- Jon Belkowitz is the Chief Technical officer at Intelligent Concrete, LLC specializing in Concrete Research, Development and Education with a focus on Nanotechnology.

- Before Intelligent Concrete, LLC, he served in the United States Air Force from 1996 to 2006 specializing in Civil Engineering. His tour of duty introduced Jon to a wide variety of concrete types and uses which were dependent upon the engineering practices of different host nation forces, developing nations, and disaster repair initiatives.

- Jon has worked in private testing laboratories on structural engineering and materials development projects to include the application of nanotechnology in concrete.

- Jon received his Masters of Material Science from University of Denver and his PhD in Mechanical Engineering with a specialty of Nanotechnology in Concrete at Stevens Institute of Technology in Hoboken, New Jersey.

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Nano Silica-Enhanced Concrete

A Progress Report

Jon Belkowitz, PhD
Chief Technology Officer
Intelligent Concrete, LLC
Email: Jon@Intelligent-Concrete.com

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SP Specification Products

E5

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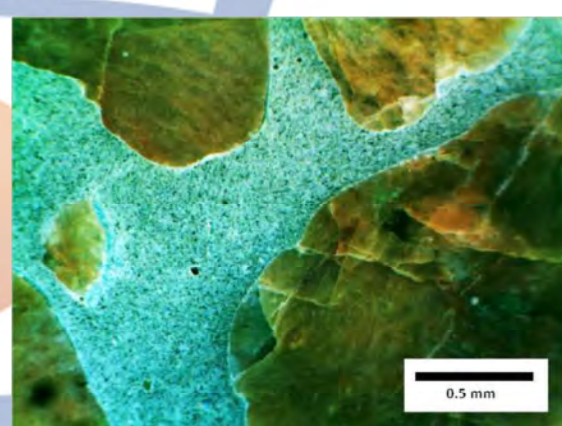
Overview

- Research Motivation
- Standards, Guides, Activity
- Emerging Research
- Nano Silica Case Studies
- Questions



Magnified Cross Section of Concrete

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Background

- Jon Belkowitz, PhD

INTELLIGENT CONCRETE

- Concrete Enthusiast

- Combined Levels of Testing

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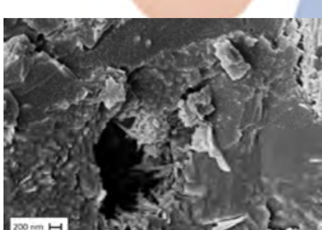
Consulting Services

A Technical Representative for Construction Industry

Research and Development Consulting
Targeted to ensure your emerging technologies are implemented strategically for commercial application.

Forensics Analysis and Litigation Work
Targeted toward market materials, engineering specifications and project needs.

Educational Seminars
From the basic applications to the novel technologies, our educational seminars are designed to educate you to keep your edge in the market.



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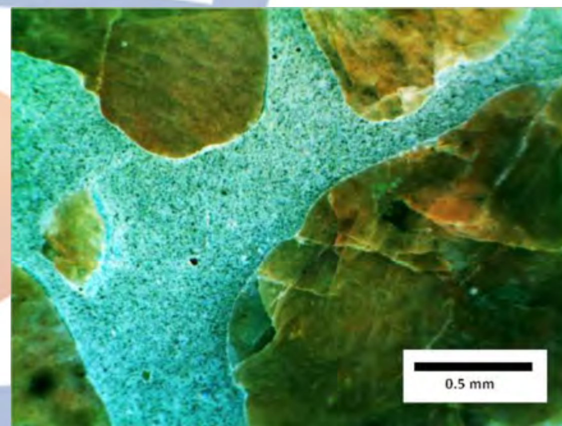

Magnified Cross Section of Concrete

Research Motivation

Solving Today's Problems, With Yesterday's Technology

- 600,000 Concrete Bridges
- $ 48 Billion (US) Industry
- $ 8.3 Billion Yearly Maintenance Cost
- Enhancement of Concrete Durability Needed

Research Motivation[1]

1. The Use of Higher Alkali Cements
2. The Use of Lower Quality / Reactive Aggregates
3. Ineffective Pozzolans

1 Hurcomb, D., K. Bartojay, and K. Fay. *New Recommendation for ASR Mitigation in Reclamation Concrete Construction.* U.S. Department of Interior MERL Laboratory, 2009.

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Purpose

Learning Objectives

1. Discuss recent techniques, standards and guide activity, and case studies related to the material aspects of nano silica-enhanced concrete;

2. Describe emerging ideas in concrete research to increase resistance to physical and chemical attack; and

3. Summarize recent information related to nano-enhanced concrete for structures and infrastructure.

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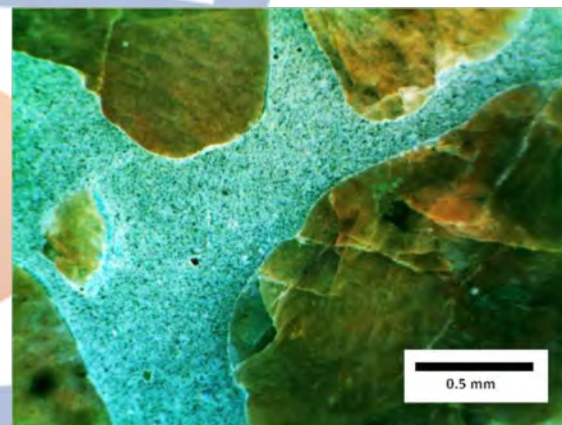
Overview

- Research Motivation
- Standards, Guides, Activity
- Emerging Research
- Nano Silica Case Studies
- Questions



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Start with A Definition

Liquid Dispersion of Nano Silica Particles

- **Liquid Dispersion**
- **Clear to Milky Appearance**
- **Surface Area – 80 to 500 m²/g**
- **Solids Content – 15 to 50%**

Nano Silica Dispersion

Green, B. ACI Materials Journal, SP-254-8, 121–132, 2008.

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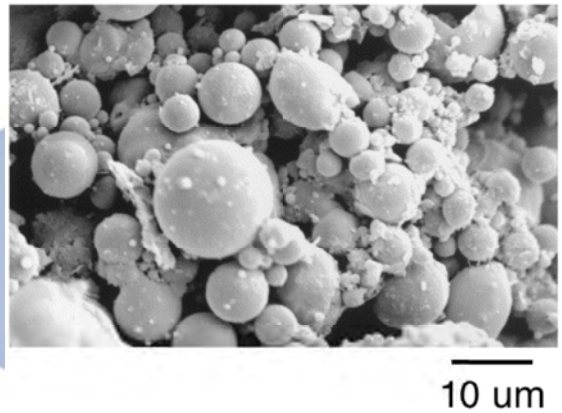
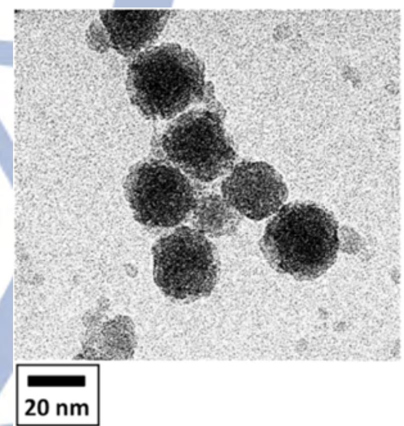
Enhancing with Newer Technology

Not Replacing Current Technologies – Enhancing



- **Class F Fly Ash**



- **Nano Silica**

FOR REFERENCE

A strand of hair is approximately 100,000 nm in diameter.

•Green, B. ACI Materials Journal, SP-254-8, 121–132, 2008.
•Kudyba-Jansen, A., Hintzen, H., Metselaar, R. Materials Research Bulletin, 36, 1215 – 1230, 2001.

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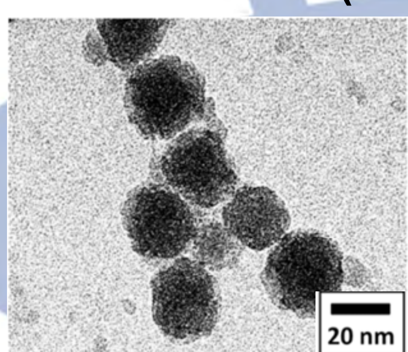
Pozzolanic Reaction

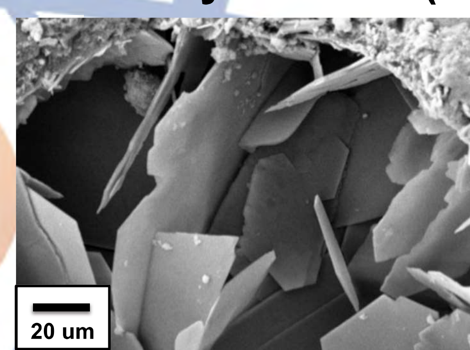
And more…

Colloidal Silica (CS)



+

Calcium Hydroxide (CH)



- CS promotes pozzolanic reaction and the development of C-S-H at the expense of CH
- Particle-to-Particle Packing / Void Filling
- Creates an environment not conducive to Chemical and Physical Attack

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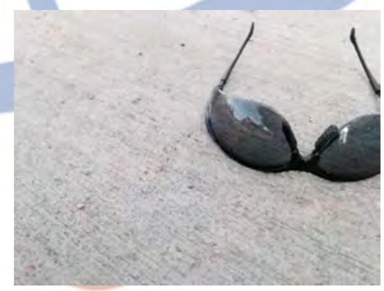
How-To

Controlling Nano Silica Delivery on the Jobsite

- **Sequencing***
  - **Easily Dispersed at <u>tail-end</u> of mixing**
  - **Dilution before Mixing is needed**
  - **Place NS on concrete**
  - **Mix for 70 – 100 Revs**
  - **Fits into the normal critical path of batching concrete to leaving the plant**

Placement of Nano Engineered Concrete



7 Years Later No Surface Defects / Cracking

****** Patent Pending Process***

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Specifications

ASTM Specifications

ASTM WK53768

New Specification for Colloidal Silica

(What is a Work Item?)

Developed by Subcommittee: C09.24 | Committee C09 | Contact Staff Manager

MORE C09.24 STANDARDS | RELATED PRODUCTS | COPYRIGHT/PERMISSIONS

WK53768

1. Scope

This specification covers colloidal silica for use in hydraulic cement concretes where pozzolanic action is desired. In this use, colloidal silica functions as a heterogeneous nucleation site for ions released during cement hydration leading to the desired pozzolanic result. Colloidal silica has become more popular over the last 25 years as a means to reduce the permeability of concrete, increase the strength, and increase the durability to physical and chemical attack. The first documented use of colloidal silica in grout and concrete goes back to the late 1990s. Its because of these enhancements imparted to concrete that colloidal silica has become more accepted in the concrete and construction industry. The need for a new ASTM Specification for Colloidal Silica has been at the forefront of the technical transfer movement for this technology. Despite the rise in the popularity of using colloidal silica in concrete, the main obstacle that prohibits the entry of colloidal silica into day-to-day concrete is the lack of an ASTM standard specification. Engineers, superintendents, architects, and concrete producers are uneasy using a concrete product unless there is an ASTM specification governing its entry into the concrete arena. An ASTM standard specification would facilitate the validation of decades of research that has been invested in proving this technology as well as allow colloidal silica manufacturers an entry point into the concrete industry. Most importantly, the development of an ASTM standard specification for colloidal silica would give concrete producers and engineers another tool to enhance concrete structures and infrastructure throughout the world.

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Standard Practices

Nano Silica Over Time – 7-Year Placement

- On-Going Deicer Problem with Few Viable Solutions
- Limitations on Matured Technologies
- Quality Aggregate Supply is Dwindling
- Nano Silica Lab Use
- Commercial Success
- **Nano Silica on Concrete Jobsites – ASTM C 494, Type S**

Placement of Concrete with Nano Silica

E5

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Current Specification Direction

ASTM C 494 Testing

This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

ASTM INTERNATIONAL **Designation: C494/C494M – 19**

Standard Specification for Chemical Admixtures for Concrete[1]

This standard is issued under the fixed designation C494/C494M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 This specification covers materials for use as chemical admixtures to be added to hydraulic-cement concrete mixtures for the purpose or purposes indicated for the eight types as follows:

1.1.1 *Type A*—Water-reducing admixtures,

1.1.2 *Type B*—Retarding admixtures,

1.1.3 *Type C*—Accelerating admixtures,

1.1.4 *Type D*—Water-reducing and retarding admixtures,

1.1.5 *Type E*—Water-reducing and accelerating admixtures,

1.1.6 *Type F*—Water-reducing, high range admixtures,

1.1.7 *Type G*—Water-reducing, high range, and retarding admixtures, and

1.1.8 *Type S*—Specific performance admixtures.

1.2 Unless specified otherwise by the purchaser, test specimens for qualifying an admixture shall be made using concreting materials as described in 11.1 – 11.3.

NOTE 1—As discussed in Appendix X2, it is recommended that, whenever practicable, supplementary tests be made by the purchaser using the cement, pozzolan, aggregates, air-entraining admixture, and the

ments of this specification. Proof of compliance shall be based on comparisons of the average test results from the batches of test concrete and the average test results from the batches of reference concrete. Admixtures (except for Types B, C, E, and S) shall qualify for provisional compliance if the time of setting, length change, and durability factor meet the physical requirements and any of the alternative compressive strength requirements shown in parentheses in Table 1 are met through the date of provisional acceptance (see Note 4). If subsequent test results at six months or one year fail to meet the requirement of at least 100 % of reference strength, the provisional compliance of the admixture to this standard is withdrawn and all users of the admixture shall be notified immediately. Uniformity and equivalence tests of Section 6 shall be carried out to provide results against which later comparisons shall be made.

NOTE 4—Allowing for provisional compliance while retaining longer term compressive strength requirements promotes more rapid qualification of new materials, but also provides assurance that new admixture technologies will not exhibit unexpected longer term performance. The alternative compressive strength requirements in Table 1 are based on

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Tests Conducted

ASTM C 494 Testing

- Evaluating two (2) nano silica admixtures compared to one (1) concrete reference.
- Laboratory Testing, at Intelligent Concrete, LLC facility
  - Fresh Properties (C 143, C 231, C 138, C 1064)
  - Semi-Adiabatic Temperature Test (SATT)
  - Time of Set (C 403)
  - Compressive Strength (C 39)
  - Flexural Strength (C 78)
  - Shrinkage (C 157 MOD)
  - Abrasion Resistance (C 779)
  - Resistance to Freeze/Thaw (C 666)
  - Alkali-Silica Reactivity (ASR) (C 1567 / C 1260)

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Tests Conducted

ASTM C 494 Testing

- Upcoming Tests / Results
  - Fresh Properties – COMPLETED
  - Semi-Adiabatic Temperature Test – COMPLETED
  - Time of Set – COMPLETED
  - Compressive Strength
    - 1-,3-,7-,28-,90- and 180-Days – COMPLETED
    - 365-Days – EXPECTED APR2021
  - Flexural Strength – COMPLETED
  - Shrinkage (C 157 MOD)
    - 64-Weeks – EXPECTED JULY2021
  - Abrasion Resistance – COMPLETED
  - Resistance to Freeze/Thaw – EXPECTED JULY2021
  - Alkali-Silica Reactivity (ASR) – COMPLETED

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Overview

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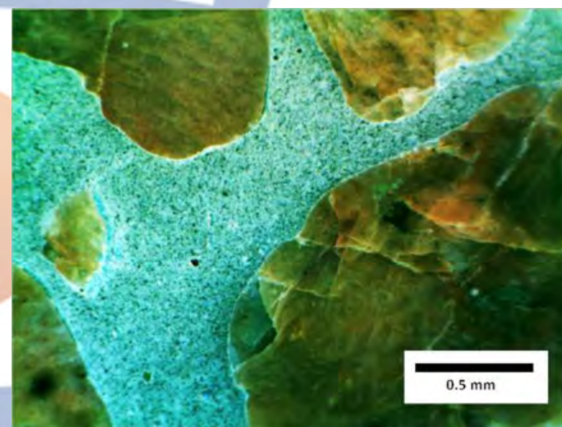


Magnified Cross Section of Concrete

Emerging Research

Investigation of Ca-Oxychloride Formation

- Prof. Jason Weiss
- Low temperature differential scanning calorimeter (LTDSC) test method.
  - Quantify the chemical reaction that occurs be- tween the cementitious matrix and the deicing salt to form calcium oxychloride.

OSU
Oregon State
UNIVERSITY

Emerging Research

Investigation of Ca-Oxychloride Formation

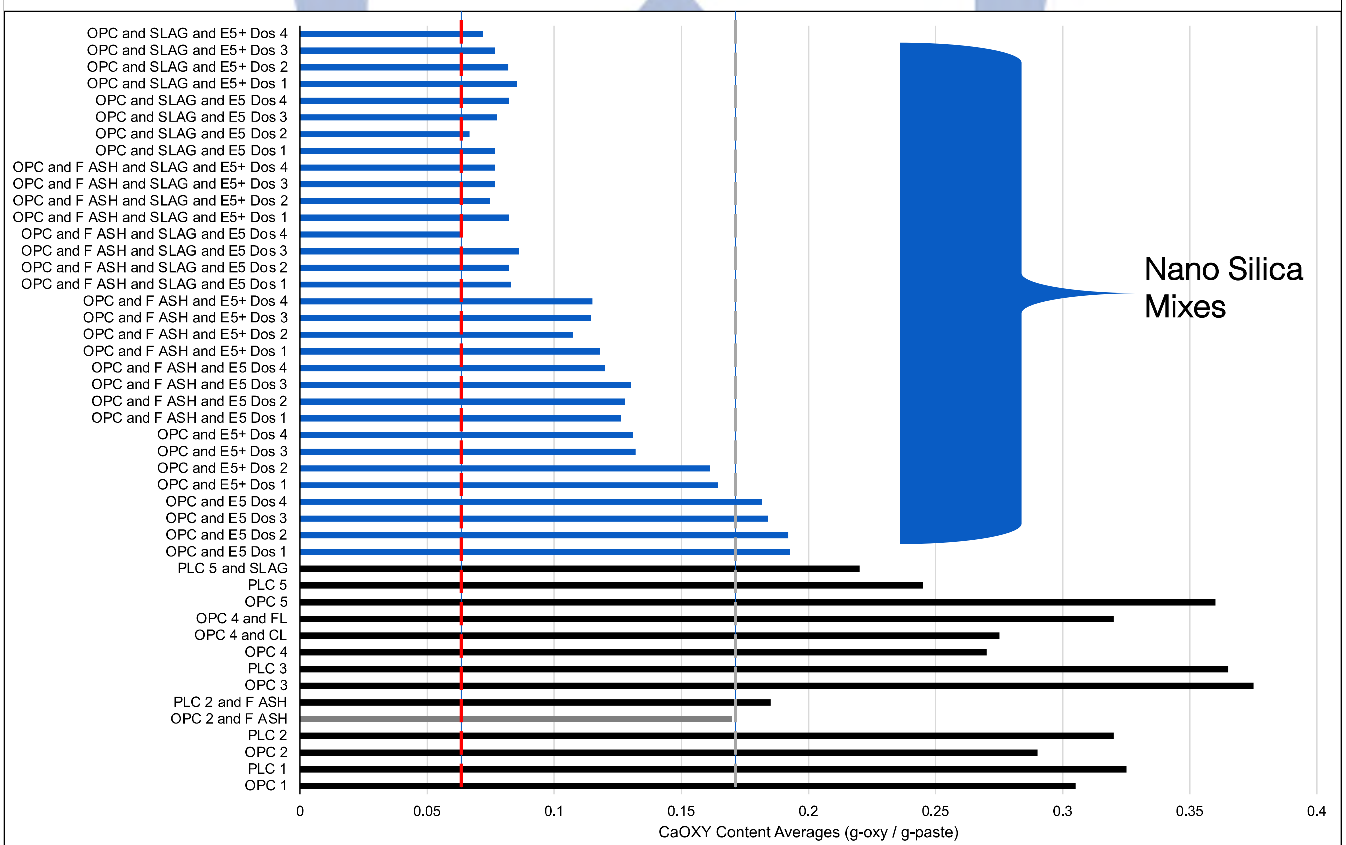
- Cementitious Powder
  - Buzzi Type I Cement
  - Class F Fly Ash
  - Slag
- Nano Silica
  - E5 Internal Cure
  - E5+ Internal Cure
- Method
  - ASTM C 305 Mixing
  - 28-Day Cure

Specification Products

E5

REFERENCE SAMPLES (BLACK BARS) FROM: Suraneni, P., Monical, J., Unal, E., Farnam, Y., Villani, C., Barrett, T. J., & Weiss, W. J., (2016). Performance of concrete pavement in the presence of deicing salts and deicing salt cocktails (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2016/25). IN: Purdue University.

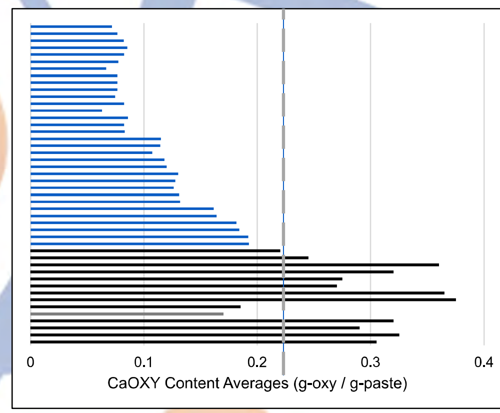
Emerging Research



Emerging Research

Investigation of Ca-Oxychloride Formation

- Indication that a reduction in Ca-Oxy formation with addition of nano silica
- Ca-Oxy reduction in line with CH reduction
- Combination of Class F Fly Ash, Slag and Nano Silica achieved the lowest Ca-Oxy



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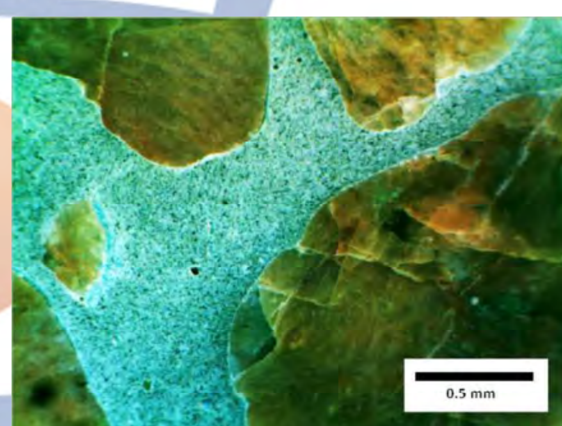

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Case Study 1 – Impact of Nano Silica on Resistance to Deicing Brines

Research and Development Effort with Commercial Concrete Provider in Colorado

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Nano Silica-Enhanced Concrete

Mix Design

Materials	BASELINE pcy (fl oz per cwt)
Portland Cement	525
Class F Fly Ash	80
Concrete Sand	1220
67/57	1775
P Gravel	200
HRWR, Type A and F	(4.0)
E5+	(4.0)
Air Entraining Agent	(1.0)
Slump (in)	6.0 – 7.0
Air (%)	4.5 – 6.5

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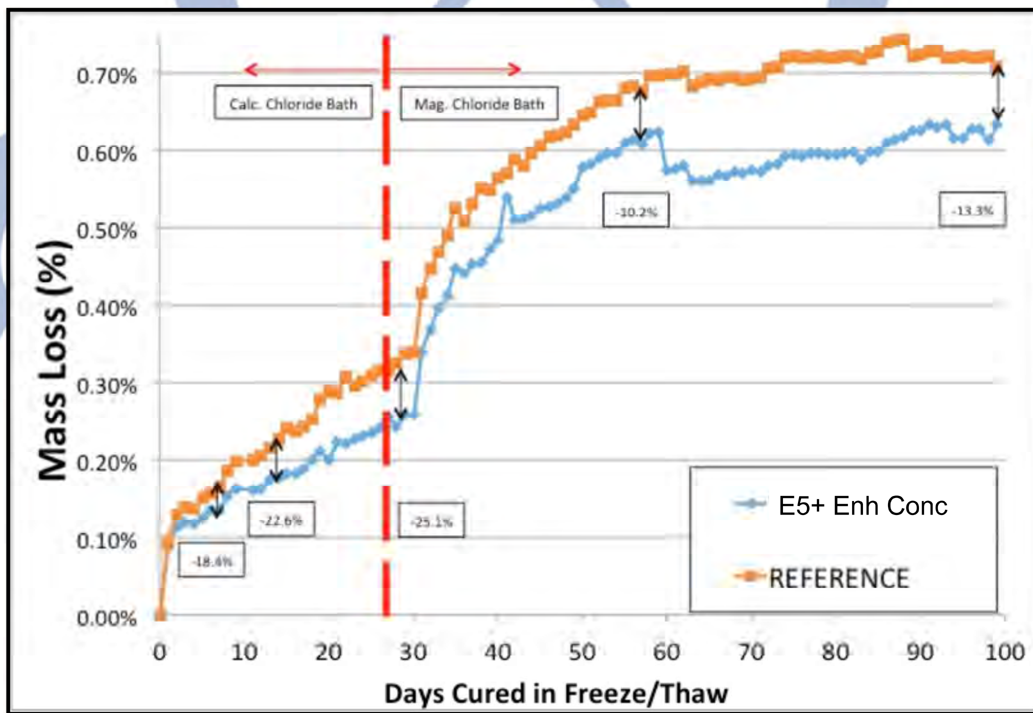
Concrete Testing

Mass Loss



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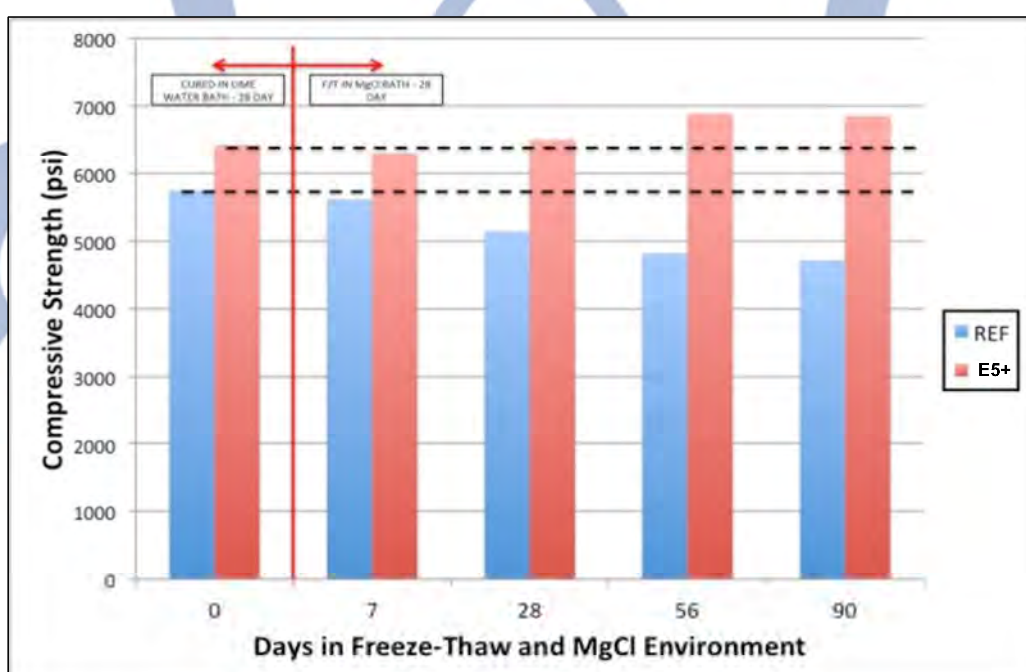
Concrete Testing

Compressive Strength



** 7 Day WS Cylinders were poorly made with significant flaws that could have had an impact on compressive strength*

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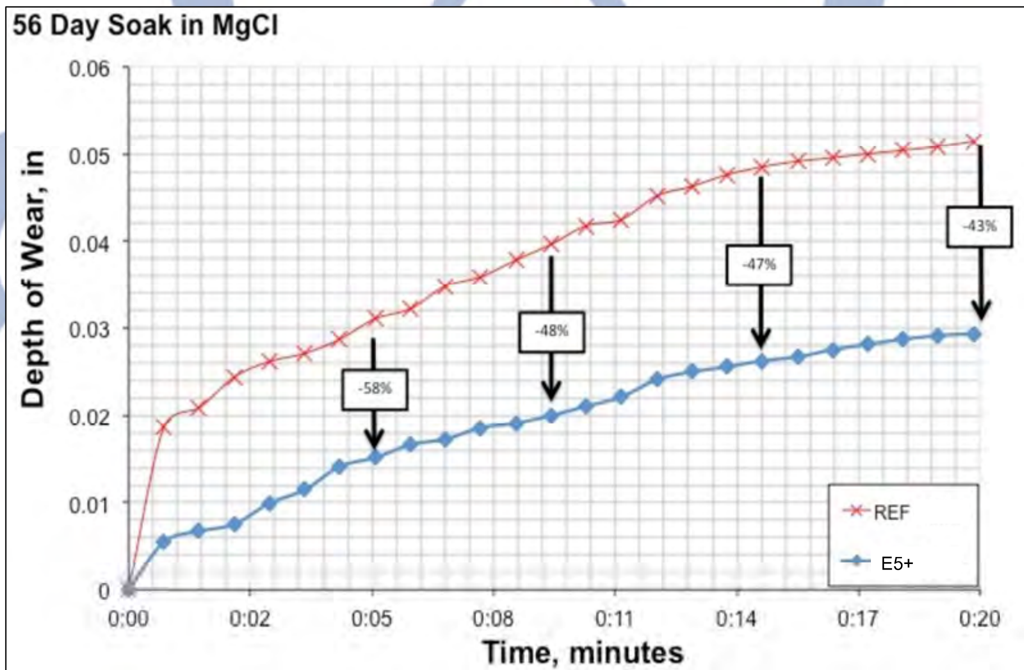
Concrete Testing

Abrasive Wear – 56-Days



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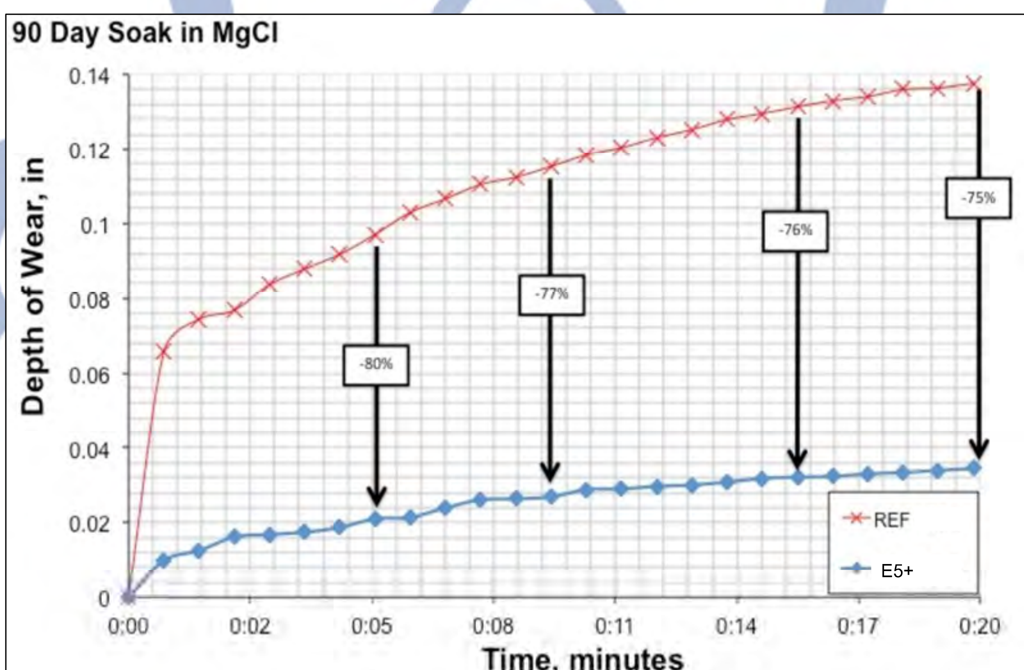
Concrete Testing

Abrasive Wear – 90-Days



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Case Study 2 – Eagle County Airport AARF

1ST Commercial Appl of Nano-engineered Concrete in USA

- Belkowitz, J., Belkowitz, W., Best, M., and Fisher, F. T. (2014) "Colloidal Silica Admixture". Concrete International, 36 (7), 59-65.

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Eagle County Airport AARF

Strength at:
24 Hour – 3500 psi
28 Days – 5500 psi

Materials / ID	Pounds per Cubic Yard	
	REFERENCE	NANO SILICA
Portland Cement	560	565
Class F Fly Ash	140 (20%)	136 (19.5%)
Nano Silica	-	4 (0.5%)
HRWR	12.0 fl oz per cwt	6.0 fl oz per cwt
Air Entraining Agent	0.5 fl oz per cwt	0.5 fl oz per cwt
w/c	0.35	0.35

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Concrete Placement

Paver and Hand Placement

Strength at:
24 Hour – 3500 psi
28 Days – 5500 psi

Placement of Nano Silica Concrete

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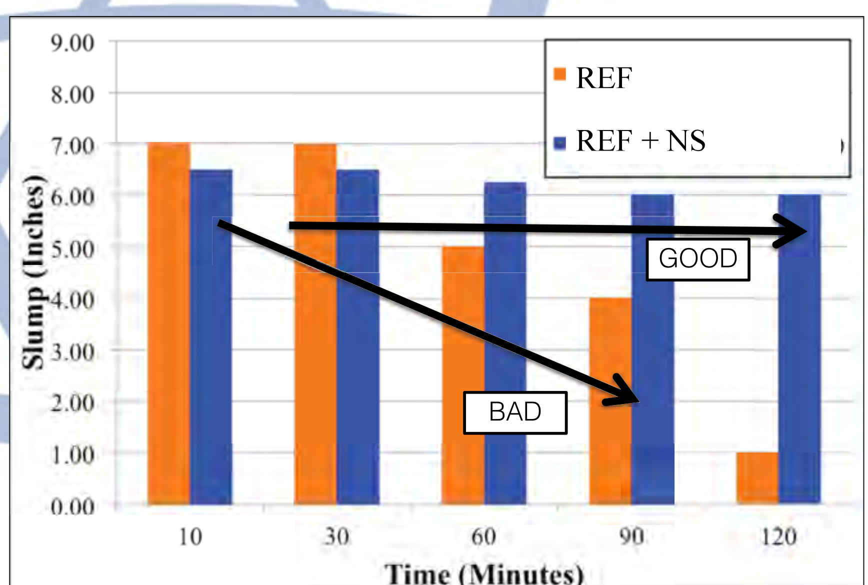
1. Maintain/Enhance Fresh Properties

Slump Retention

- Reduction in HRWR Dosage
- Slump Life Increased by 90 minutes



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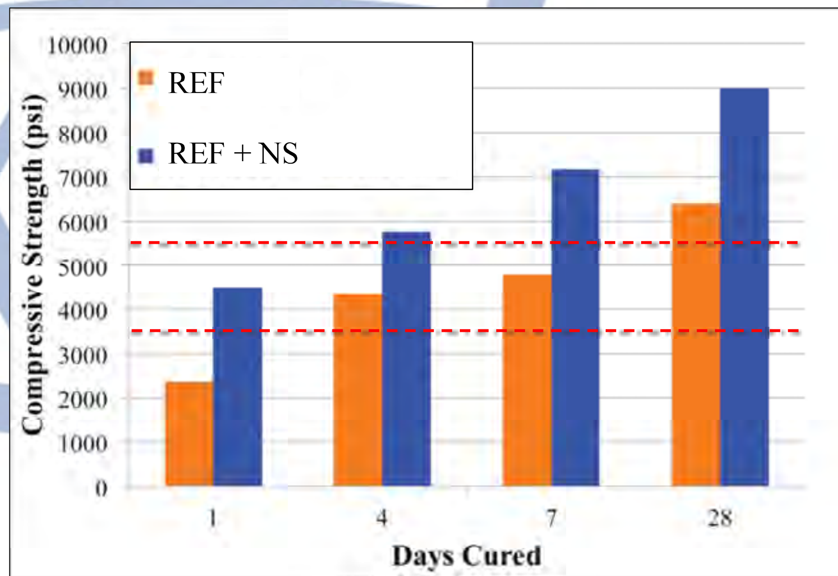
2. Enhance Early & Later Hardened Properties

Development of Strength

- Class F Fly Ash delays hydration & early strength gain
- Combination of Fly Ash and Nano Silica increased strengths:
  - 24 hr, + 60%
  - 4 Day, + 35%
  - 7 Day, + 50%
  - 28 Day, + 40%



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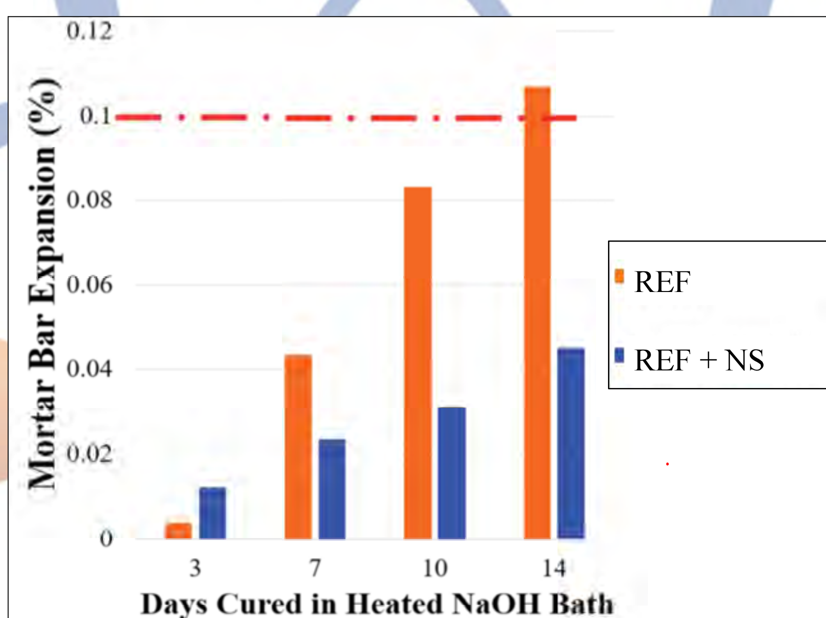
3. Maintain/Enhance Resistance to Chemical Degradation



Maximum Expansion of 0.10% at 14 Days for most Government Agencies

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7 Years Later

Surface Degradation from Tire Wear on Standard Concrete

Standard Concrete Mix with Moderate to Extreme Surface Abrasive Wear

Nano Silica Mix with Little to No Surface Abrasive Wear

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7 Years Later

Surface Degradation from Tire Wear on Standard Concrete

Standard Concrete Mix with Moderate to Extreme Surface Abrasive Wear

Nano Silica Mix with Little to No Surface Abrasive Wear

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Case Study 3 – State of Indiana Bridges

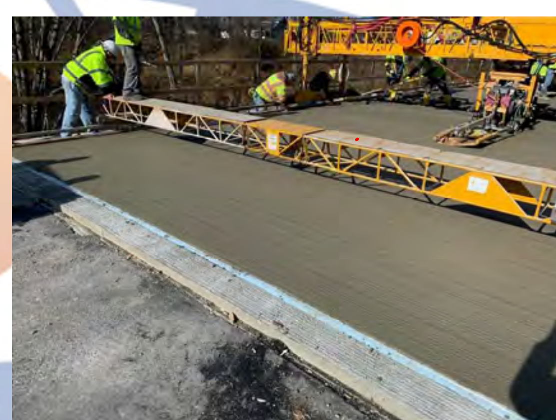
Bridge Decking – Highway 475W

- Courtesy of Dan McCoy of RLMcCoy Concrete

State of Ind.

Bridge Decking and Overlays – Highway 475W

- Liquid Fly Ash Replacement
- Cementitious Reduction
- Yield with Coarse and Fine Aggregate
- Maintenance of Fresh Properties
- Increase in
    - Compressive Strength
    - Cementitious Eff.



- Courtesy of Dan McCoy of RLMcCoy Concrete

State of Ind.

Bridge Decking – Highway 475W

Materials / ID	Pounds per Cubic Yard	
	REFERENCE	E5 Liquid Fly Ash Concrete
Cement, C 150 Type I	658	580
Micro Silica	3%	-
LFA (fl oz per cwt)	-	8
E5 (fl oz per cwt)	-	4
w/cm	0.42	0.47
28-Day Average (psi)	5700	7200
28-Day Cement	8.70	12.40

78 lb per cubic yard reduction in powder.

- Courtesy of Dan McCoy of RLMcCoy Concrete

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Case Study 4 – Colorado Concrete

Woodmen Valley Heights Campus Project

- **Specification Products donated several hundred yards of concrete containing E5 Nano Silica to help finish curbs and sidewalks, improving the facility's accessibility.**
- **Intelligent Concrete, LLC managed the project design, timeline, and testing.**

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Case Study 4 – Tests Conducted

Woodmen Valley Church Field Trial Testing

- Woodmen Valley Church, Laboratory Testing
  - Fresh Properties – COMPLETED
  - Compressive Strength
    - 3-,7-,28- and 56-Days – COMPLETED
  - Flexural Strength
    - 28-Days – COMPLETED
  - Scaling (C 672)
    - 50-Day Cycles – COMPLETED

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Case Study 4 – Field Trials

USAFA FERL Facility Project

- A reinforced concrete slab was placed on the USAFA base in front of the FERL facility.
- Concrete mixtures placed include a Reference mix and two mixes enhanced with E5 Nano Silica.
- Cadets attended pour and learned about concrete placement and finishing.

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Case Study 4 – USAFA Cadet Education

In-Person Visits: Learning How to Make and Test Concrete

- **Each Cadet mixed, made, and tested 6 cylinders.**
- **Through this, Cadets learned how to:**
  - **Mix concrete and cast cylinders per ASTM C 192**
  - **Test for fresh properties**
  - **Perform ASTM C 39 tests for concrete's compressive strength at 7- and 28-days.**

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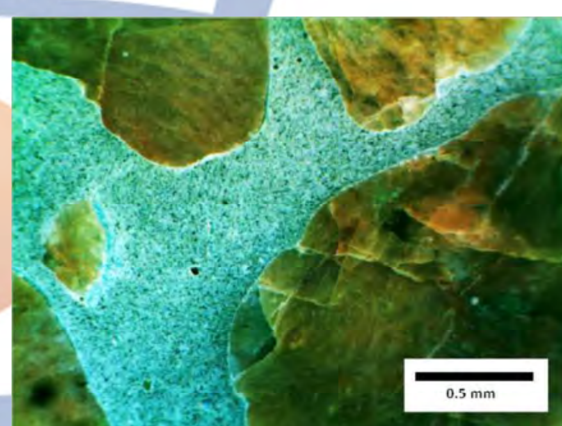

Magnified Cross Section of Concrete

INTELLIGENT CONCRETE

QUESTIONS

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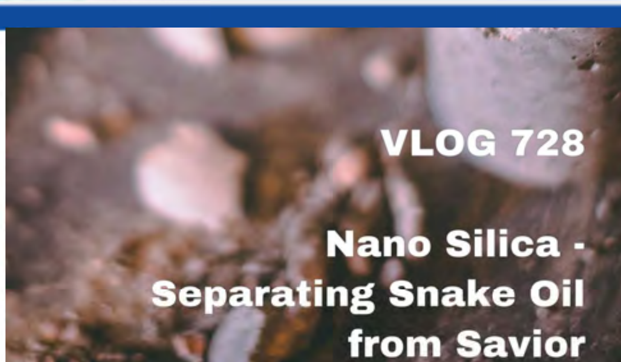

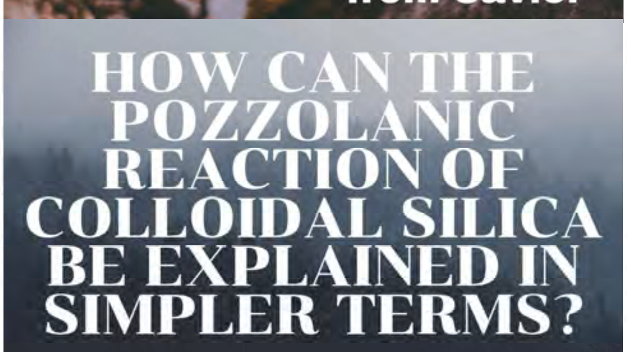

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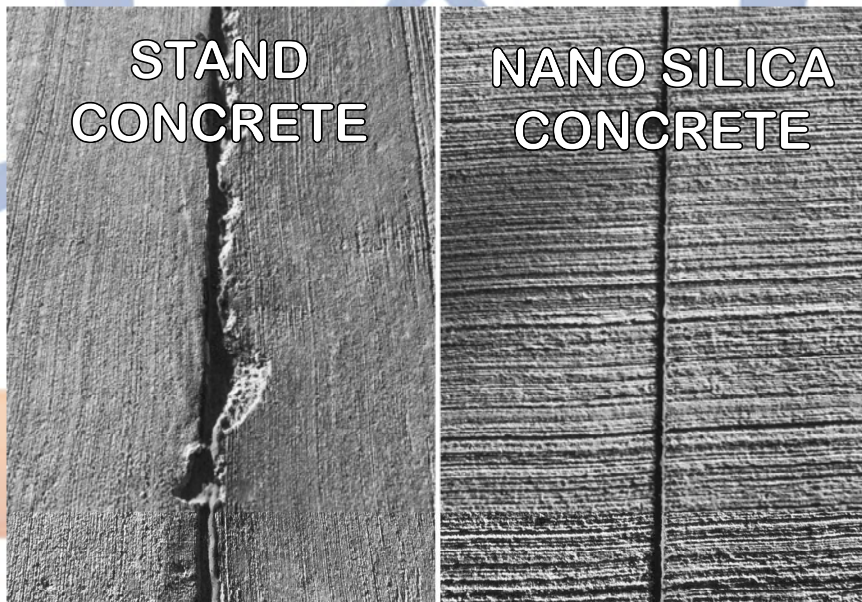
Questions



Test Section at Denver International Airport after 6 weeks, 2016

"Our Biggest Problem, We are Solving Today's Problems with Yesterday's Technologies" – WB, 2012