Macro Polymeric Fiber Reinforcement for Concrete

Pennsylvania Concrete Conference

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Agenda

Crack Control
- Plastic shrinkage
- Drying shrinkage
- Other sources

"Micro" vs. " Macro" Fibers

Standard Tests for Performance
- ASTM C1609-05 tests

Benefits of Macro Polymeric Fibers
- vs. Welded Wire Mesh
- vs. Steel Fibers

Applications:
- Overlays and Inlays
- Slabs-on-ground
- Topping on precast
- Composite decks

Software

Summary

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Crack Control

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Crack Control

- Mix optimization
  - Aggregate size, gradation
  - Paste and water content
  - Other components
- Shrinkage Reducing Admixtures
  - Reduces drying shrinkage and curling
  - Ultimately, approximately 40% reduction in drying shrinkage
- Fibers reinforcement
  - Micro fiber
  - Macro fiber

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Shrinkage Cracking & Curling

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PRIMARY TYPES OF CRACKING

- Plastic Shrinkage, Plastic Settlement
- Drying Shrinkage
- Thermal (early thermal contraction, external seasonal, F-T)
- Structural (design loads, reflective, creep)
- Chemical (corrosion, ASR, carbonation)

PRIMARY TYPES OF CRACKING

plastic shrinkage crack

drying shrinkage crack

structural crack

thermal cracking

Magnitude of Drying Shrinkage

Long term

- Typical: 0.08% (800 millionths or 800 microstrains) 25 mm in 30 meters (1 inch in 100 ft)
- Low: .04% / High: .12%

28 Day

- Typical: 0.04 - 0.045 %
- Low: 0.025% / High: 0.06%

Drying Shrinkage Timing

14-34% of ultimate --- 14 days

40-80% of ultimate --- 90 days

66 to 85% of ultimate --- 365 days

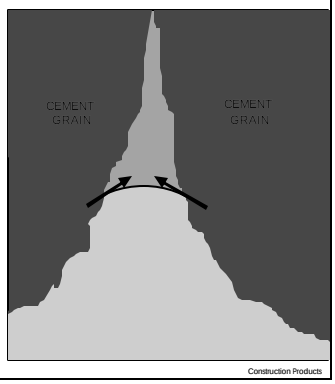
Background
What causes drying shrinkage?

Drying Shrinkage is a complex phenomena involving several different mechanisms

Capillary action and surface tension of water are primary causes of shrinkage for internal humidity ranging from 40 to 100% (which covers virtually all field concrete)

Understanding Shrinkage

- **Pores lose water due to hydration and evaporation**
- **As pores become less than fully saturated, a meniscus forms at the air-water interface due to surface tension**
- **The surface tension of the pore solution which forms meniscus also exerts inward pulling force on the side walls of the pore**
- **These forces in all pores, in range of 2.5 to 50 Nm, are the primary cause of shrinkage**



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Construction Products

"Micro" vs. "Macro" Fibers

Micro (Low Volume Addition) Fibers

- Diameters, Equivalent < 0.012" (0.3 mm)
- Polypropylene
- Nylon, Carbon
- 0.03 – 0.1% volume
- Mainly control plastic shrinkage cracking

Macro (High Volume Addition) Fibers

- Diameters, Equivalent > .012" (0.3 mm)
- Steel, Synthetic
- 0.3 – 1.0% volume
- Improve concrete material characteristics
  - Flexural toughness, Impact resistance, Fatigue resistance

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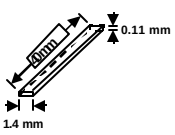
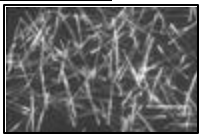
Example of Macro Fiber Reinforcement

Polypropylene/Polyethylene Monofilament Fiber

Specific Gravity	0.92
Absorption	None
Modulus of Elasticity	9.5 GPa (1378 ksi)
Tensile Strength	620 MPa (90 ksi)
Melting Point	160°C (320°F)
Ignition Point	590°C (1094°F)
Alkali, Acid & Salt Resistance	High





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Third Point Loading Test (ASTM C 1609)

Closed Loop System

Sample Size: 6" x 6" x 20" (150mm x 150mm x 500mm)

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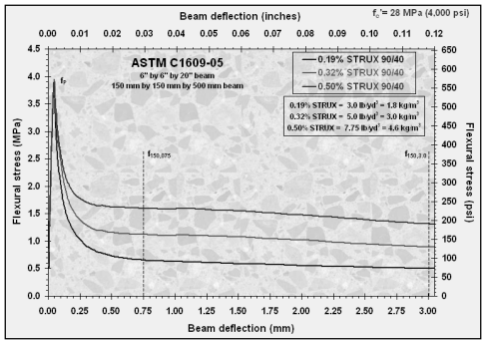

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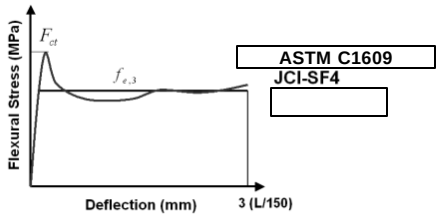
Equivalent flexural strength



Equivalent Flexural Strength: Have the same toughness obtained from experiment to a deflection of L/150 (same area under load-deflection)

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Con Expo Demo

March 2002, Las Vegas
16 lb Bowling Ball Drop

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Illinois DOT Modifications to ASTM C 1609

Add as follows:

- The Department will require this test method utilize 6 x 6 x 20 in. (150 x 150 x 500 mm) specimens, tested on an 18 in. (450 mm) span.
- Calculate the residual strength ratio, to the nearest 0.1, as follows:

$$R_{150}^{150} = \frac{f_{150}^{150}}{f_1} \times 100$$

- Where R_{150}^{150} equals the residual strength ratio [percent] at net deflection f_{150} with span length L.
- Comment: R_{150}^{150} may also be referred to as $R_{150,3}$, indicating 3-mm net deflection.

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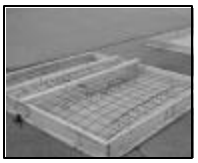
Large Scale SOG Test
University of Illinois

7.2' x 7.2' x 5.1" Slabs (2.2 m x 2.2 m x 132 mm)

- WWM: 6 x 6 – W2.9 (positioned at top-third of the slab)
- Example Macro Fiber– 0.33% vol: 5 lbs/cy; 0.48% vol: 7.5 lbs/cy

Ready Mixed Concrete

Materials	WWM Mix		STRUX 90/40 Mix	
	lbs/cyd	kg/m^3	lbs/cyd	kg/m^3
Coarse Aggregate	1,678	995	1,644	975
Fine Aggregate	1,388	823	1,359	806
Cement	612	363	607	360
Water	300	178	307	182
W/C Ratio	0.49		0.51	
% Air	1.8%		2.9%	
f'c	5,960 psi	41.1 MPa	5,235 psi	36.1 MPa



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Large Scale SOG Test

Subgrade: 8" (203 mm) thick compacted clay

500 kN capacity MTS Hydraulic Actuator

Center Loading until Puncture Failure

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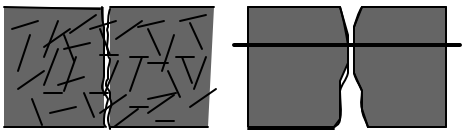
Example Macro Fiber Provides Tight Crack Control



Uniform Crack Width with Example Macro Fiber

Wider Cracks Away from WWM/Rebar

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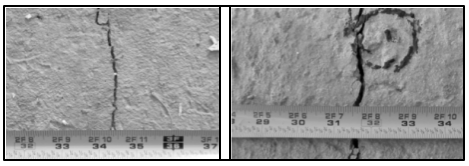
Example Macro Fiber vs. WWM



Example Macro Fiber ≈ 1/16" (1.6 mm)

WWM ≈ 3/16" (4.8 mm)

- Crack Width Measurements for Large Scale SOG Test

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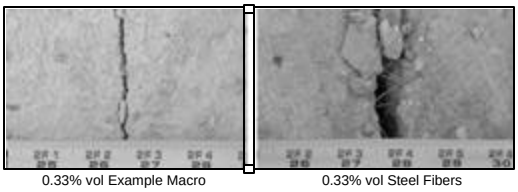
Example Macro Fiber vs. Steel Fibers

At a same % volume, Example Macro Fiber represents 15 times more fibers compared to typical 2.4" (60 mm) flat steel fibers.



0.33% vol Example Macro Fiber ≈ 1/16" (1.6 mm)

0.33% vol Steel Fibers > 5/16" (7.9 mm)

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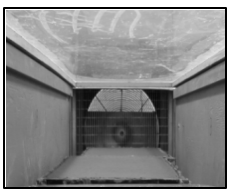
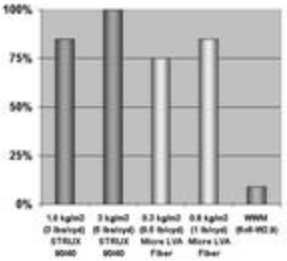
Plastic Shrinkage Crack Reduction





Temperature: 104°F (40°C)

Relative Humidity: 15 – 30%

High Speed Fan until Final Set

Compare Crack Area vs. Plain Concrete.

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Example SOG Design Software

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Background

ACI 360R-06, Design of Slabs-on-Ground, Chapter 10, Fiber-Reinforced Concrete Slabs-on-Ground presents design methodology.

The formulas used in this software are primarily based on the Losberg Yield Line model*.

- "Macro" fibers increase post-cracking strength and re-distribute stresses during and after slab fracture.
- This software also considers Ultimate Strength design and Serviceability when recommending the slab thickness and fiber dosage.

Only for Slabs-on-Ground

Only for Example Macro Fiber.

* The traditional SOG design has been based on work developed by Westergarrd (1926, 1948).

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Capability

Software can handle various loading cases including:

- **Racking System** (Single Post, Multiple in a Line, Multiple in a Box)
  - Center Load & Corner Load
  - Edge Load (Contraction, Dowel & Free Edge Joints)
- **Wheel Loads** (Single Wheel, Multiple Wheels on one or two axles)
  - Center Load & Corner Load
  - Edge Load (Contraction, Dowel & Free Edge Joints)
- **Uniform Load**
- **Line or Wall Load**

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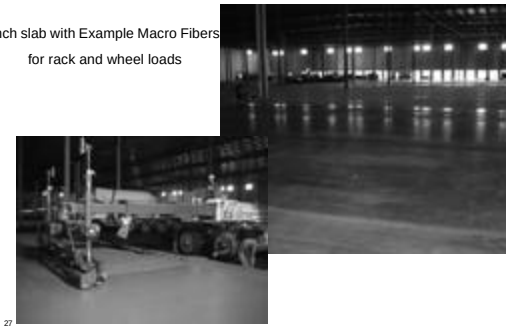
Affiliated Foods Midwest, Kenosha, WI

8 inch slab with Example Macro Fibers for rack and wheel loads



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Affiliated Foods Midwest
Video

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Provina St. Joe Hospital Parking Garage
Joliet, IL

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Provina St. Joe Hospital Parking Garage
Joliet, IL

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Typical Macro Fiber Experience (circa '06)

Since 2000, 1.3 million cubic yards of concrete for slabs-on-ground

And 700,000 cubic yards of concrete in precast

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Example Macro Fiber for Composite Decks

UL fire rating for Floor-Ceiling D700, D800, D900 Series Designs.

1, 1.5, 2 hour rating up to 5 lbs/cy dosage

Floors without total protection

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Example Macro Fiber for Composite Decks

ANSI/SDI-C1.0 Standard for Composite Steel Deck, October 2006

4 lbs/cy dosage as a "suitable alternative to welded wire fabric specified for temperature and shrinkage reinforcement."

Additional steel required for negative reinforcement

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Cristo Rey Jesuit H. S./Colin Powell Youth Leadership Center, Minneapolis, MN

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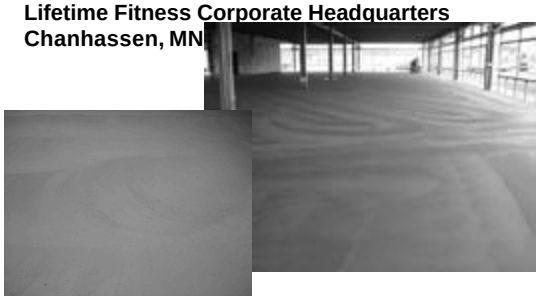
Lifetime Fitness Corporate Headquarters Chanhassen, MN



Example Macro Fiber used for composite deck and topping on precast.

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Lifetime Fitness Corporate Headquarters Chanhassen, MN

Example Macro Fiber used for composite deck and topping on precast

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Lifetime Fitness Corporate Headquarters Chanhassen, MN

Example Macro Fiber used for composite deck and topping on precast

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Highway A Overlay, Munich, Germany

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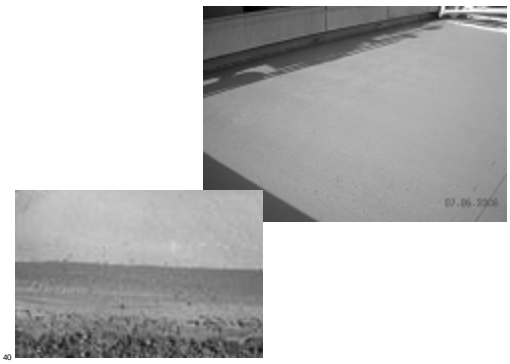
Highway A Overlay, Munich, Germany

Highway A Overlay, Munich, Germany



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Highway A Overlay, Munich, Germany

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Highway A Overlay, Munich, Germany

Freedom Mall Whitetopping
Charlotte, North Carolina

Parking Lot Whitetopping

Over deteriorated asphalt

3" to 5" thick

Example Macro Fiber dosage:

4 lbs/cy

5,000 psi mix

5,000 cy placed in 2008

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Freedom Mall Whitetopping
Charlotte, North Carolina

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Freedom Mall Whitetopping
Charlotte, North Carolina

Illinois Inlays and Overlays with Example Macro Fiber

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Bus Pad Overlays, Western Ave., Chicago, IL

Constructed in 2003

10 ft. by 100 ft. sections

Joints at 40" by 48"

4" thick overlay with 7.5 lbs/cy of Example Macro Fiber

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IDOT Overlay – Parking Lot

Illinois DOT, District 1 parking lot, 45,000 sqft.
2" thick, 7.5 lbs/cy Example Macro Fiber, joints at 24"
4" thick, 4 lbs/cy Example Macro Fiber, joints at 48"

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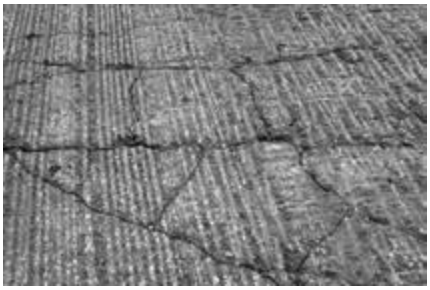
IDOT Overlay – Parking Lot



Prepared (milled) existing asphalt, deteriorated condition

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IDOT Overlay – Parking Lot

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IDOT Overlay – Parking Lot

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IDOT Overlay – Parking Lot

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IDOT Overlay – Parking Lot

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IDOT Overlay – Parking Lot

Illinois DOT, District 1 parking lot, 45,000 sqft.

2" thick, 7.5 lbs/cy Example Macro Fiber, joints at 24"

4" thick, 4 lbs/cy Example Macro Fiber, joints at 48"

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Schank Ave., Mundelein, IL Overlay

4" thick whitetopping over asphalt, 4 lbs/cy with Example Macro Fiber

Joints at 4 ft to 5 ft

About ¼ mile long.

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Schank Ave., Mundelein, IL Overlay

One of several overlays in Illinois cited in research work by Illinois Center for Transportation

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Schank Ave., Mundelein, IL Overlay

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Schank Ave., Mundelein, IL Overlay

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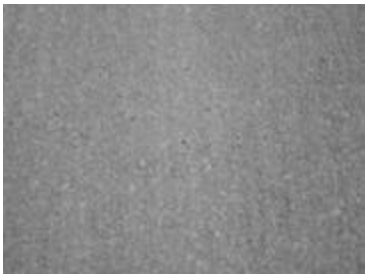
Dan Ryan Expressway Overlay
Chicago, IL



Prepared bridge deck surface prior to overlay

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Dan Ryan Expressway Overlay
Chicago, IL

Bridge deck, water saturated, covered. Trucks drive on cover until concrete is placed.

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Dan Ryan Expressway Overlay
Chicago, IL

Concrete mix at time of placement.

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Dan Ryan Expressway Bridge Overlay
Chicago, IL

Spreading concrete

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Dan Ryan Expressway Overlay
Chicago, IL

Overlay after spreading. Note finish operation and covering after placement in background.

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Dan Ryan Expressway Overlay
Chicago, IL

Finished overlay after wet cure

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Dan Ryan Expressway Overlay
Chicago, IL

1 million sqft of 2.25" overlay was placed during the summers of 2006 and 2007. Mix contained 3 lbs/cy Example Macro Fiber. Special provi sion is available.

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Dan Ryan Expressway Overlay
Chicago, IL - Video

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Ultra-Thin Whitetopping (UTC) Design Software

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Summary		Conventional fibers for plastic shrinkage	Welded wire mesh and light rebar	Example Macro Fiber fiber reinforcement
Plastic Concrete	Safe, easy handling	X		X
	Plastic shrinkage crack control	X		X
Hardened Concrete	Drying shrinkage crack control		X	X
	Post-crack load-carrying capacity		X	X
	Impact resistance			X
	Non-corroding	X		X

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Did we cover it all?

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  - Other sources
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- **Software**
- **Summary**

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Thank You.

Any Questions or Comments?

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