



# **GreenCrete** Intelligent Concrete

PJA Holdings, LLC

**September 2016**

# Technology Overview

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- **Introduction**

- **GreenCrete Overview**

- Mix Design Technology

- **GreenCrete Test Information and Results**

- GreenCrete References and Case Study: Revel Casino

- **GreenCrete Construction Stakeholders Value Proposition**

# GreenCrete Overview

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GreenCrete provides premier concrete technology revolutionizing the construction industry by bringing the next generation in concrete production and associated technologies

- Mix Design Technology
- Cost Savings
- Data Integration
- Superior Concrete Performance

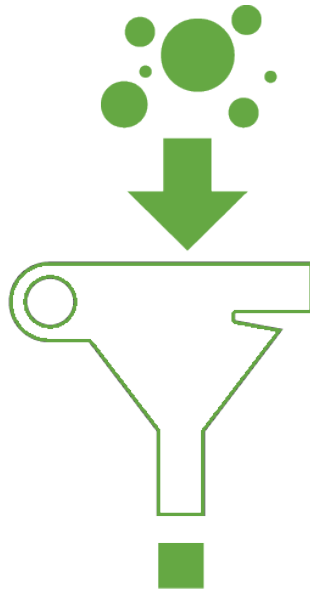
The result - A higher performing, more economical and more environmentally friendly concrete

Designed specifically for workability, strength, durability and any specification

# GreenCrete Overview

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## Mix Design Technology: Proprietary testing methods



- GreenCrete conducts proprietary material tests necessary for optimum mix design formulation
- Results from proprietary tests are applied to GreenCrete mix algorithms. Tests are conducted on the following ingredients:
  - Cement
  - Coarse aggregates
  - Fine aggregates
  - Supplementary cementitious materials (SCMs)
  - Admixtures
- GreenCrete maintains databases of materials, their sources, their chemical and physical properties, and their interrelationships which are continuously updated and monitored

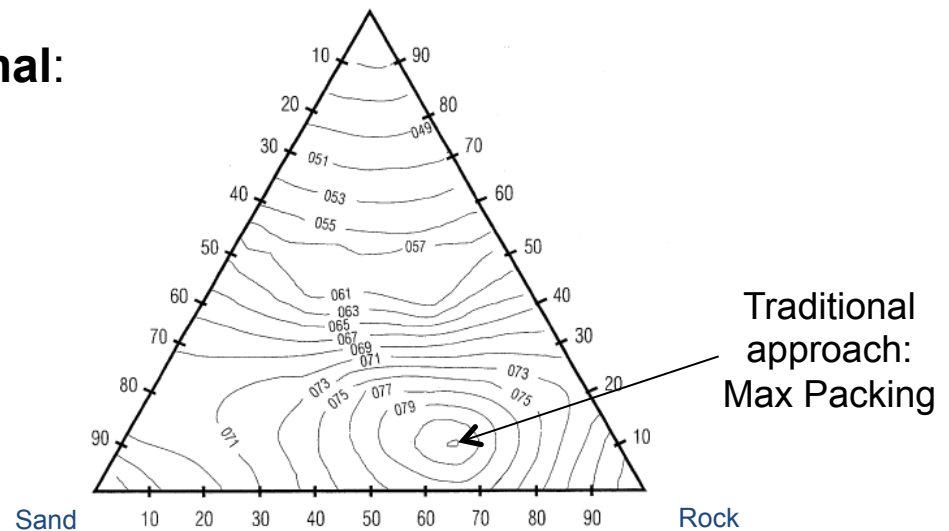
# GreenCrete Overview

## Mix Design Technology: Unique Approach

GreenCrete has studied material characteristics and has developed a novel approach to concrete mix designs

### ■ GreenCrete designs for optimal:

- Workability
- Strength
- Cost
- Any performance specification



GreenCrete has identified the optimum particle packing (not the maximum) through the application of its proprietary materials testing methods and computer algorithms

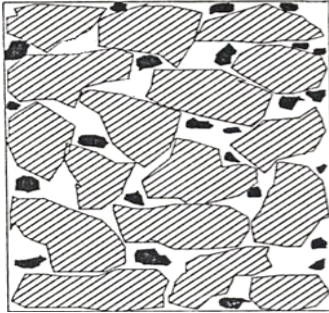
GreenCrete utilizes your materials and optimizes for workability and cost effectiveness

# GreenCrete Overview

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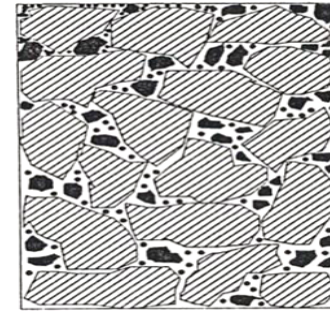
## Mix Design Technology: GreenCrete versus Conventional

### Standard Mix Designs



- Larger void spaces require more cement paste
- Cement paste is the weakest and most expensive material in concrete
- Excess cement generates excess heat of hydration
- Industry commonly allows driver-added water to meet workability requirements, which reduces strength

### GreenCrete Mix Designs



- Void spaces are reduced by optimizing packing of raw materials
- Aggregates replace excess cement paste to give improved stability, less shrinkage and lower cost
- Lower hydration temperatures
- Easier handling, better consistency and easier finishing

GreenCrete mix designs produce higher quality concrete and can be produced at a reduced cost relative to conventional mixes

# GreenCrete Overview

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## Mix Design Technology: Designing for workability

### ■ CONVENTIONAL APPROACH

- Design for slump
- QC measurement
- Approximation of workability at best
- Managed with water, which effects strength through water/cement ratio
- Results in higher standard deviation

### ■ GreenCrete APPROACH

- Design for cohesion and viscosity
- Viscosity is a characteristic experienced by the workers onsite
- Optimizes rheology of the concrete
- Reduces segregation, bleeding and improves finishability

# GreenCrete Overview

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## Designed to Specification

**The GreenCrete System is designed specifically for workability, strength and durability to meet any specification.**

### Designed for specified engineering characteristics including:

- Strength
- Shrinkage
- Creep
- Modulus of Elasticity
- Freeze Thaw
- Rapid Chloride Permeability
- Self Consolidating Concrete
- Pervious Concrete
- Other

### Unique GreenCrete Specifications:

- 100 year design life
- Permeability Test (ASTM C 1202)
- Shrinkage Test (ASTM C 157)

Shrinkage shall not exceed 0.042 percent to initial comparator reading

- Monitoring internal and external concrete temperatures

Max difference shall not exceed 20°C; Internal not to exceed 65°C;

### Representative Specification Designs:

- **One World Trade** (Heat of Hydration; MOE of 48 GPa)
- **Revel Casino** (High-Early)
- **Great Belt Link Connection** (Slip Form)
- **Carbon Neutral City** (Low Carbon Footprint)
- **International Causeway** (Marine Application)
- **International Canal** (Marine Application)



# GreenCrete Test Information and Results

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## Regional Testing Information: Geographically Diverse Locations

### GreenCrete Testing Program

- Each location had 4 GreenCrete designs tested with local raw materials
- Target Specifications:
  - 25 MPa Air **Target Slump:** 175 mm (7 inches)  
Air: 6%
  - 25 MPa Non-Air **Target Slump:** 175 mm
  - 40 MPa PSI Non-Air **Target Slump:** 175 mm
  - 65 MPa + (low W/C) Non-Air **Target Slump:** 250 mm (10 inches)
- *All mixes contained Ordinary Portland Cement, local fly ash, local sand, 3/4'' aggregates and superplastizer*
- *No slag or silica fume were included in these mix designs for testing purposes*

### Tests Conducted:

- Compressive Strength
- Modulus of Elasticity
- Rapid Chloride Permeability
- Drying Shrinkage
- Air Void Analysis
- Freeze Thaw

# GreenCrete Test Information and Results

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## Test Highlights

### Test Results

- Compressive Strength

*GreenCrete exceeded local compressive strength results*

- Modulus of Elasticity

*GreenCrete achieved excellent Moduli results*

- Rapid Chloride Permeability

*GreenCrete attained latex-modified concrete density (ASTM test standard)*

- Drying Shrinkage

*GreenCrete achieved market-leading drying shrinkage results*

- Air Void Analysis

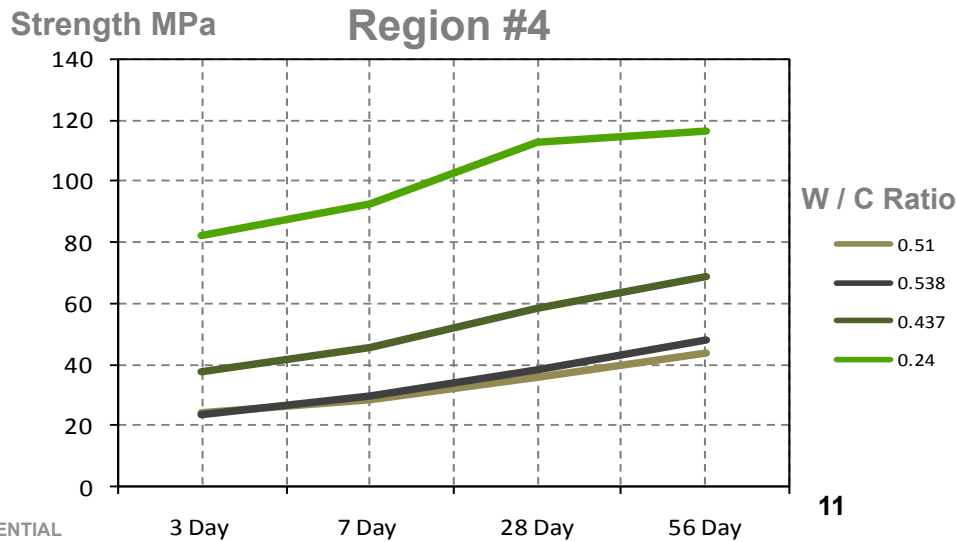
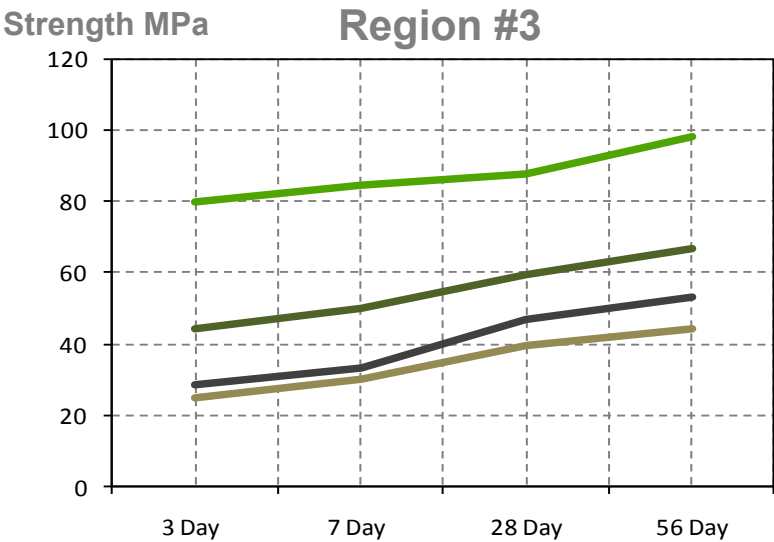
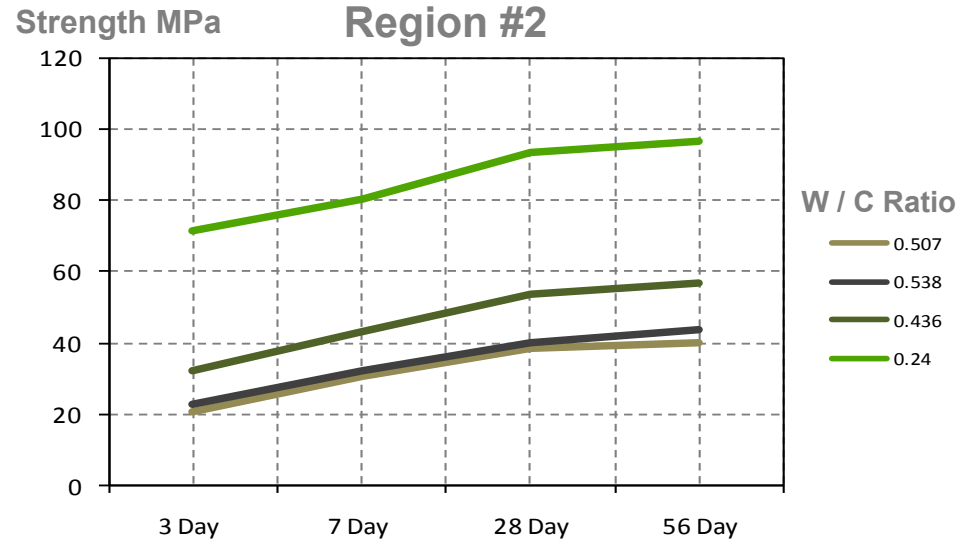
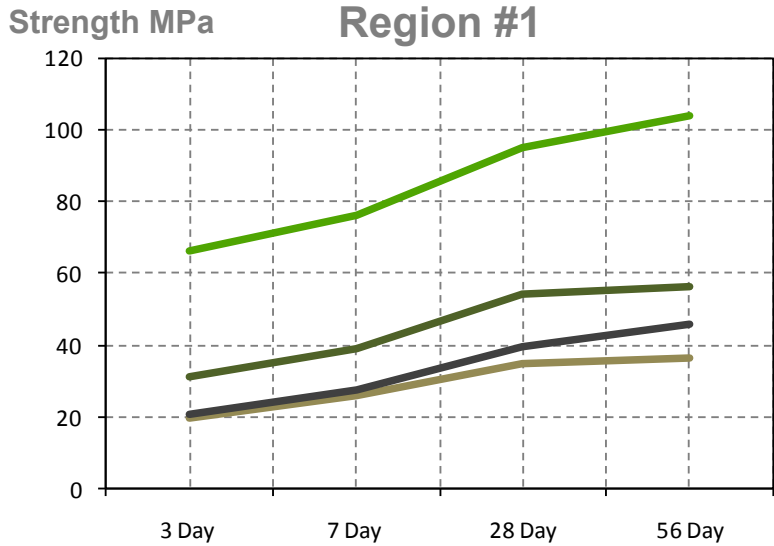
*GreenCrete accomplished superior air void spacing numbers*

- Freeze Thaw

*GreenCrete achieved outstanding durability results*

# GreenCrete Test Information and Results

## Compressive Strength: Strength Progression



# GreenCrete Test Information and Results

## Durability and Drying Shrinkage

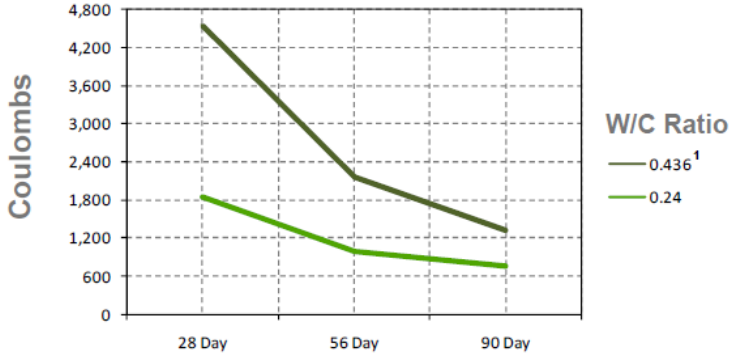
The GreenCrete system of design is very effective in decreasing the drying shrinkage at lower W/C ratios essential for long term durability and service life.

- Drying shrinkage values will vary with local raw materials as these results indicate.
- Typically, the GreenCrete system can reduce drying shrinkage 15% to 35% versus conventional mixes produced with the same material.
- Designed for specified engineering characteristics including:
  - Strength
  - Shrinkage
  - Creep
  - Modulus of Elasticity
  - Freeze Thaw
  - Rapid Chloride Permeability
  - Self Consolidating Concrete
  - Pervious Concrete
  - Other

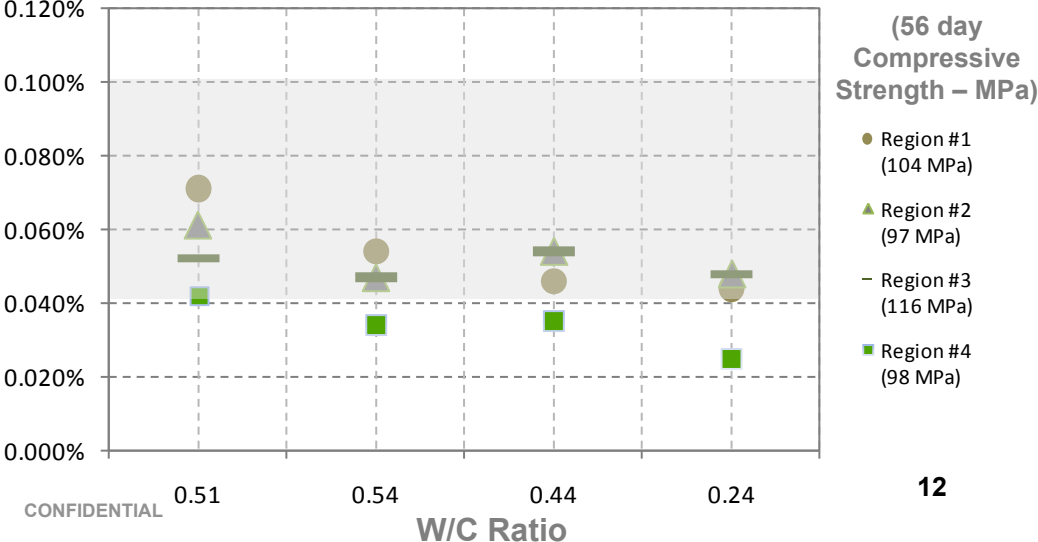
<sup>1</sup> Mix is air-entrained

*Grey shading represents industry average*

Durability: Rapid Chloride Permeability Test ("RCPT")



Drying Shrinkage



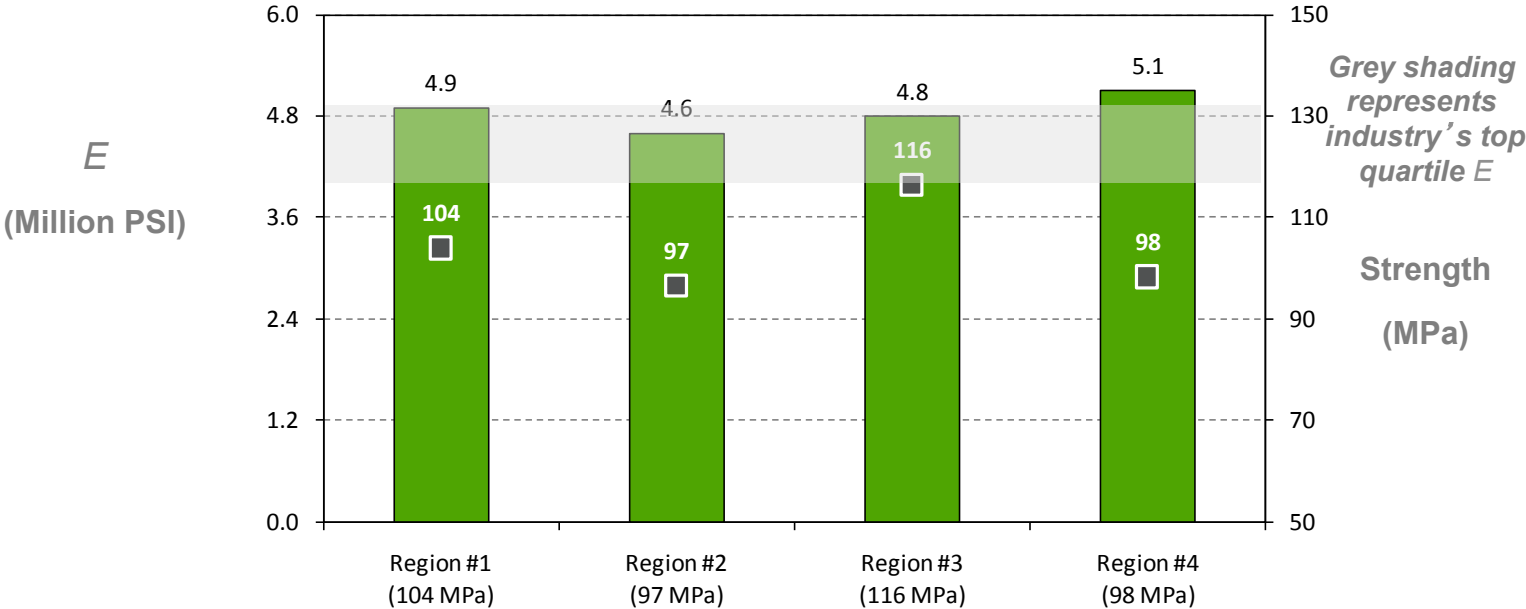
# GreenCrete Test Information and Results

## Modulus of Elasticity (“E”)

Mix designs utilizing the GreenCrete system of mix formulation produces maximum moduli and strengths with the local materials for each of the regions tested.

- The highest compressive strength does not always produce the highest *E* as displayed in this series of tests.
- GreenCrete can help achieve the highest *E* for a given set of materials.

*E* Test Results @ 28 Days\*



# GreenCrete Test Information and Results

## Hardened Air Void and Freeze-Thaw Analysis

GreenCrete mixes create a higher cohesion of the mortar system that produces a unique air void system, which generally consists of a large number of very small bubbles with excellent specific surface areas and distance factors.

- The spacing factor is important because the closer the voids are to one another, water travels shorter distances in order to expand.
- GreenCrete mixes produced using the GreenCrete system achieved spacing factors that exceed the industry average range from 0.23 mm to 0.17 mm.
- GreenCrete mixes produced using the GreenCrete system were all very freeze-thaw durable.
- Durability factors above 80% are considered a sign of durable concrete.

Hardened Air Void Analysis and Freeze Thaw Durability Testing				
Region	#1	#2	#3	#4
<b>Air Content</b>				
Plastic:	7.40	6.70	7.40	7.40
Hardened:	9.22	9.86	11.06	6.62
<b>Specific Surface (mm-1):</b>	35.27	35.20	27.86	44.80
<b>Spacing Factor (mm):</b>	0.086	0.084	0.094	0.097
<b>Void Frequency:</b>	0.813	0.867	0.770	0.741
<b>Average Chord Length:</b>	0.113	0.114	0.144	0.089
<b>Paste-to-Air Ratio:</b>	3.040	2.940	2.620	4.380
<b>Freeze Thaw:</b>	92.7%	90.7%	93.7%	94.0%

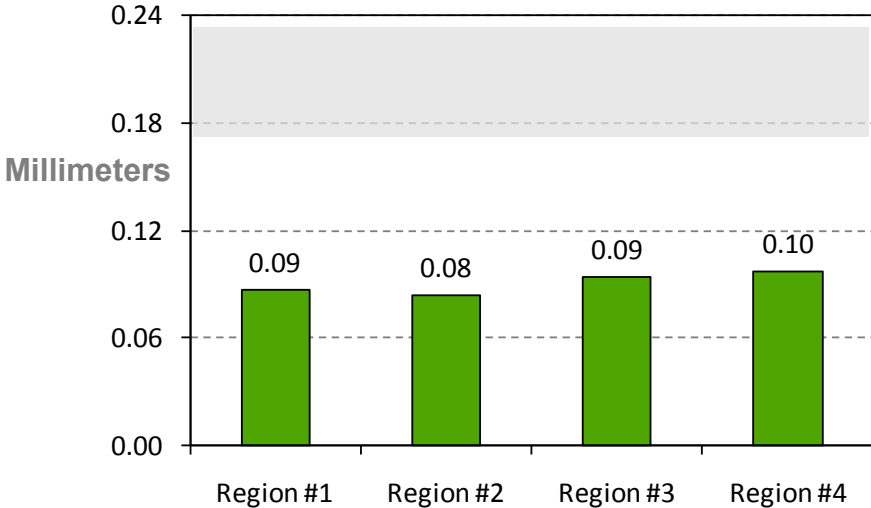
# GreenCrete Test Information and Results

## Air Void Spacing and Durability Factors

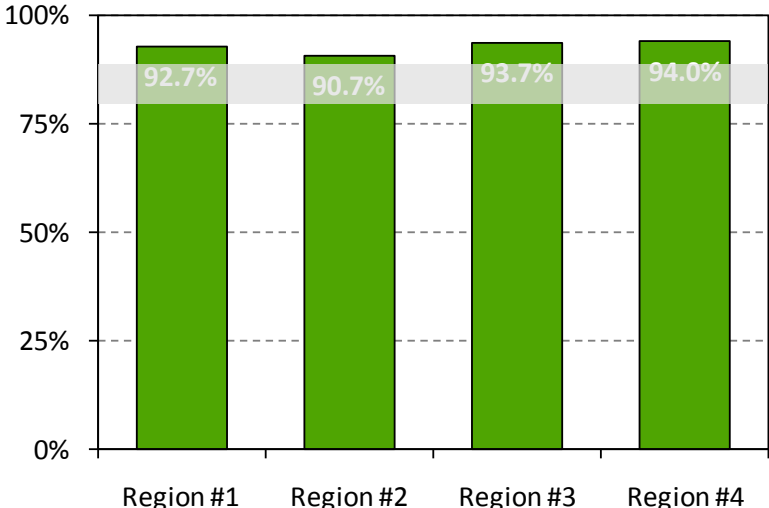
GreenCrete mixes performed well in the air void spacing and durability factors for all regions.

- GreenCrete mixes produced using the GreenCrete system achieved spacing factors that surpassed the industry average range.
- Industry average air void spacing and durability factors range from 0.230 mm to 0.170 mm and 80% and 90%, respectively.

### Air Void Spacing Factor



### Durability Factor



*Grey shading indicates industry averages*

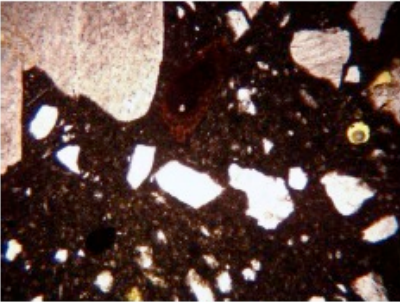
# GreenCrete Test Information and Results

## Local Test Results, RJ LeeGroup, Inc.

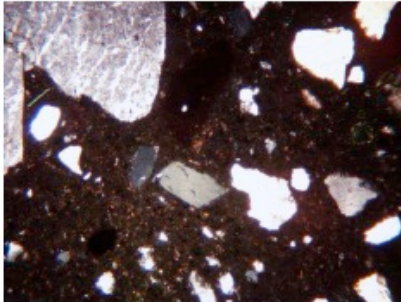
RJ LeeGroup reported that the specimens were “of similar composition; high quality, well-compacted concrete with dense cement paste” and “evaluated to be durable, high performance concrete.”

- Samples were analyzed following ASTM C 856, “Standard Practice for Petrographic Examination of Hardened Concrete”

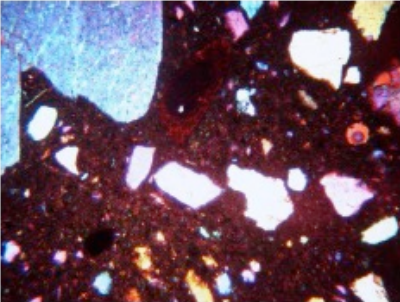
### Conventional 60 MPa



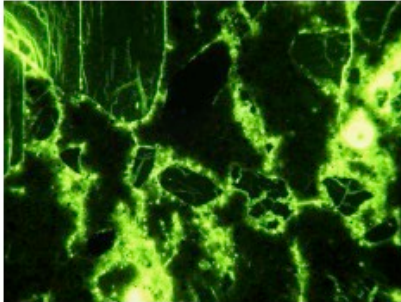
(a) Plane polars



(b) Crossed polars

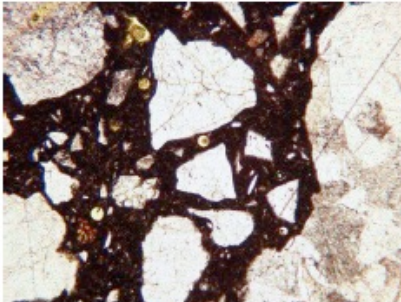


(c) Gypsum plate

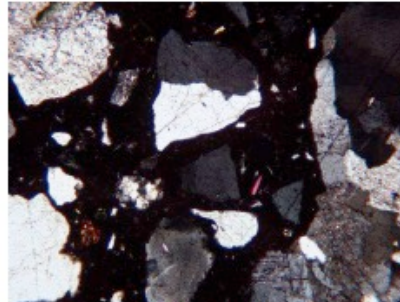


(d) Fluorescent mode

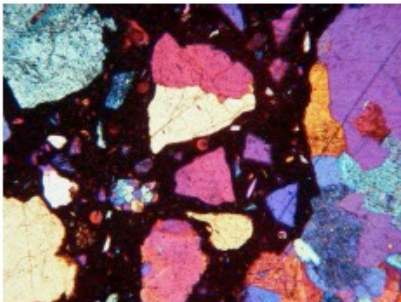
### GreenCrete 60 MPa



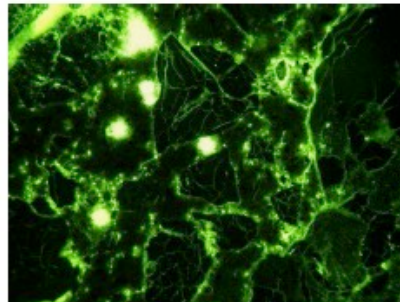
(a) Plane polars



(b) Crossed polars



(c) Gypsum plate



(d) Fluorescent mode

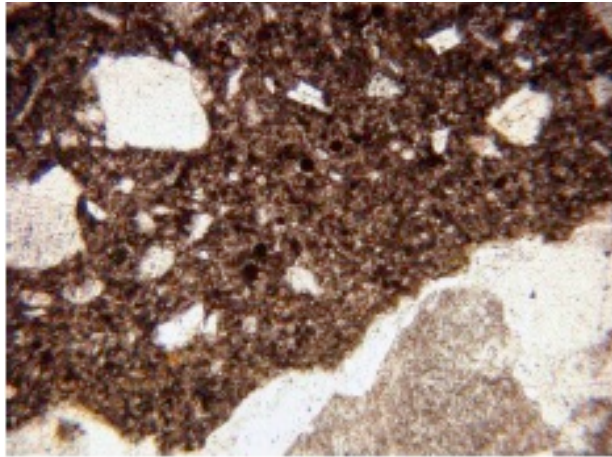


# GreenCrete Test Information and Results

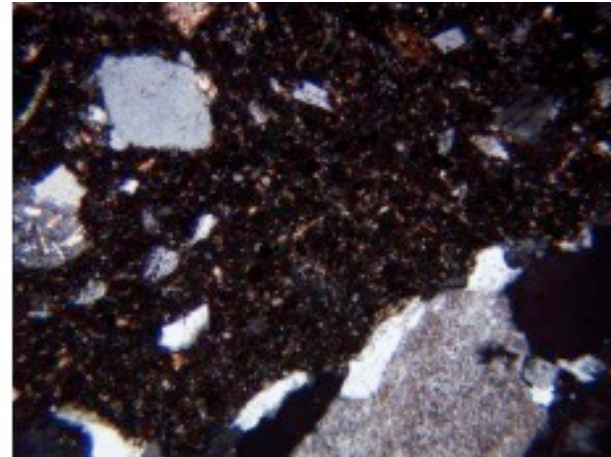
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Local Test Results, RJ LeeGroup, Inc.

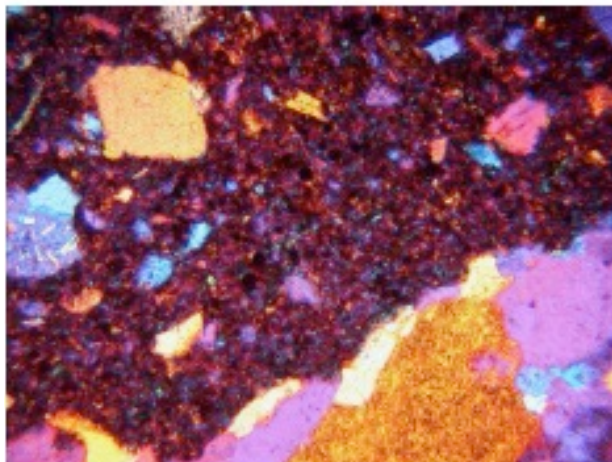
GreenCrete's 100 MPa mix exhibits a "very dense cement paste".



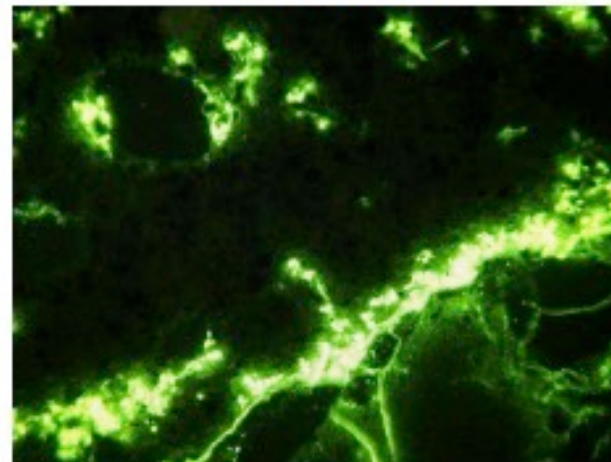
(a) Plane polars



(b) Crossed polars



(c) Gypsum plate



(d) Fluorescent mode

Figure 14. CN80299/2, RJLG ID 3637777. Optical images in different light modes showing aggregate in very dense cement paste. Image area is 2.6 mm wide.

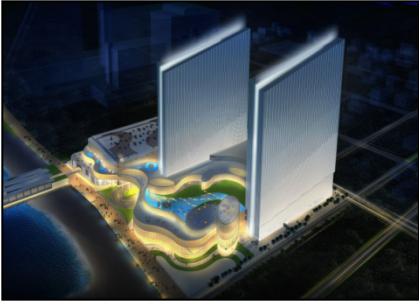
# GreenCrete Projects and References

## GreenCrete Case Study: Revel Tower

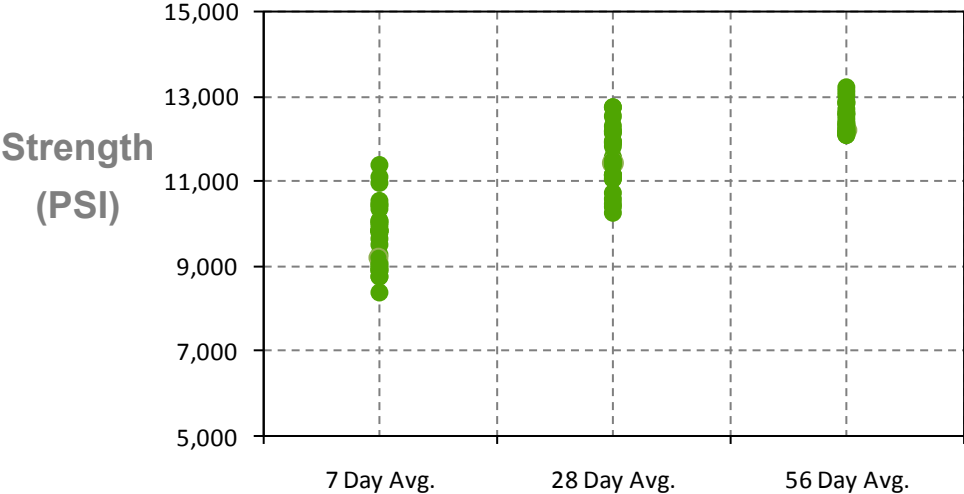
The GreenCrete System allows for greater consistency, which allows producers to achieve lower standard deviations and coefficients of variation.

- Industry averages for Coefficient of Variation range between 8% to 10%.
  - Implies a market standard deviation of 1,035 and 1,116, for the 28 day and 56 day, respectively.
  - GreenCrete achieved standard deviations of 674 and 342, for the 28 day and 56 day, respectively.
  - GreenCrete exceeded industry averages by 35% and 70%.

Test Information	
Project	Revel Tower
Mix ID	IC12000
Testing Agency	Craig Testing Laboratory
Design Strength	12000 psi at 56 Days
Test Samples	30
Test Period	8/8/2008 - 8/15/2008



**GreenCrete IC12000 Test Results**



Test Analysis				
	Average (PSI)	Stand. Dev.	Coeff. of Var.	% of Strength
7 Day	9,579	1,081		77.2%
28 Day	11,499	674	5.9	92.7%
56 Day	12,402	342	2.8	103.4%