• 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.

Nano Silica-Enhanced Concrete

A Progress Report

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

Overview

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

Magnified Cross Section of Concrete
Background

- Jon Belkowitz, PhD
- Concrete Enthusiast
- Combined Levels of Testing

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

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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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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%
Enhancing with Newer Technology

Not Replacing Current Technologies – Enhancing

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

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
How-To

Controlling Nano Silica Delivery on the Jobsite

• Sequencing*
  • Easily Dispersed at tail-end 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

* Patent Pending Process

Specifications

ASTM Specifications

WK53768
New Specification for Colloidal Silica

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 area. 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.
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**

Acknowledgements
Acknowledgements

Current Specification Direction

ASTM C 494 Testing
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)

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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Emerging Research

*Investigation of Ca-Oxychloride Formation*

- Prof. Jason Weiss
- Low temperature differential scanning calorimeter (LTDSC) test method.
  - Quantify the chemical reaction that occurs between the cementitious matrix and the deicing salt to form calcium oxychloride.
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
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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Magnified Cross Section of Concrete
Case Study 1 – Impact of Nano Silica on Resistance to Deicing Brines

Research and Development Effort with Commercial Concrete Provider in Colorado

Nano Silica-Enhanced Concrete

Mix Design

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

Mass Loss

Concrete Testing

Compressive Strength

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

Abrasive Wear – 56-Days

Concrete Testing

Abrasive Wear – 90-Days
Case Study 2 – Eagle County Airport AARF

1ST Commercial Appl of Nano-engineered Concrete in USA


Eagle County Airport AARF

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

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

Paver and Hand Placement

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

1. Maintain/Enhance Fresh Properties

Slump Retention

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

3. Maintain/Enhance Resistance to Chemical Degradation

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

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
Case Study 3 – State of Indiana Bridges

Bridge Decking – Highway 475W

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

<table>
<thead>
<tr>
<th>Materials / ID</th>
<th>Pounds per Cubic Yard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>REFERENCE</td>
</tr>
<tr>
<td>Cement, C 150 Type I</td>
<td>658</td>
</tr>
<tr>
<td>Micro Silica</td>
<td>3%</td>
</tr>
<tr>
<td>LFA (fl oz per cwt)</td>
<td>-</td>
</tr>
<tr>
<td>E5 (fl oz per cwt)</td>
<td>-</td>
</tr>
<tr>
<td>w/cm</td>
<td>0.42</td>
</tr>
<tr>
<td>28-Day Average (psi)</td>
<td>5700</td>
</tr>
<tr>
<td>28-Day Cement</td>
<td>8.70</td>
</tr>
</tbody>
</table>

78 lb per cubic yard reduction in powder.

- Courtesy of Dan McCoy of RLMcCoy Concrete

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.
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

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.
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.

Overview

- Research Motivation
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Magnified Cross Section of Concrete
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