Introduction of Nano & HP Fiber-Reinforced Link Slab Technologies

Celik Ozyildirim, Ph.D., P.E.

Date

Name Surname

Job Title, Division

A partnership of the ***Virginia Department of Transportation***
and the ***University of Virginia*** *since 1948*

Outline

Nanomaterials

- Titanium Dioxide
- Siliceous nano material (as SCM: supplementary cementitious material)
  - Nanosilica
  - Nanoclay

Fiber reinforced concrete

- High-performance fiber reinforced cementitious composites (HPFRCC)
- Potential applications for HPFRCC (link slab, thin overlays)

Titanium Dioxide – TiO_2

- In almost every sunscreen
- Most widely used white pigment; used as a white food coloring; used to whiten skimmed milk; in paints
- In cosmetic and skin care products, used both as a pigment and a thickener
- In plastics and other applications for its UV resistant properties where it acts as a UV absorber

IN CONCRETE

- Photocatalyst decompose organic materials and air-borne pollutants (self-cleaning concrete)

SCM

- Fly ash – utilities
- Slag – iron making (not steel)
- Silica fume – ferro silicon
- Metakaolin – partially calcined clay
- Cement + Water $\longrightarrow$ C-S-H + CH   Hydraulic
- Pozzolan + CH + Water $\longrightarrow$ C-S-H   Pozzolanic

Siliceous Nanomaterial

- Nanometer = 10^{-9} meters
- Has particles with at least one dimension < 100 nm (average cement particle size is 15000 nm)
- Small particle size = more surface area per volume
- Types include nanoparticles, nanotubes,
- Very reactive, dense cement paste, improved paste aggregate interface
- Improvements in permeability, strength, shrinkage, ductility, and impact resistance

VTRC Study
(VTRC 10-R18)

- 26 Concretes
  - 2 Control Concretes
  - 3 Concretes with common SCMs
  - 21 Concretes with different types and amounts of nanomaterials (1 nanosilica [NS], 6 nanoclays [NC])
- Macroscale Testing (strength, E, permeability, length change)
- Microscale Testing (atomic force microscope [AFM], nanoindentation)

SCM

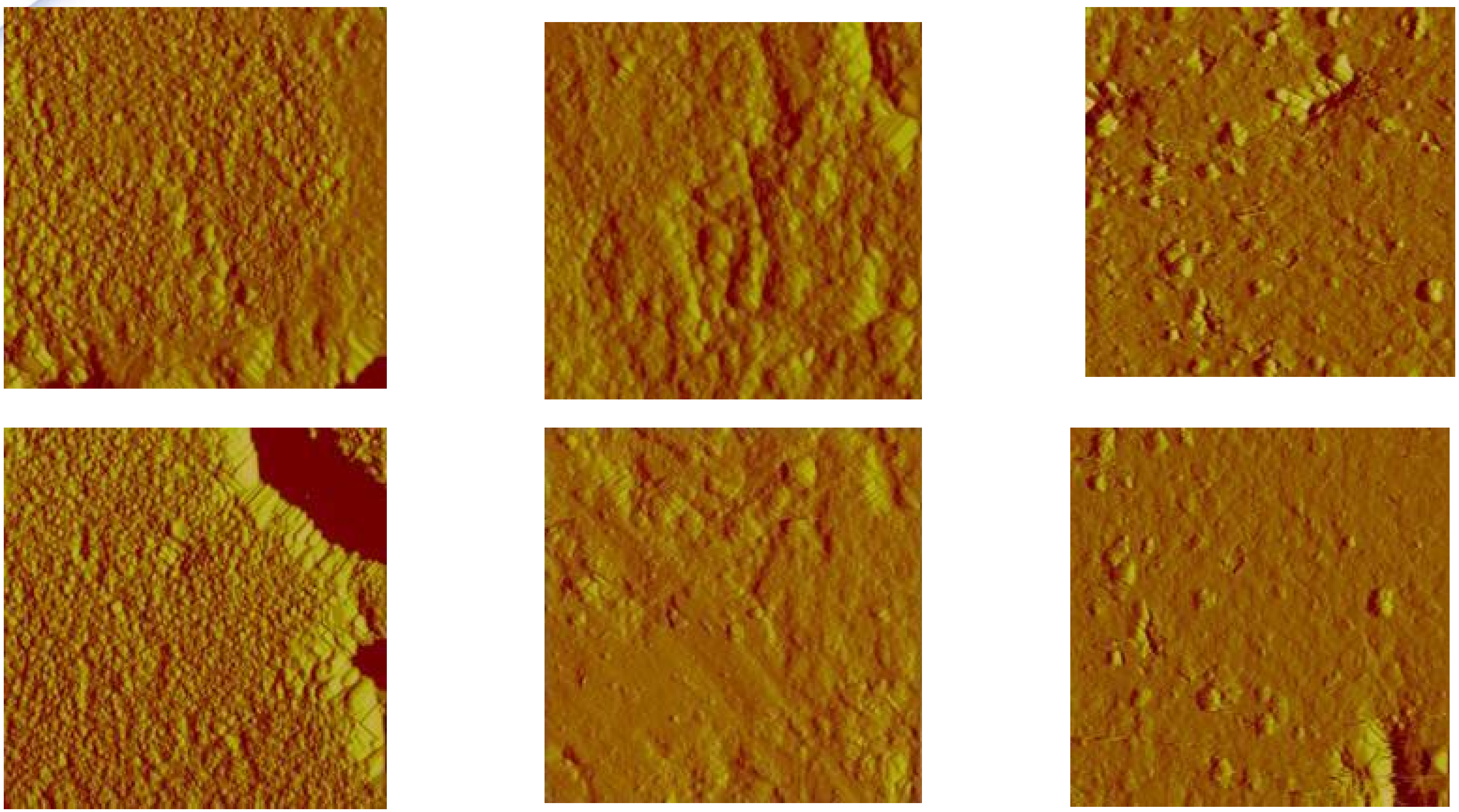
Designation	Replacement (%)
Fly ash	21
Slag	40
Silica fume	7
NS	3
NC1	3
NC2	0.5
NC3	0.5, 2, 4
NC4	0.25, 0.5, 2
NC5	0.5, 1, 3
NC6	0.5, 1, 3

Atomic Force Microscope - AFM

- An extremely fine sharp tip comes in contact or very close to the sample.
- Radius of curvature of the tip is on the order of nanometers.
- The sample is then scanned beneath the tip.
- Different forces either attract or repeal the tip causing deflections.
- Deflections are measured using a laser and processed using imaging software.
- Image is a topographical representation of the sample.

AFM Concrete Images

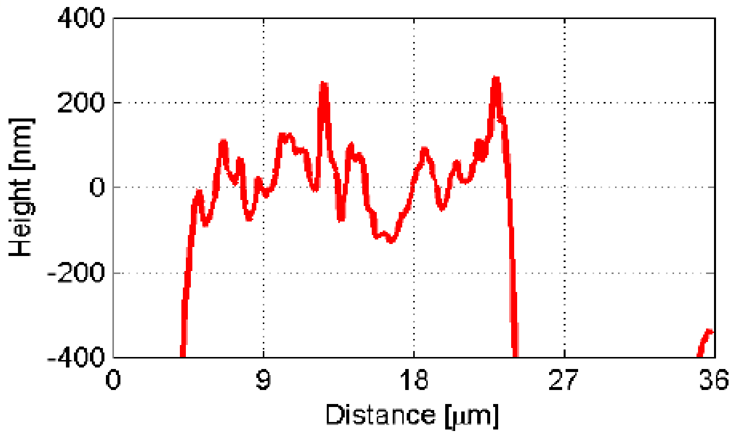
35.8 µm by 35.8 µm

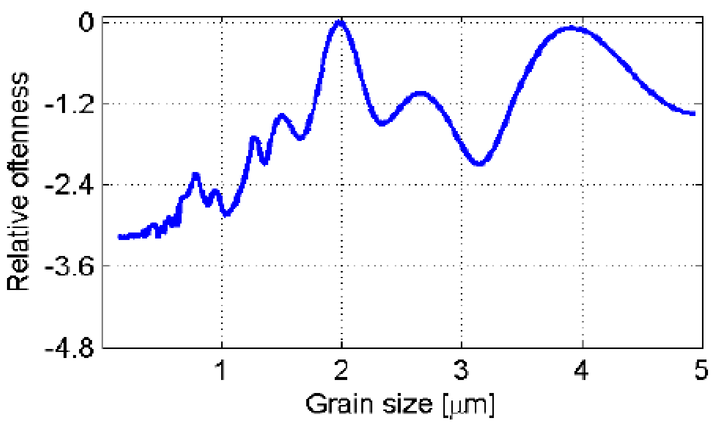


Regular Silica Fume Ludox

AFM Image Analysis

•Power Spectral Density



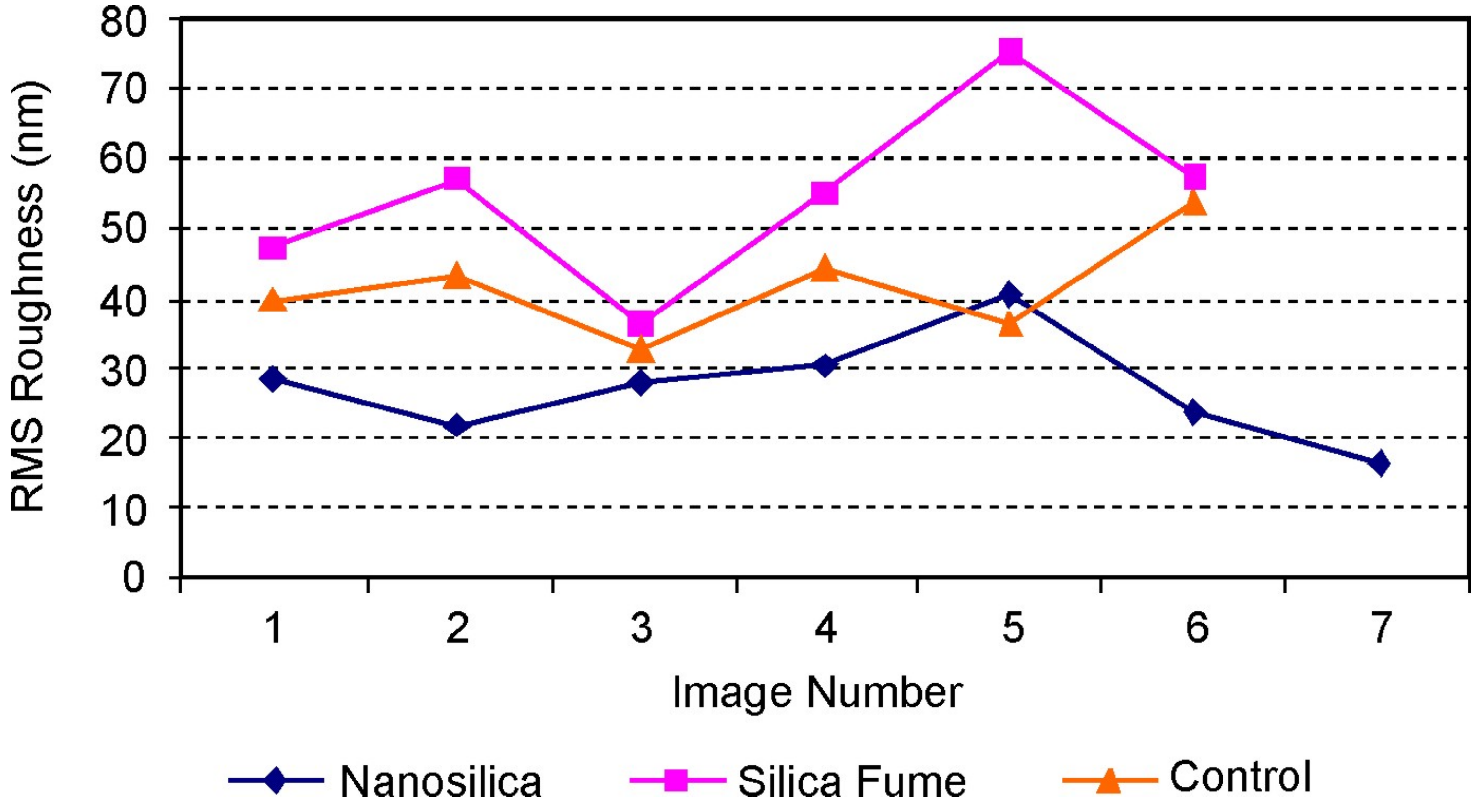


Root mean square (RMS) Roughness

Integrate the PSD over a frequency and take the square root

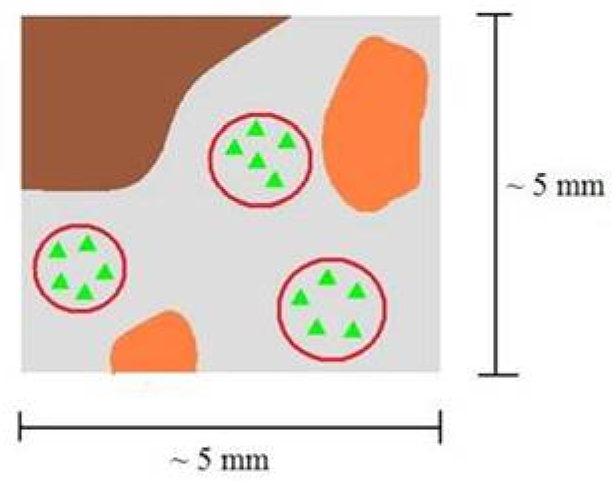
Roughness values indicate the uniformity of the paste

Roughness Results



Nanoindentation Details

- Indented using a Berkovich tip (3 sided pyramid)
- Indented 5 µm into the surface



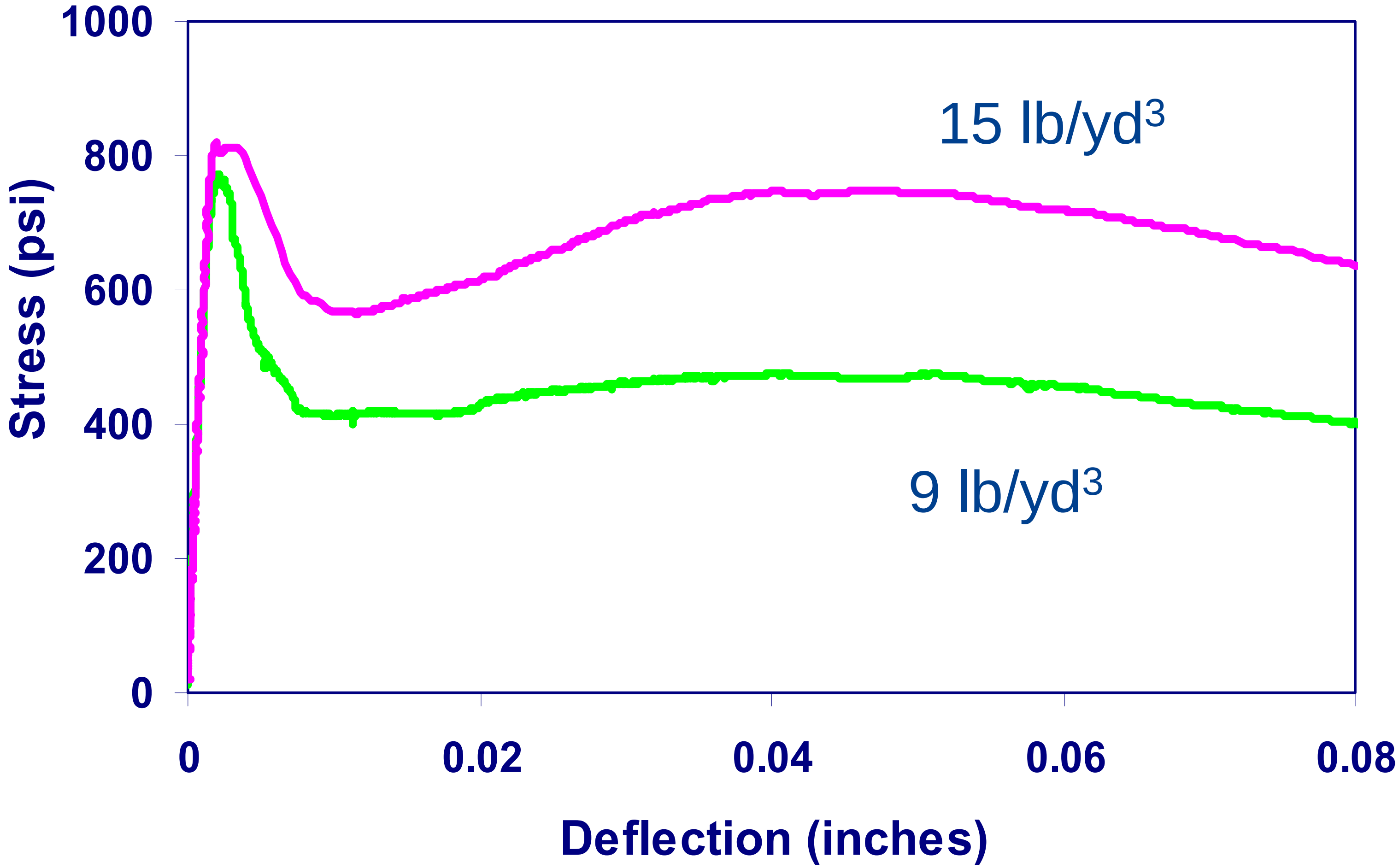
Findings and Observations

- Difficult to obtain nanomaterials that can enhance concrete properties.
- Nanoparticles have the potential to improve properties at very small addition rates.
- Dispersion and clumping is an issue.
- Environmental impact due to size; powder versus solution

Next Step

- Looking for nano particles
- Asking for effective dispersants
- Determine the optimum amounts

Fiber Reinforced Concrete
Residual Strength with Synthetic Fibers



Route 11 over Maury River

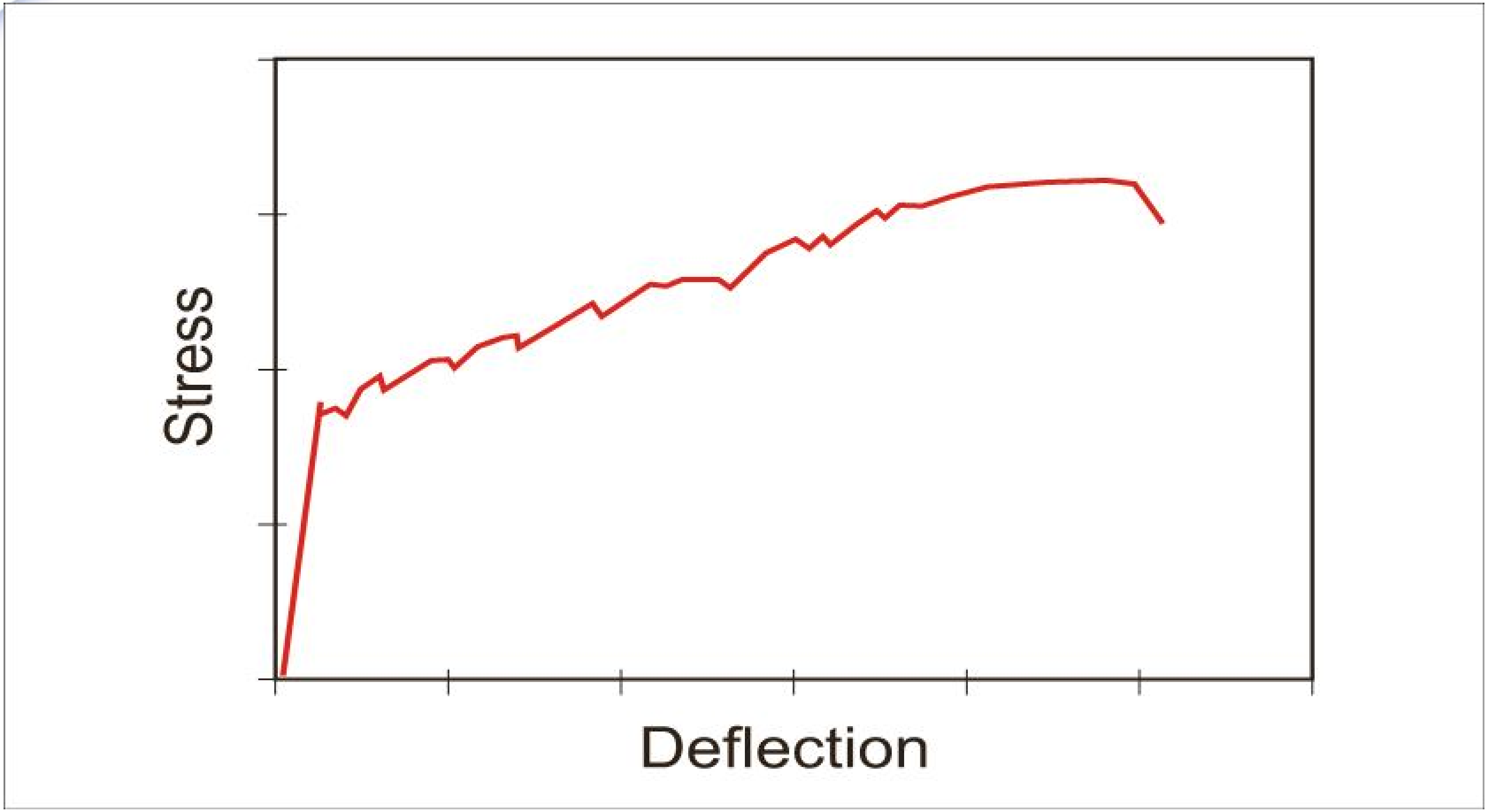
Route 106 over Chickahominy River

Route 17 at Yorktown

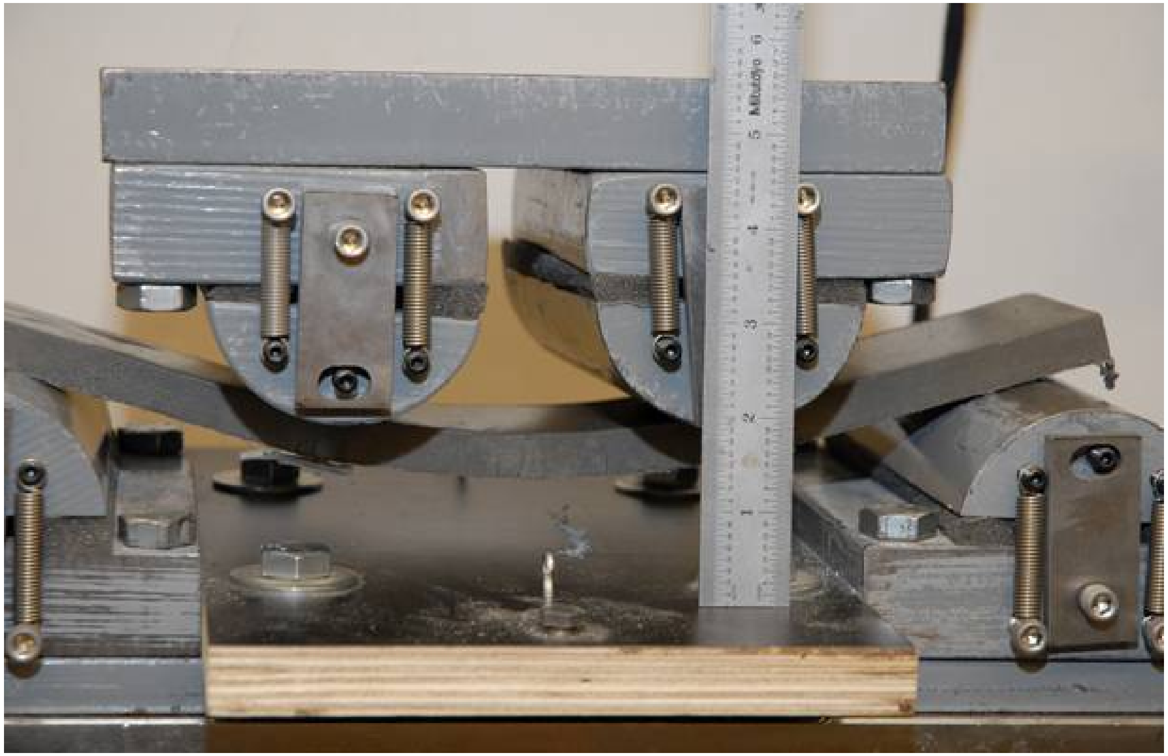
FRC Crack Survey
Route 11, Lexington, VA - 5 years after

Dimension	Control	Fiber
Total Length (ft)	151	59
Average Width (mm)	0.53	0.29

High Performance Fiber Reinforced Concrete
Strain Hardening



HPFRCC



High Performance Fiber Reinforced Cementitious Composites - HPFRCC

- High ductility and toughness
- Strain hardening that leads to multiple micro-cracks at large deformations
- Maximum crack width <100 µm, even at ultimate load
- Increased durability and service life

UHPFRC

Engineered Cementitious Composite - ECC Bendable Concrete

- Dr. Victor Li, University of Michigan

USED IN

- High rise buildings in Japan as coupling beams to mitigate earthquake damage
- Extruded pipes
- Repair of a dam and retaining wall in Japan
- Link slab in Michigan

VTRC Study
(VTRC 08-R12)

- Type II Portland cement
- Class F fly ash
- Fibers
- Sand
- Water
- High-range water-reducing admixture

Fibers

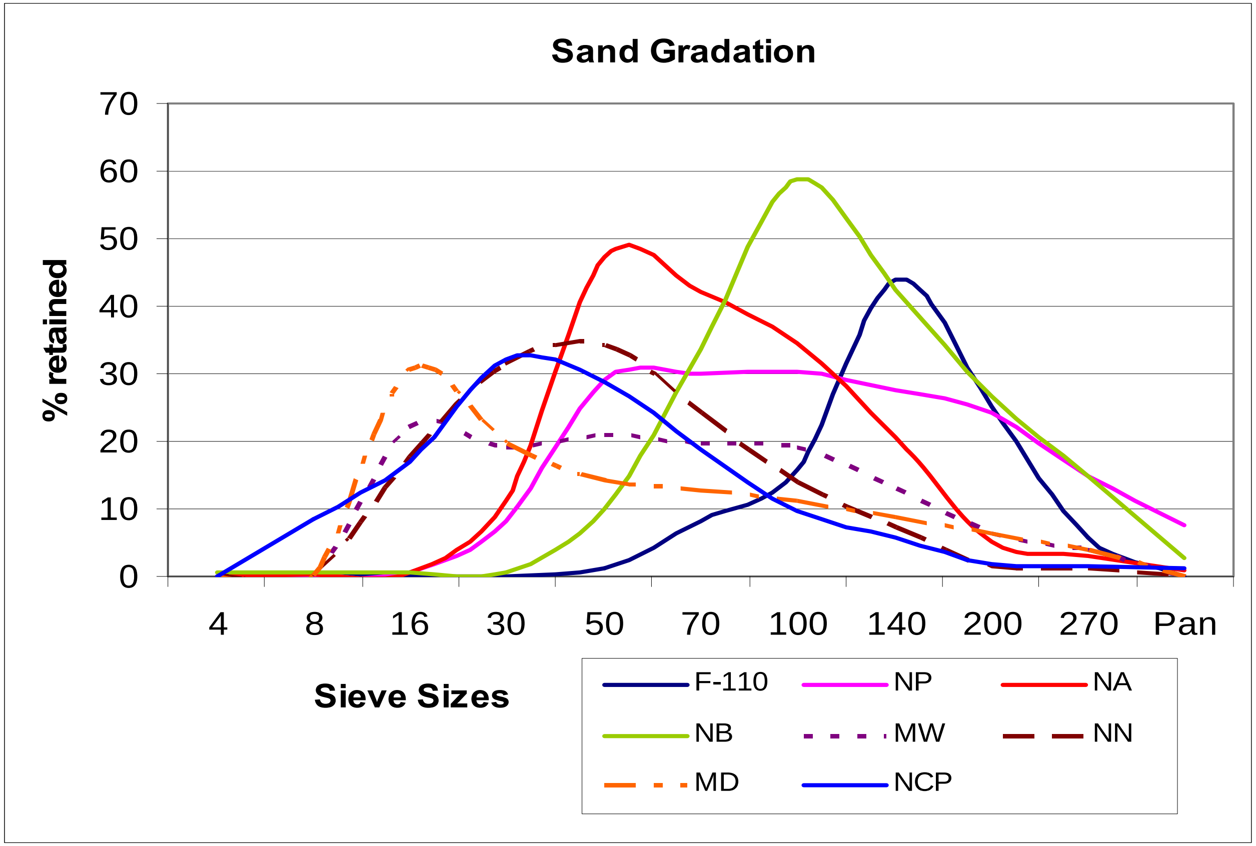
- PVA – Polyvinyl Alcohol
- Steel (SH) – Triangular cross-section and twisted along its length.
- Steel (SB) – Round in cross-section with hooked ends.

VTRC Study - Sand

Special natural silica sand – F-110

Natural sand – (NA, NB, NP, NN, and NCP)

Manufactured sand – (MD and MW)



Proportions

w/cm = 0.31

Fibers: 2% by volume

Fly ash/pc = 2.2

Ingredient	lb/yd^3
Water	644
Cement (pc)	651
Fly Ash	1428
Sand	755
PVA fiber	44

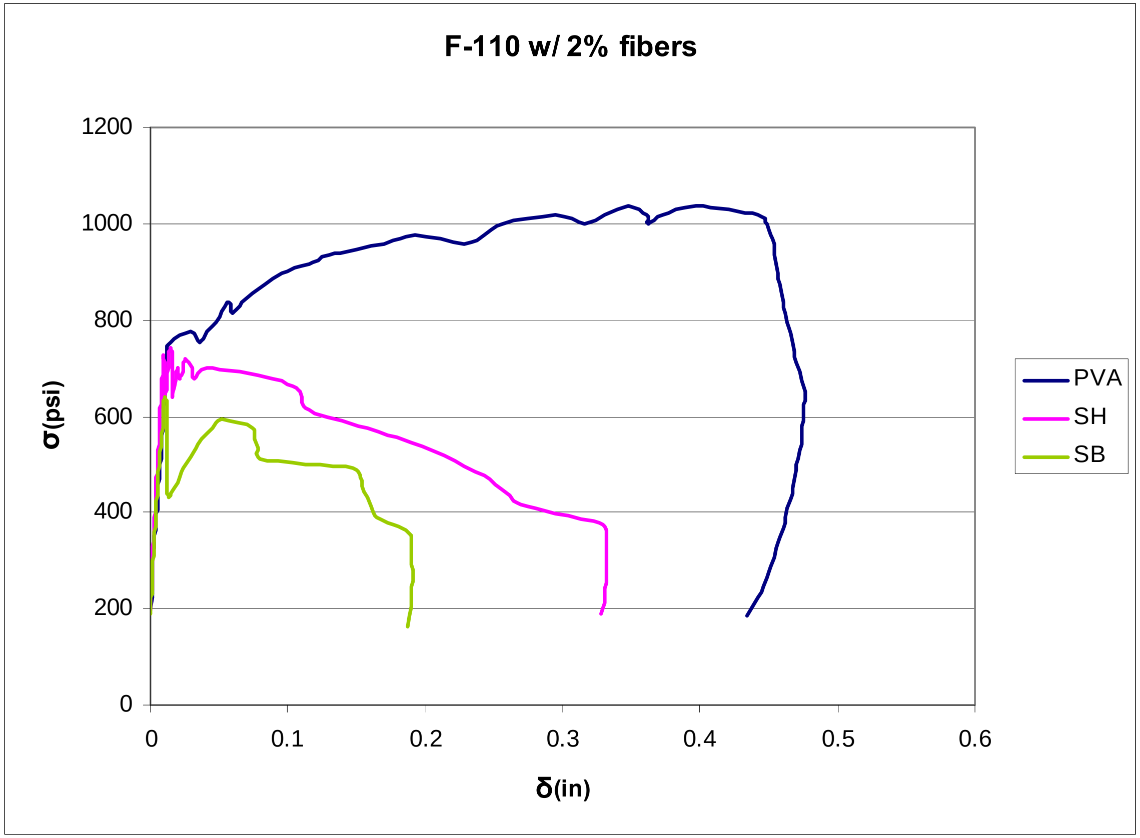
Strength

- Cube strengths exceeding 3000 psi were obtained at 28-days.
- At 90-days, strengths exceeded 4000 psi with most exceeding 6000 psi.
- At 28-days, flexural strength of 1-in beams exceeded 600 psi except one.
- At 90-days, flexural strengths were high with many exceeding 1000 psi.

Permeability, Shrinkage, and Freeze/Thaw Resistance

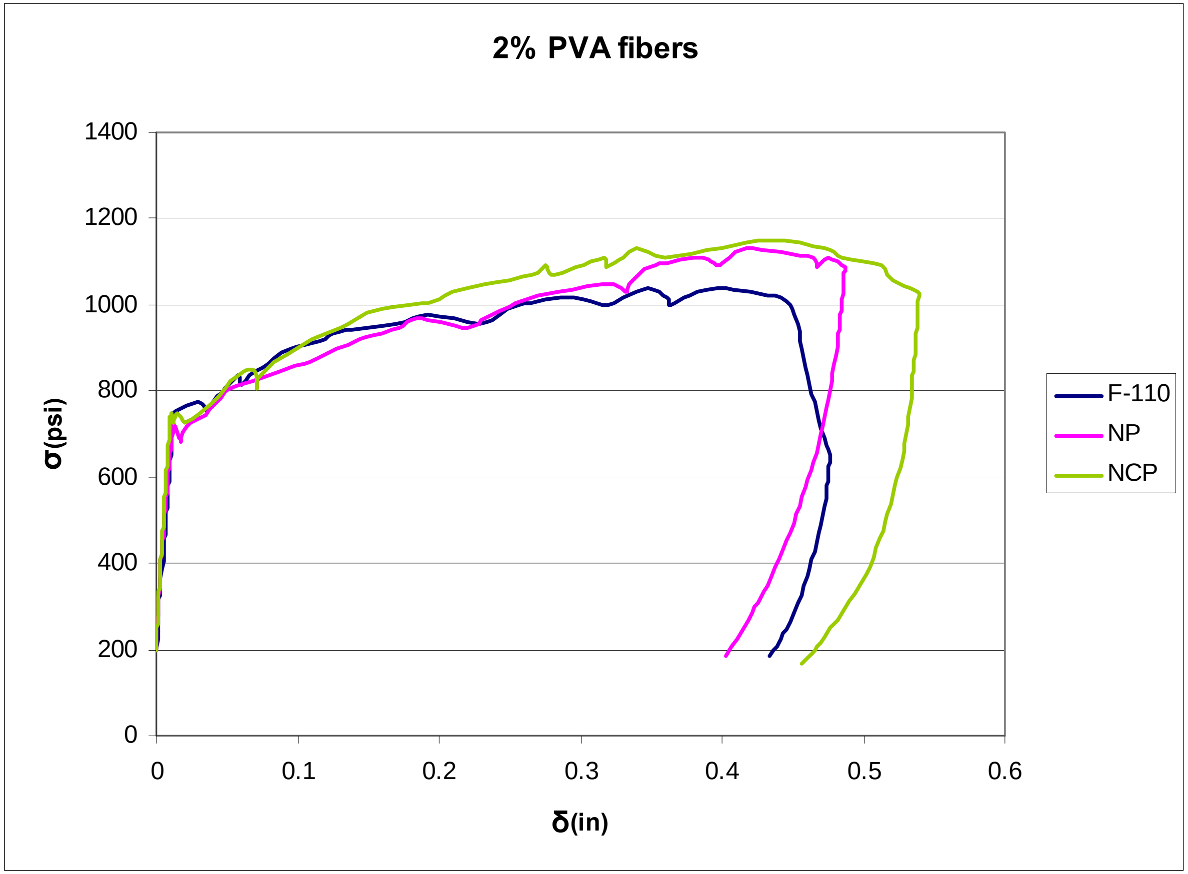
- Very low permeability
- High shrinkage (due to high cement content and low water cementitious material ratio) but expected to have very tight cracks
- Acceptable freeze/thaw resistance in laboratory tests; even though, and air entraining admixture was not added.

Flexural Stress vs Midspan Deflection



1-in beams with PVA, SH and SB fibers mixed with F-110 sand at 28 days.

Flexural Stress vs Midspan Deflection



1-in beams with F-110, mortar (NP) and concrete (NCP) sand and PVA fibers at 28 days.

Deflection at Failure

Large deflections in beams with steel (SH) fibers (left) and PVA (right)

Cracking Pattern at Failure

Cracks in beam with steel (SH) fibers (left) and PVA (right)

Findings and Observations

- HPFRCC with PVA provided strain hardening and multiple micro-cracking using locally available sand.

- HPFRCC with PVA fibers can provide high residual strength up to 0.5-in deflection in 1-in thick beams. In 4-in beams the deflection was less, but still reached a large average value of 0.13-in.

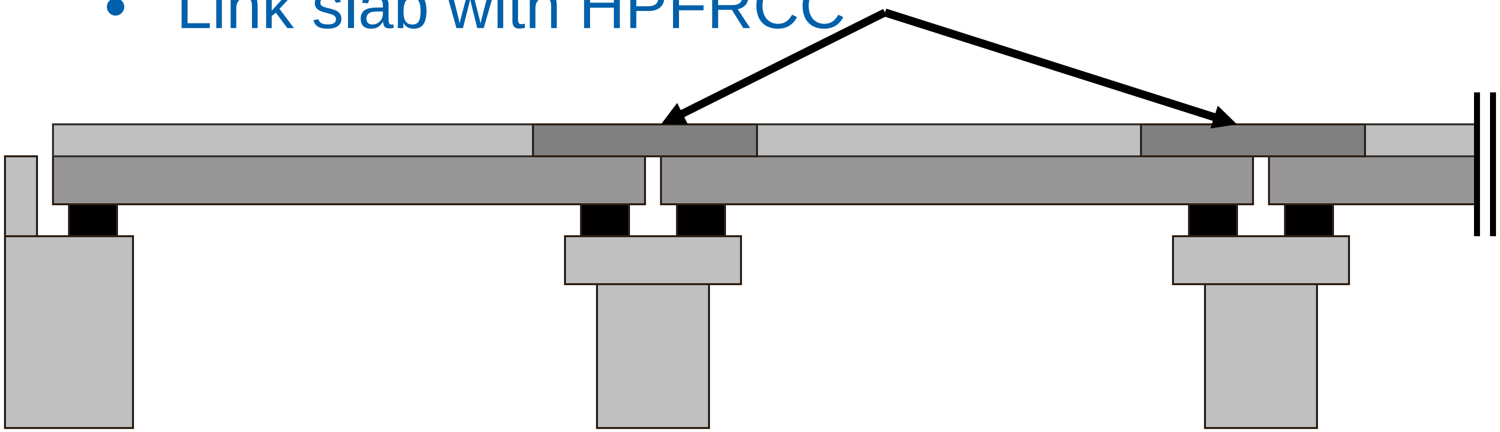
Findings and Observations

- Permeability of HPFRCC with high amount of Class F fly ash is very low.
- Shrinkage of HPFRCC is large; however, distress is not expected due to the presence of fibers that provide high tensile strain capacity.
- Non air-entrained HPFRCC can provide satisfactory freeze/thaw durability.
- Recommend trying in link slabs and thin overlays.

Leaking Joints

Link Slab

- Joints leak
- Eliminate joints
- Link slab with HPFRCC



Michigan Study

- First ECC link slab completed in December, 2005
- Grove Street Bridge over I-94 in Ypsilanti
- 40 cubic yards of ECC in ready mixed concrete trucks
- A length of 7.5% of each adjacent bridge span was replaced with ECC to accommodate the thermal, shrinkage, and live load deformation
- 16’-11” in the longitudinal direction and 66’-5” in the transverse
- High skew angle of 45 degrees
- Early age cracking: crack widths, approximately 0.006” to 0.01”, < AASHTO limit of 0.013”, but > ECC of 0.004” (0.1 mm).
- The crack width did not increase after 3 winters.

Michigan Study

Early Age Cracking – MDOT Report RC-1506, 2008

Potential Sources of early age cracking

- Excessive shrinkage of ECC
- High restraint
- Epoxy reinforcement as stress concentrator: Nearly all cracks seem to initiate from steel reinforcement (may be due to change of geometry and weak bonding between ECC and ECR)
- Early age shrinkage before σ-δ curve development
- High skew angle: link slabs not to exceed 25º
- Improper curing: wet burlap and plastics were not applied until several hours later, no continuous wet curing for the first several days

Michigan Study

New Link Slab Special Provision 1/2008

- Skew no more than 25º
- Expansive cement
- Shrinkage reducing admixture
- Max shrinkage at 28 days: 1100 microstrain
- Max average crack width: 0.004 in (0.1 mm)
- Night placement during summer when the air temperature > 50 ºF
- Curing compound upon finishing, wet curing as soon as surface supports for at least 7 days

Next Step

- Place it in a link slab
- Place it in a thin overlay (1 inch or more)

Thank You

A partnership of the ***Virginia Department of Transportation***
and the ***University of Virginia*** *since 1948*