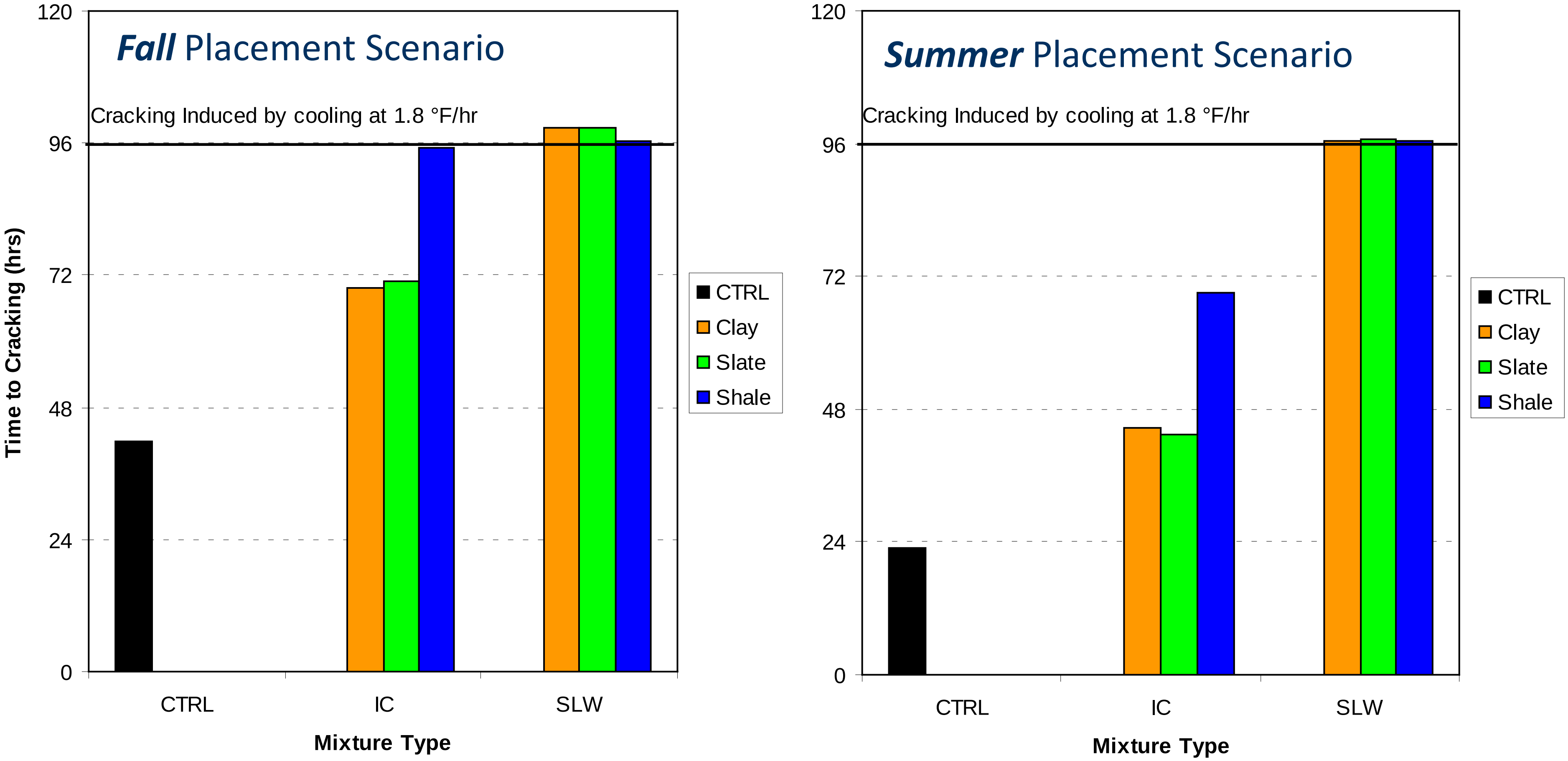


Results
Thermal Stress Development





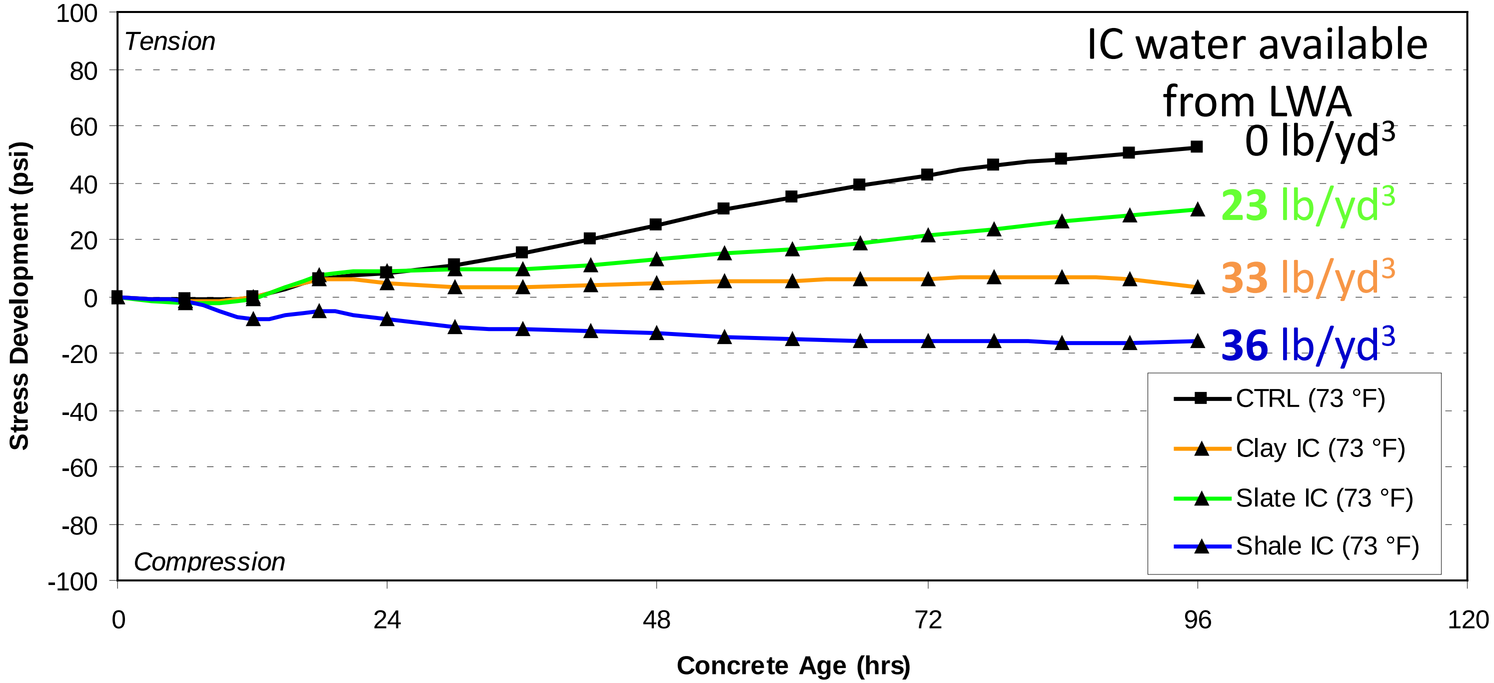
Results



Fall Placement Scenario
Cracking Induced by cooling at 1.8 °F/hr
Time to Cracking (hrs)
120
96
72
48
24
0
CTRL
IC
SLW
Mixture Type
CTRL
Clay
Slate
Shale
Summer Placement Scenario
Cracking Induced by cooling at 1.8 °F/hr
120
96
72
48
24
0
CTRL
IC
SLW
Mixture Type
CTRL
Clay
Slate
Shale

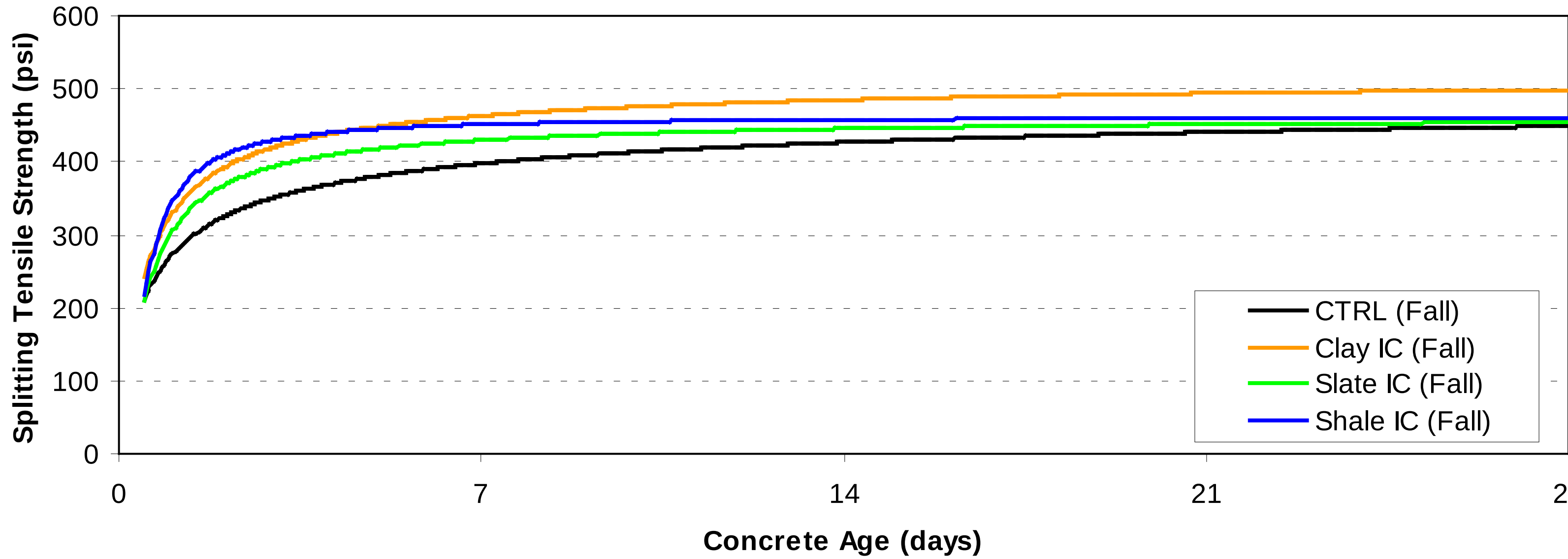
Results

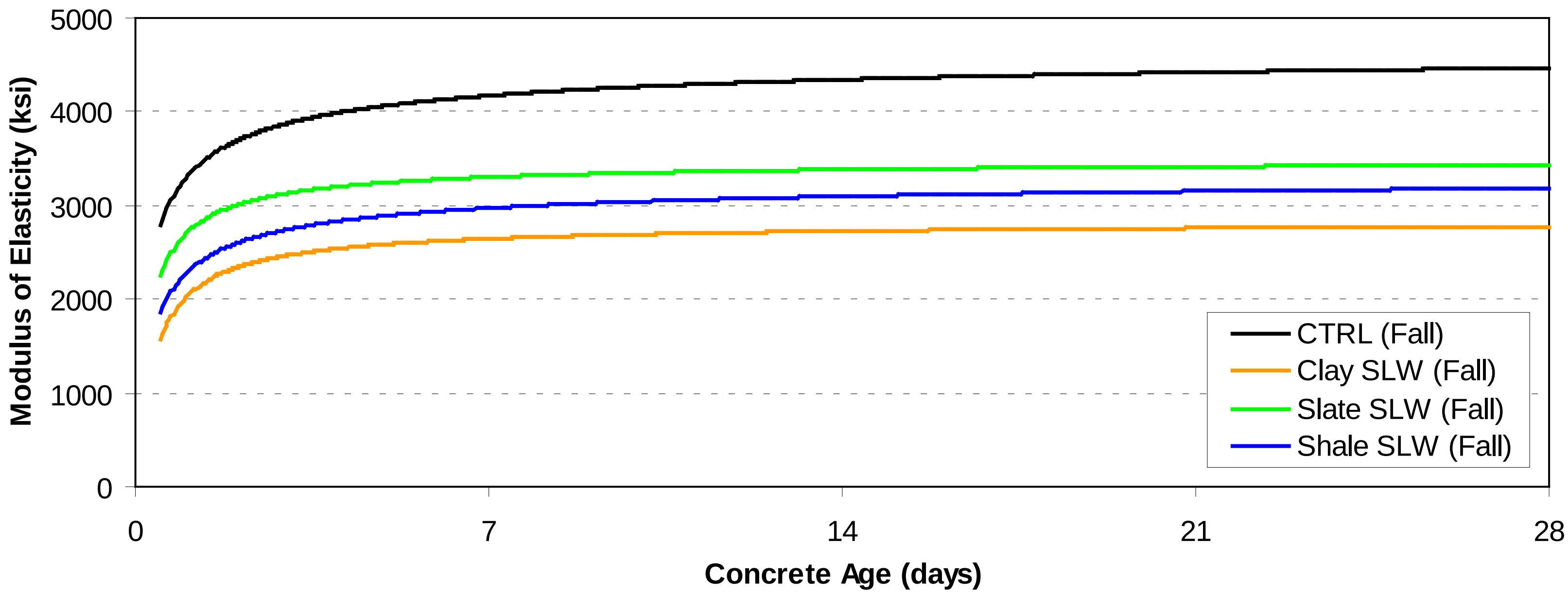
Isothermal Stress Development



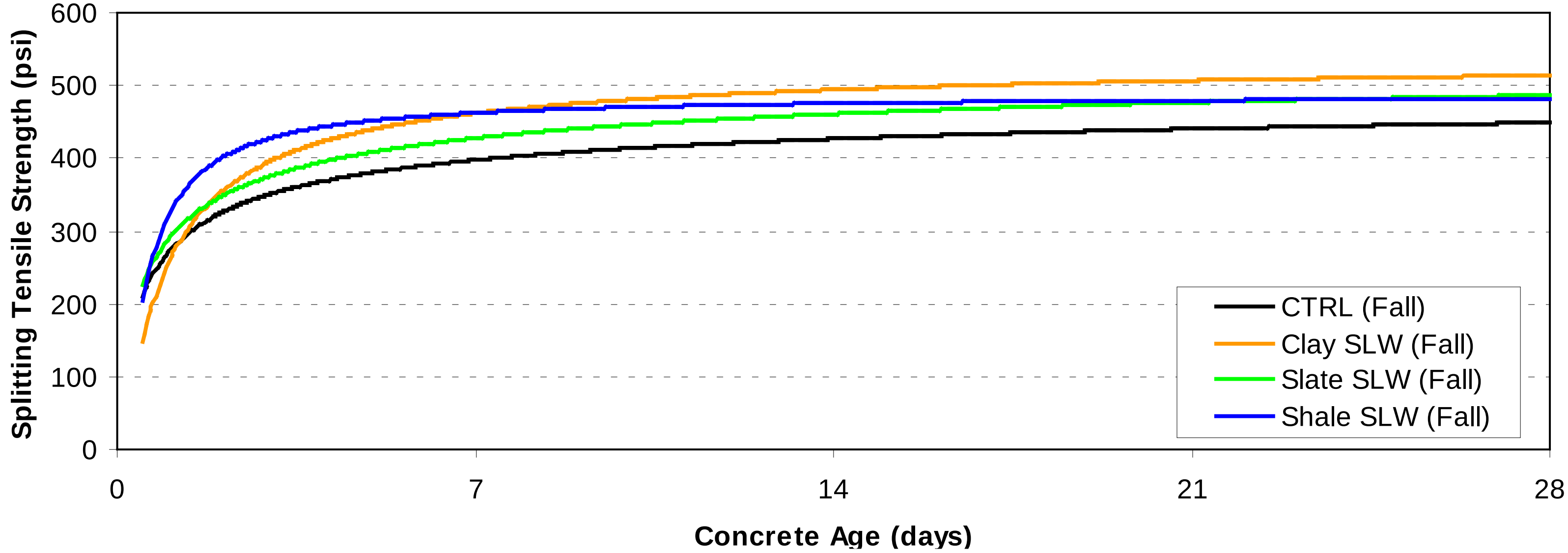
Results

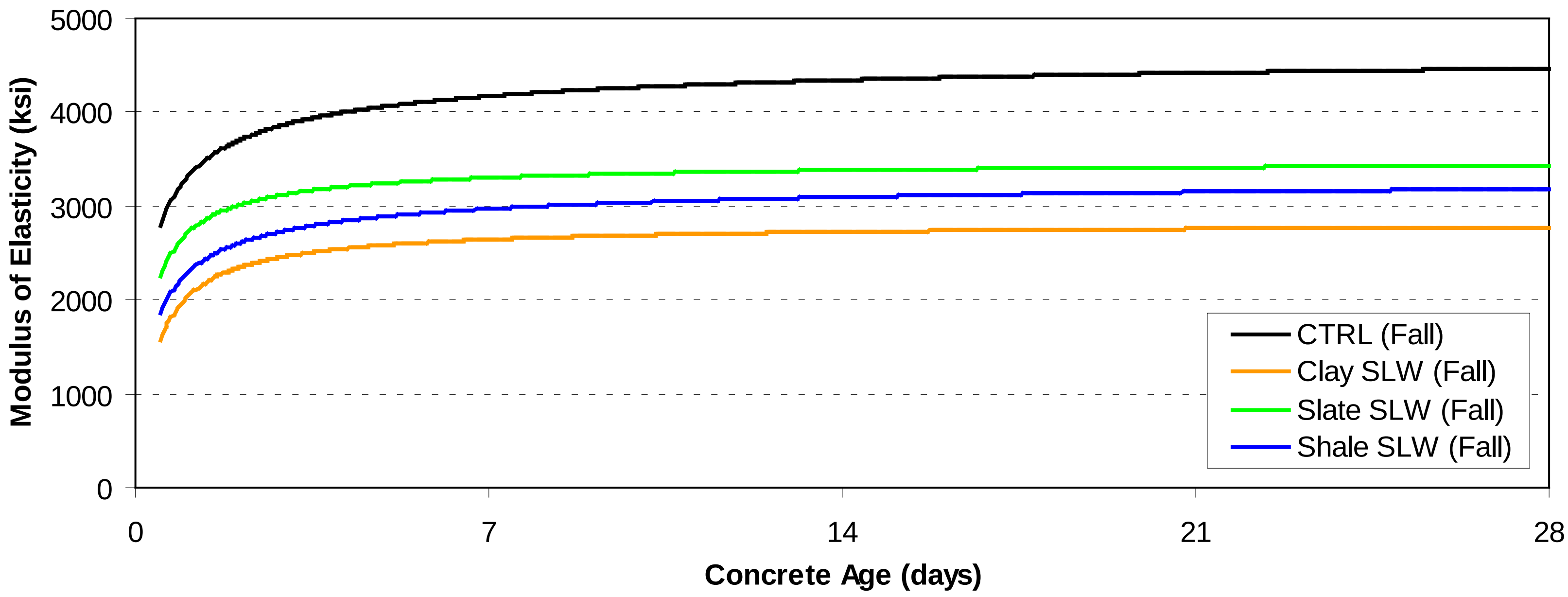
Mechanical Property Development





Results
Mechanical Property Development





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Conclusions

- Decreased placement and curing temperatures reduce tensile stresses and delay cracking
  - Fall placements have less thermal cracking
- Lightweight aggregate use decreases the modulus of elasticity and coefficient of thermal expansion of the concrete
- Lightweight aggregate use increases splitting tensile strength through increased cement hydration.
- Use of saturated lightweight aggregates reduces the stress development caused by autogenous shrinkage
  - LWA provides internal curing

Conclusions

- Use of lightweight aggregate *decreases* the modulus of elasticity, coefficient of thermal expansion, and autogenous shrinkage, thus *reducing* restraint stresses and *delaying* the occurrence of cracking

- Increased cracking times lead to *larger* crack spacing on bridge deck and *fewer* cracks

Thank You For Your Time!

Questions?

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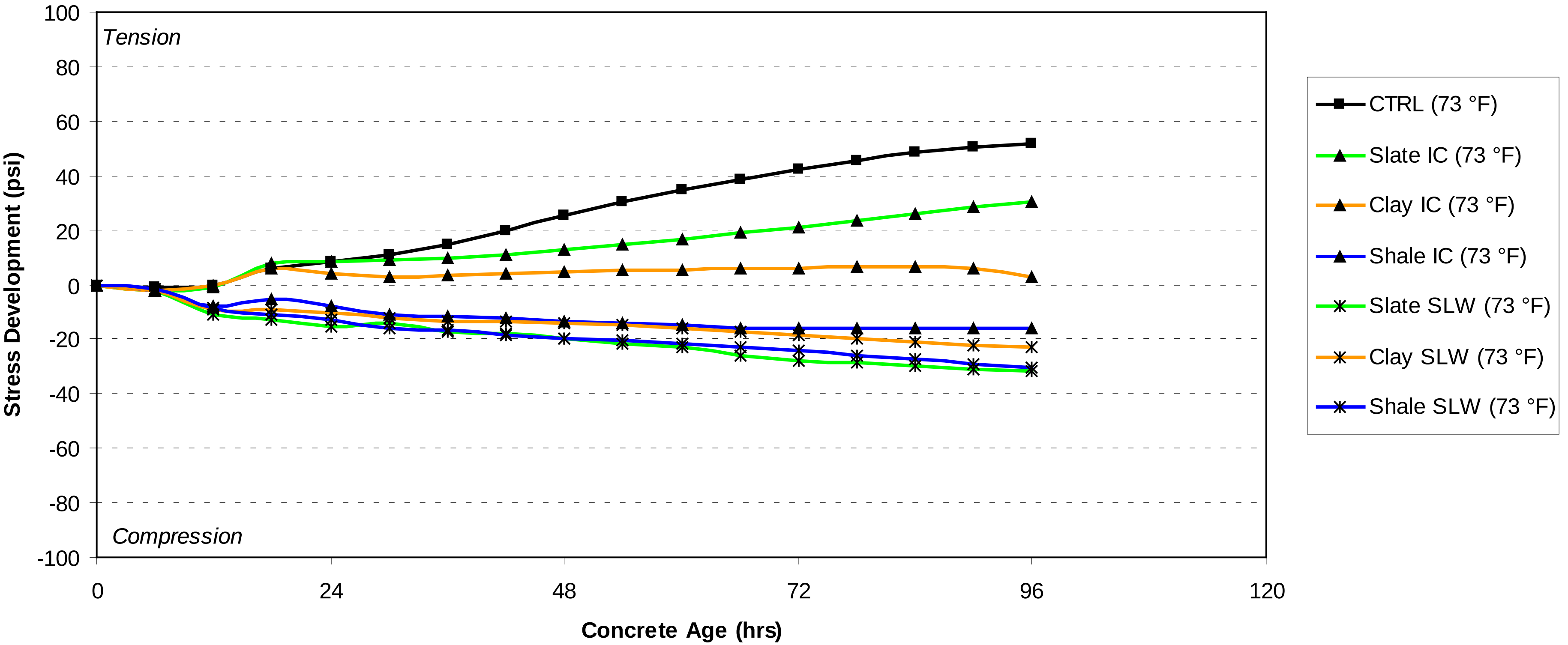
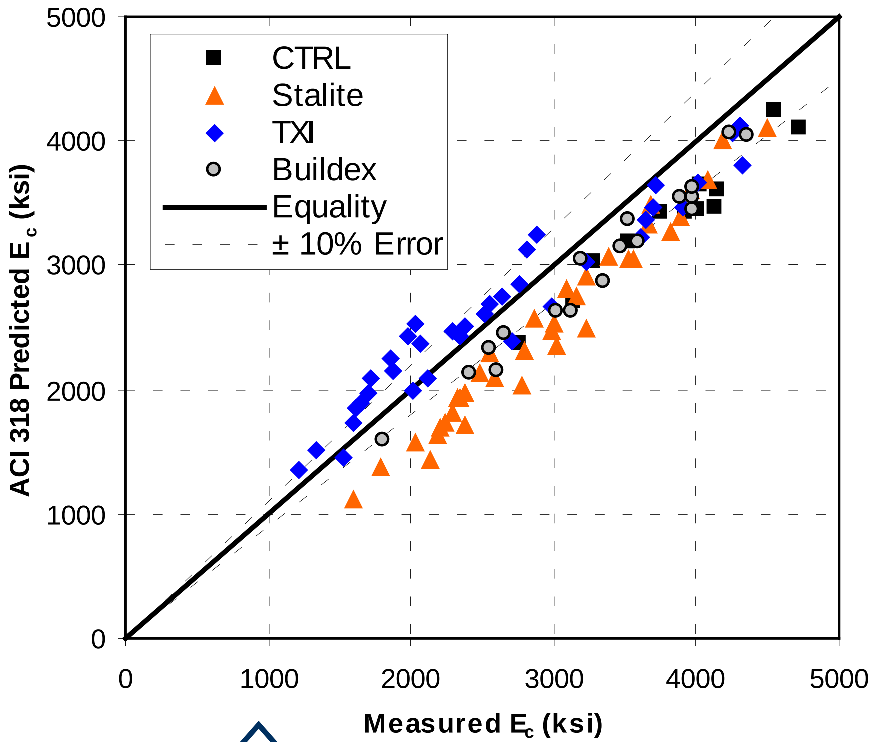
Isothermal Stress Comparisons



Modulus of Elasticity Comparisons



Fresh Density

ACI 318 Prediction Equation:

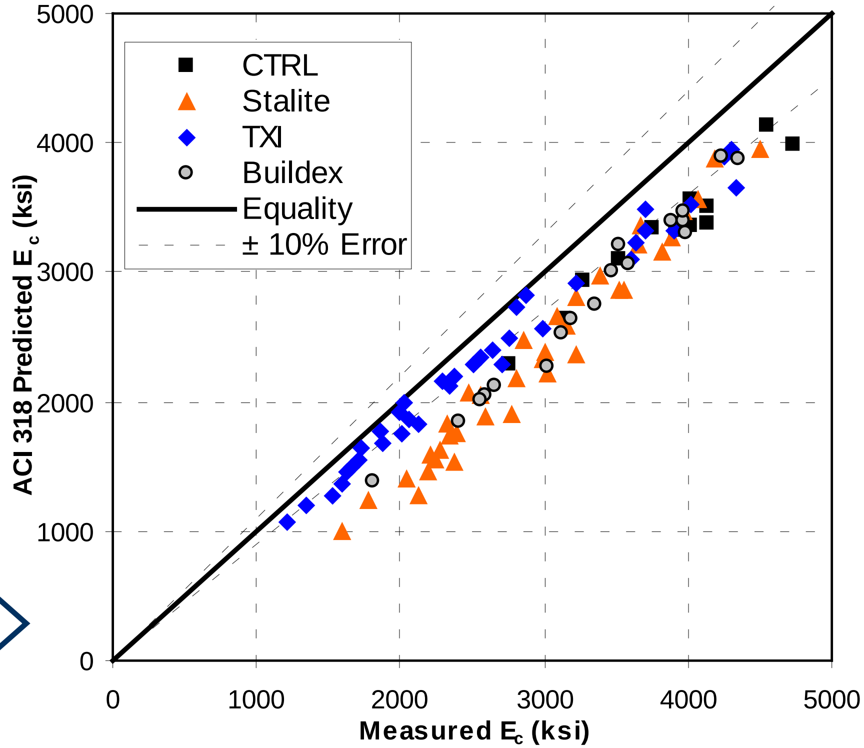
$$E_c = 33 w_c^{1.5} \sqrt{f_c}$$

where :

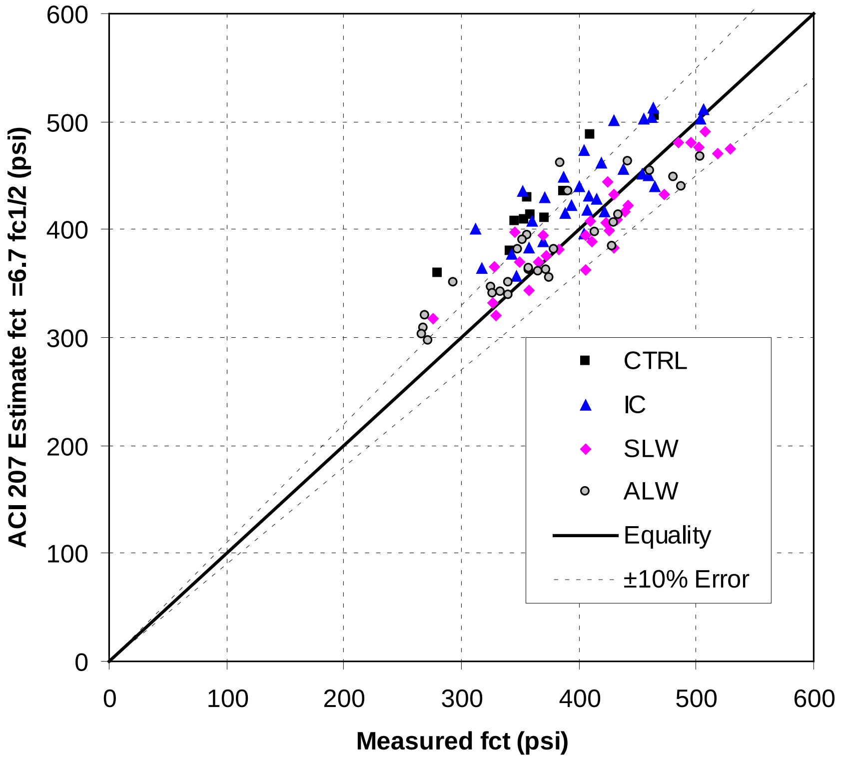
w_c = density of concrete

f_c = compressive strength

Calculated Equilibrium Density



Splitting Tensile Comparisons



$$F_t = 6.7 f_c^{\frac{1}{2}}$$

$$F_t = 1.7 f_c^{\frac{2}{3}}$$