Grace Construction Products

Use of Fibers to Control Cracking of Concrete

For Minnesota Concrete Council

Presented by

Joseph Balik, P.E.

Grace Construction Products

March 24, 2011

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Agenda

Overview of Grace
Causes/types of cracking
Fiber types
Performance tests
Design tools
Applications
Summary and Q & A

1

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Grace Construction Products
- Global Projects Group
Consultants on Material Technology

2

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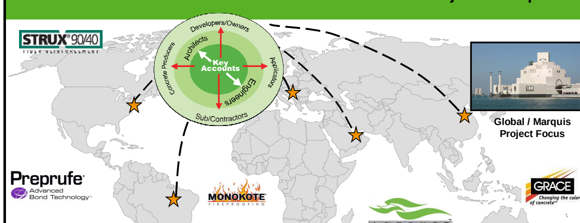
Construction Products | **Global Projects Group**



Value to A & E Community

- Portfolio of construction chemicals and building materials
- "One stop shop" from design to construction
- Access to world-class materials R & D
- Provide a link to the locality of project

Mission Statement

Global material consultants – assisting the designer to overcome architectural/engineering challenges, through a close relationship built on trust and technical excellence

Value to Owner

- Cost-effective solutions to complex design challenges
- Fewer costly project field changes
- Assurance of performance with long-term service life
- Projects on schedule and within budget

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Grace Construction Products Portfolio

Construction Chemicals | **Building Materials**

Concrete Admixtures
Durable and Architectural Concrete
Cement Additives

Structural Waterproofing
Fire Protection
Pipeline Corrosion Protection

Specialists in Construction Chemicals and System Solutions backed by a Global Infrastructure

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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)

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PRIMARY TYPES OF CRACKING


plastic shrinkage crack


drying shrinkage crack


structural crack


thermal cracking

Hot, Dry, Windy?

7

Plastic Shrinkage Cracking

8

Plastic Shrinkage

- **Volume change in the concrete due to water evaporation**
- **Occurs within the first 2 to 24 hours**

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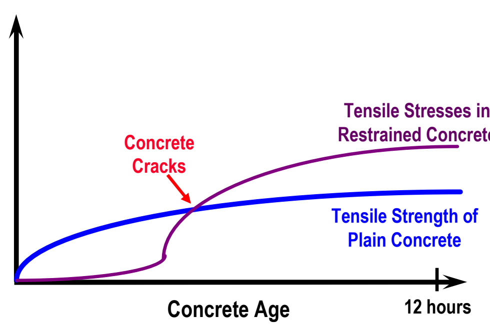
Much of the volume change (shrinkage) takes place before the concrete has had a chance to develop sufficient strength

10

Mechanism of Plastic Shrinkage Cracking

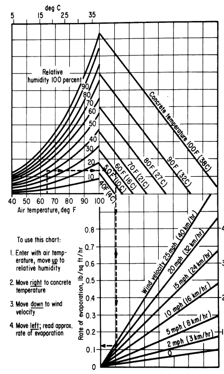


11

Rate Of Evaporation And Plastic Shrinkage Cracking

- **> 0.1 Potential Cracking**
- **> 0.2 Cracking**

ACI 305 Fig. 2.1.5



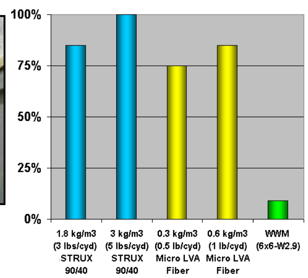
12

How Do We Measure Plastic Shrinkage Performance?

- **ICBO test procedure is currently the standard**
  - Wind Tunnel with:
    - High Temperature
    - High Wind Speed
    - Low Relative Humidity
  - Cracks induced at thin section in the center of the slab
  - Measure the number, length and width of cracks

13

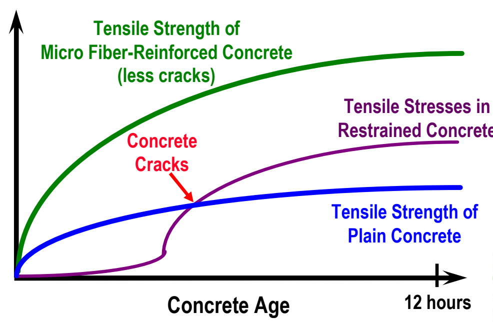
Plastic Shrinkage Crack Reduction



Temperature: 104°F (40°C)
Relative Humidity: 15 – 30%
High Speed Fan until Final Set
Compare Crack Area vs. Plain Concrete.

14

Fibers Provide Concrete with Early Tensile Strength



15

Magnitude of Drying Shrinkage
ASTM C 157

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

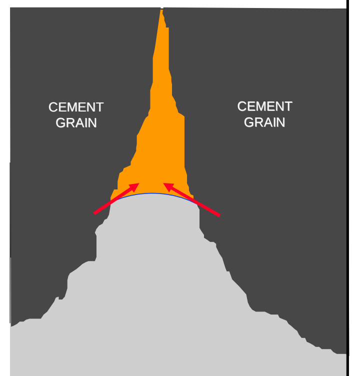
Background
What causes drying shrinkage?

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)

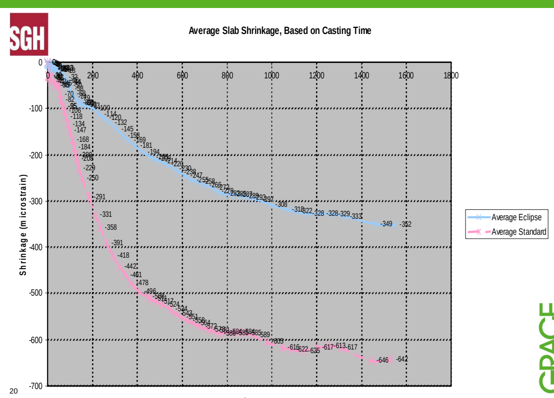
Understanding Shrinkage

- 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



19

Independent Testing by Simpson, Gumpertz and Heger, Inc, Boston Office



20

Drying Shrinkage

Factors affecting shrinkage
(In order of importance - approx)

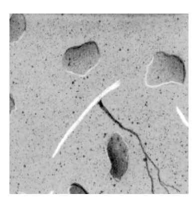
- Aggregate to paste ratio
- Stiffness of aggregate
- Water content
- Pore size distribution f(w/c, fineness, pozzolans, admixtures)
- Aggregate absorption and shrinkage
- Aggregate cleanliness
- Cement chemistry
- Lower cement content

Drying Shrinkage

Other factors affecting shrinkage

- Temperature (mainly due to impact on water demand)
- Member volume to surface area ratio (more massive members shrink slower)
- Environmental conditions- high water tables

Drying Shrinkage Crack Control with Fibers



Fibers intersect cracks that form in the concrete. This allows for uniform distribution of the shrinkage stresses that develop, thereby lessening cracking problems.

23

“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

24

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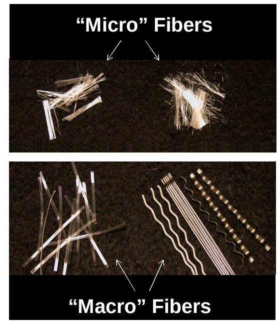
“Micro” vs. “Macro” Fibers



25

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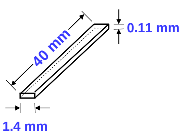
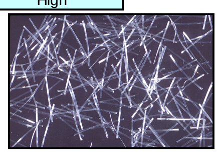
Synthetic Macro Fiber

Polyolefin 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℃ (320℉)
Ignition Point	590℃ (1094℉)
Alkali, Acid & Salt Resistance	High





26

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ASTM C1399

ASTM C1399-04 (Test Method for Obtaining Average Residual-Strength of Fiber-Reinforced Concrete)

- **ONLY 4” x 4” x 14” (100 mm by 100 mm by 350 mm) beam**
- **What is ASTM C1399?**
- This test method covers the determination of the average residual strength (ARS) of a fiber–reinforced concrete test beam supported by a steel plate underneath the entire length. The flexural beam is initially cracked from an applied load up to a deflection of 0.5 mm (0.008 in.). The steel plate is then removed and the post-crack deflections and loads are measured and recorded during the test up to a final deflection of 1.25 mm (0.05 in.)..
- **Added Comments**
  - **Originally designated for micro fibers**
  - **Very good test results with macro fibers.**
  - **Specifies fibers to be <= 1.50 inches in length**

27

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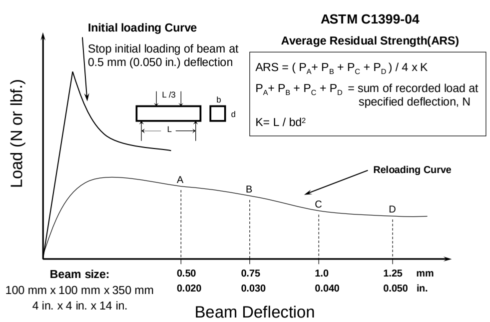
Average Residual Strength Evaluation ASTM C1399-04



28

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ASTM 1399 Average Residual Strength (ARS) Varies with fiber type, dosage, compressive strength

ARS values measured according to ASTM C1399-07

lbs/yd³	Cylinder Compressive Strength (psi)						
	3,000	3,500	4,000	4,500	5,000	5,500	6,000
3.0	95	110					
3.5	125	140	150	160	175		
4.0	150	165	175	185	200	210	220
4.5	175	185	195	210	220	230	245
5.0	195	205	215	230	240	250	260
5.5	215	225	235	245	255	270	280
6.0	230	240	250	260	275	285	295
6.5	245	255	265	275	285	300	310
7.0	260	270	280	290	300	310	320
7.5	270	280	295	305	315	325	335

30

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ASTM C 1609

ASTM C1609-05 (Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading)

- **6” x 6” x 20” (150 mm by 150 mm by 500 mm) beam**
- **This test method evaluates the flexural performance of fiber-reinforced concrete using parameters derived from the load-deflection curve. This is obtained by testing a simply supported beam under third-point load. (Unlike ASTM C1399, a steel plate is NOT used for achieving controlled cracking of concrete)**

31

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Third Point Loading Test (ASTM C 1609-05)

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

32

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What applications recommended to specify ASTM 1609?

Slab on ground, precast, etc (or any concrete member greater than 4 inches thick).

Why?

1) The larger beam allows the use of macro fibers up to 2.5 inches (65 mm) in length. This will accommodate for the majority of macro fibers on the market that have lengths between 1.5 to 2.5 inches (38mm - 65 mm).

2) The potential preferential alignment of fibers is now reduced and a more random distribution of fibers both horizontally and vertically/diagonally will occur similar to “field” concrete with fibers.

33

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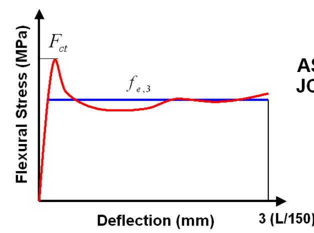
Equivalent flexural strength



ASTM C1609-05
JCI-SF4

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

34

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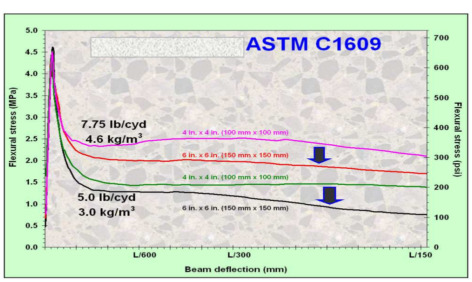
“Small’ versus ‘big’ flex beam cast from identical concrete mix.



Toughness or residual flexural strength is lower when measured with ‘big’ flex beam !!

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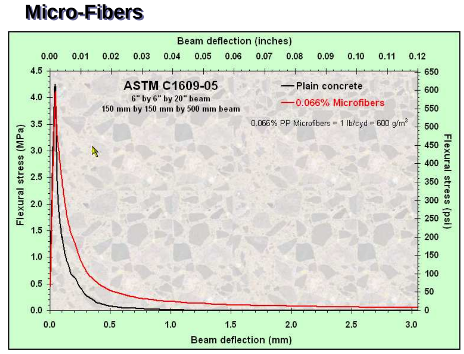
Micro-Fibers



39

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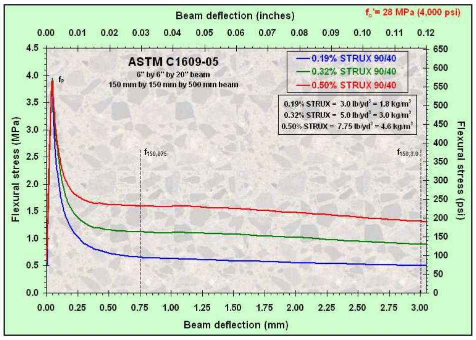
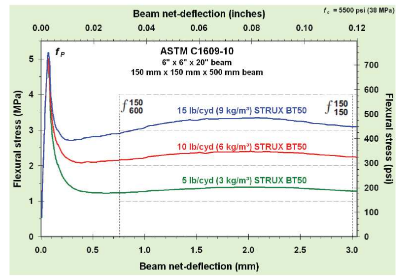
Macro- Fibers



40

New Macro Synthetic Fibers
Note higher dosage and performance



41

What to specify: Which ASTM Test?

- Specify ARS Values from ASTM C-1399 for concrete members less than or equal to 4 inches.
- Specify fe3 values from ASTM C-1609 for concrete members greater than 4 inches thick.

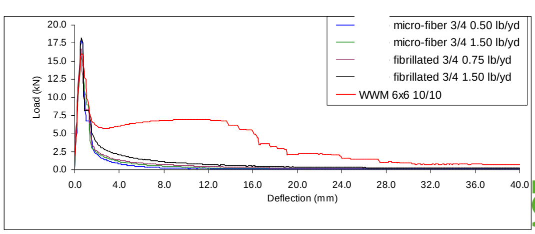
42

ASTM C 1550
Round Determinate Panel Test

32" (810 mm) diameter x 3" (76 mm) thick panel

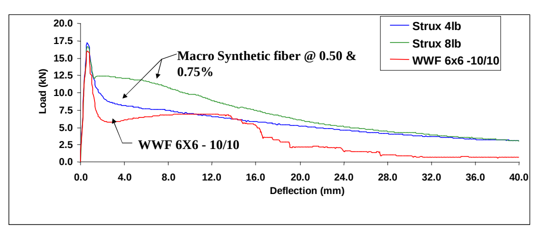
43

28 Day Load Test
Panel Results



44

Load Test
Panel Results
(up to 40 mm (1.57") deflection)



45

Large Scale SOG Test

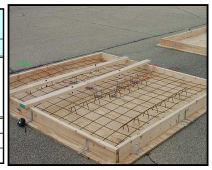
University of Illinois

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/m³	lbs/cyd	kg/m³
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

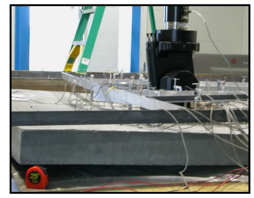


Large Scale SOG Test

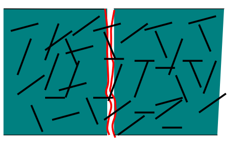
Subgrade: 8" (203 mm) thick compacted clay

500 kN capacity MTS Hydraulic Actuator

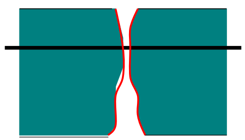
Center Loading until Puncture Failure



Example Macro Fiber Provides Tight Crack Control



Uniform Crack Width with Example Macro Fiber



Wider Cracks Away from WWM/Rebar

Example Macro Fiber vs. WWM

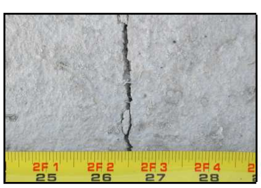
Example Macro Fiber ≈ 1/16" (1.6 mm)

WWM ≈ 3/16" (4.8 mm)

- Crack Width Measurements for Large Scale SOG Test

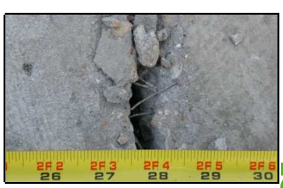
Example Macro Fiber vs. Steel Fibers

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)

Example SOG Design Software

Background

ACI 360R-10, Design of Slabs-on-Ground, Chapter 11, 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 specific fiber.

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

52

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**

53

Applications

Parking garage slab-on-ground

Bridge deck overlays

Slab-on-ground, warehouse

Pavements, whitetopping

Composite decks

- Schools
- Hospitals
- Offices

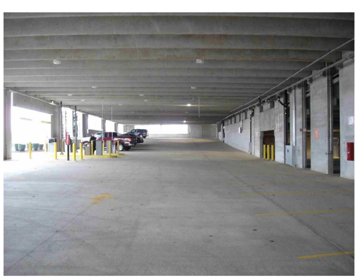
Other

54

Provina St. Joe Hospital
Joliet, IL

55

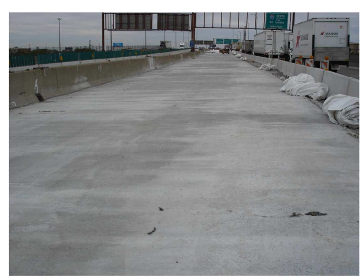
Provina St. Joe Hospital
Joliet, IL



56

Dan Ryan Expressway Bridge Overlay, 2006, 2007

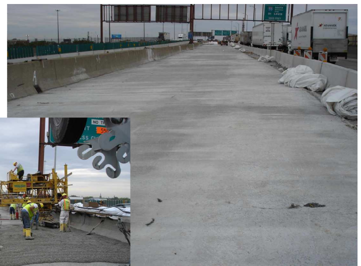
1.0 million sqft,
2.25" overlay

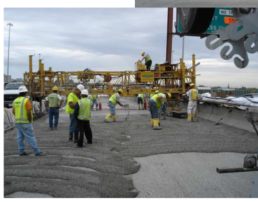


57

Dan Ryan Expressway Bridge Overlay, 2006, 2007

1.0 million sqft, 2.25” overlay





58

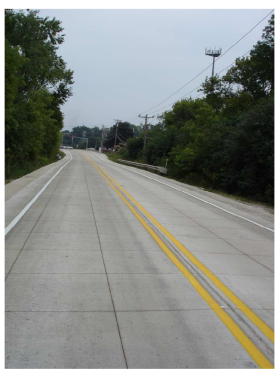
IDOT Overlay – Parking Lot

59

Schank Ave. Overlay

4” thick whitetopping over asphalt, 4 lbs/cy STRUX 90/40. Joints at 4 ft to 5 ft

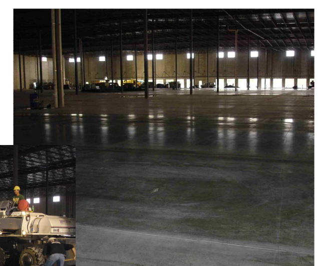
About ¼ mile long.

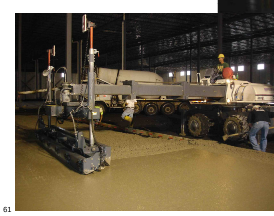


60

Affiliated Foods Midwest, Kenosha, WI

8 inch slab with STRUX 90/40 for rack and wheel loads





61

Example Synthetic 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

62

STRUX 90/40 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

ANSI/SDI-C1.0 Standard
for
Composite Steel Floor Deck

October 2006

63

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

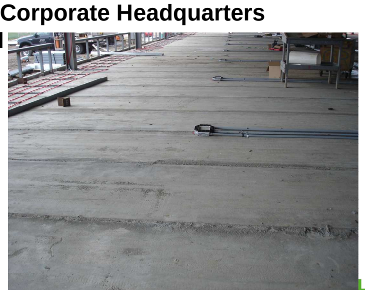
65

Lifetime Fitness Corporate Headquarters Chanhassen, MN

STRUX 90/40 used for composite deck and topping on precast.

66

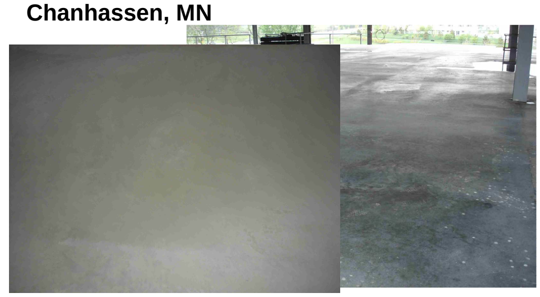
Lifetime Fitness Corporate Headquarters Chanhassen, MN



STRUX 90/40 used for composite deck and topping on precast

67

Lifetime Fitness Corporate Headquarters Chanhassen, MN



STRUX 90/40 used for composite deck and topping on precast

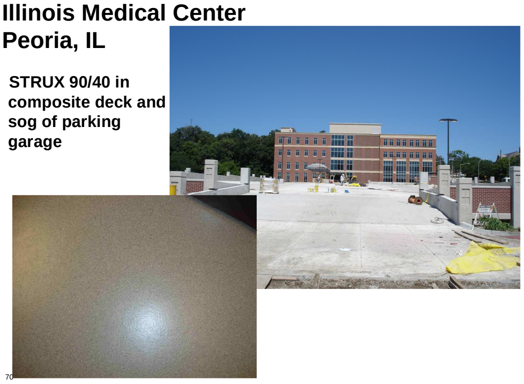
68

St. Jude Medical Office Building Little Canada, MN

STRUX 90/40 in Composite Decks

Illinois Medical Center Peoria, IL

STRUX 90/40 in composite deck and sog of parking garage



70

St. Joe Hospital
Mishawaka, IN
Concrete Placement and Finishing Video

71

Composite Deck Cost Analysis Software

72

Composite Deck Cost Analysis

Cost of WWF
- Labor
- Handling
- Waste & Overlap
- Other

Cost of macro fiber reinforcement
- Cost savings due to shortened schedule

73

Summary		Conventional fibers for plastic shrinkage	Welded wire mesh and light rebar	STRUX 90/40 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

74

Did we cover it all?

Overview of Grace
Causes/types of cracking
Fiber types
Performance tests
Design tools
Applications
Summary and Q & A

75

Thank You.

Any Questions or Comments?

www.graceconstruction.com
joseph.s.balik@grace.com