Fiber Reinforced Concrete

Fiber This! Fiber That!

What is the Truth about Fibers

Brett A. Harris
Regional Technical Services Manager, Concrete - Northeast

gcp applied technologies

Why Reinforce Concrete ?

- Plastic Shrinkage
- Thermal Induced Shrinkage (thermal shock, seasonal)
- Structural (static and live loads, reflective, creep)
- Chemical (corrosion, ASR, DEF)
- Drying Shrinkage

National Ready Mix Concrete Association Survey

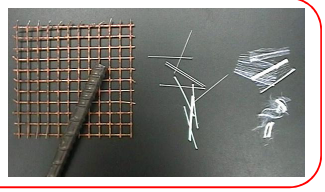
Cracking is #1 Concrete Problem

Concrete Reinforcement

Historical use of reinforcement:

Conventional reinforcing bars are used to increase the load bearing capacity of concrete.

Fibers are more effective for plastic shrinkage crack control.



No longer completely accurate;
Fibers are now used in structural applications

What is Fiber Reinforced Concrete (FRC)?

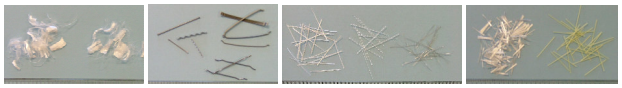
FRC is a mixture of:

- Conventional Concrete (cement, water, rock and sand) + Fibers

→ what type of fibers should I use?

Fibers can be made available in many different material types:

- Steel
- Synthetic - polypropylene, nylon, carbon, polyester, aramid, etc.
- Natural (cellulose)
- Glass (alkali resistant)



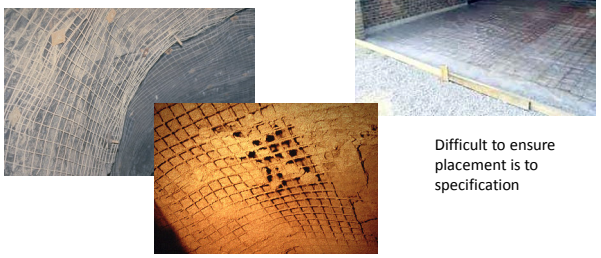
Why Use Fibers

Problems encountered with WWM and Light Rebar:

- Fabricating cages for complicated shapes, thin walls
- Cage placement in forms
- Labor costs
- Corrosion and durability issues
- Warehousing of rebar and mesh
- Safety
- Compacting/consolidating heavily reinforced pieces

Other Problems with WWM

Difficult to place and secure for irregular shapes - Voiding and Segregation



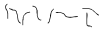
Difficult to ensure placement is to specification

Micro-fibers

Fibers for Plastic Shrinkage Only

Mostly the Domain of Synthetic Fibers at Low Fiber Addition Rates (0.1 to 0.3% Vol.) 1 to 3 lb/yd

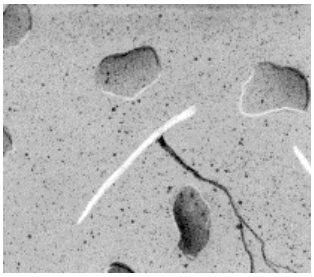
Polypropylene,
Steel, Carbon, etc...



Lengths: 1 to 50mm

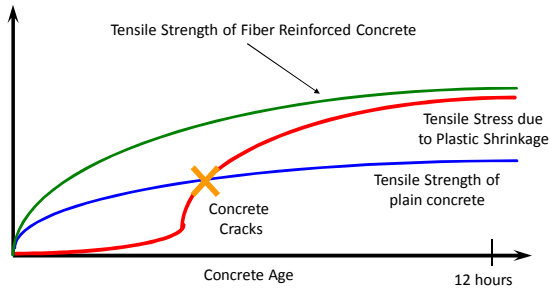
Diameters: < 25 µm

Plastic Shrinkage Protection



Fibers have been shown to reduce plastic shrinkage cracking by up to 80-90% by providing concrete with early tensile strength and by intercepting and arresting cracks as they travel through concrete.

Plastic Shrinkage



Cracks are generally shallow and random in direction

Beyond Plastic Shrinkage

Protection against plastic shrinkage cracking in concrete can be properly managed with the use of commercially available products but what happens beyond the initial set of concrete when these low volume fiber products or improperly placed WWM reinforcing alternatives are challenged by other loading conditions?

- Drying Shrinkage
- Thermal Induced Shrinkage (thermal shock, seasonal)
- Structural (static and live loads, reflective, creep)
- Chemical (corrosion, ASR, DEF)

Resistance is characterized by Toughness

Bridging the Gap

After over 20 years of development
And well over 10 years in the market

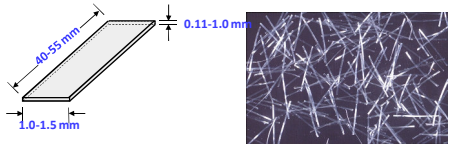
Macro Synthetic Fibers

Macro-Fibers

Typical Synthetic Fiber

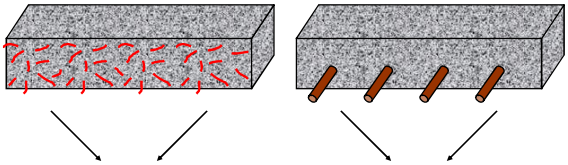
Polypropylene Monofilament Fiber

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



How Do Fibers Work in Concrete?

How can a whole bunch of short little "toothpicks" do the same job as rebar?



Fibers actually provide the same function as conventional reinforcing - prevent cracks that form in concrete from opening - the key is how much.

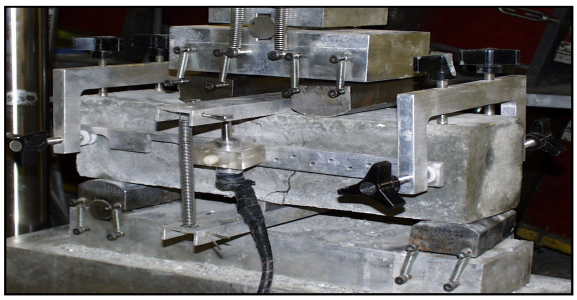
Post-Crack Control and Load Transfer with Macro Fibers

- ***Performance Based Specifications***
  - ASTM C1609-10
  - ASTM C1399-10
  - ASTM C820-11-Steel
  - ASTM C1550-02
  - Material Based Requirements (Crack Size: Width and Length)
    - Tensile Strength
    - Modulus of Elasticity

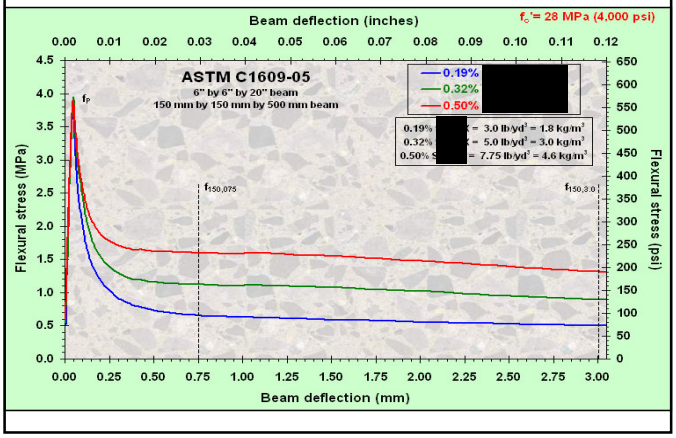
Validation Performance Testing

Third Point Loading Test (ASTM C1609-10; ASTM A820-11)

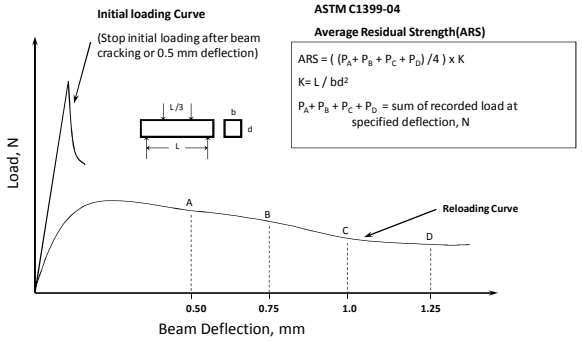
- Closed Loop System
- Sample Size: 6" x 6" x 20" (150mm x 150mm x 500mm)



Macro-Fibers



Average Residual Strength Evaluation ASTM C1399-10



ASTM C1550-02 - Round Determinate Panel Test

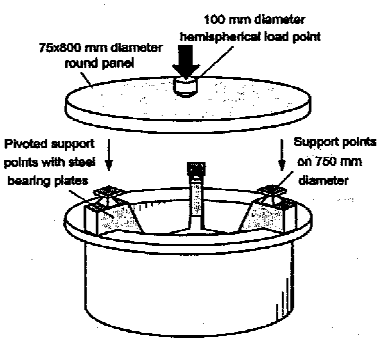
Mode of failure dominated by flexure.

This can test higher deflections compared to ASTM C1609

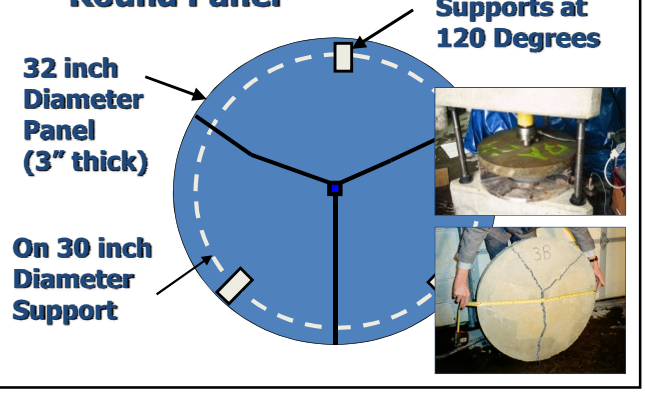
32" (810 mm) diameter x 3" (76 mm) thick panel

Wire mesh will perform better in thin elements

New Panel Test ASTM C 1550 - 02



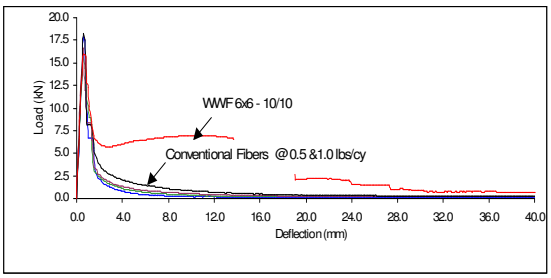
ASTM C 1550-02 Round Panel



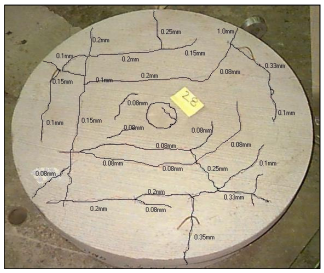
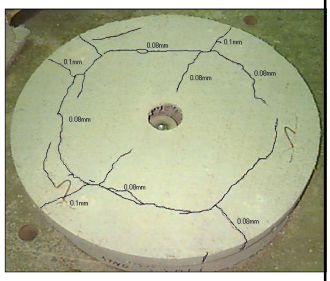
Round Determinate Panel Results

(up to 40 mm (1.57") deflections)

6x6 - 10/10 WWF vs Conventional Polypropylene Fibers



57% Energy Absorption Increase

Welded Wire Mesh	*Fiber Reinforced*
	
After 28 blows 4617 Joules	**After 37 blows 6477 Joules**

Performance Based Specifications - "R" Values -

- % of Residual Flex. Strength / Flexural Strength of the Concrete

Performance Based Specifications - "R" Values -

- What is the equivalent R-Value for a 4" thick Ditch Liner
- Current Spec. – 6" x 6", w4.0 x w4.0
- fe3 = 270psi
- Flexural Stress of 4500psi Conc. = 611psi (9.1 x SQRT (f'c))
- R-Value = 270/611 = .44 or 44%

Fe3 Values

Residual flexural strength (fe3)

Concrete fc = 4000-5000 psi (27 - 34 MPa)

Synthetic Macro Fiber Dosage (lb/cy)	Fe3 (psi)	Fiber dosage kg/m3	MPa
5	154	3.0	1.1
6	184	3.6	1.3
7	215	4.2	1.5
8	246	4.8	1.7
9	277	5.3	1.9
10	307	5.9	2.1
11	338	6.5	2.3
12	369	7.1	2.5
13	400	7.7	2.8
14	430	8.3	3.0
15	461	8.9	3.2

R Values

Residual flexural strength (fe3) / flexural strength (breaking)

Concrete fc = 4000-5000 psi (27 - 34 MPa)

Flex Strength = 611psi (based on avg f'c= 4500psi

Fiber dosage (lb/cy)	PSI, R-value	Fiber dosage kg/m3	MPa
5	154, 25	3.0	1.1
6	184, 30	3.6	1.3
7	215, 35	4.2	1.5
8	246, 40	4.8	1.7
9	277, 45	5.3	1.9
10	307, 50	5.9	2.1
11	338, 55	6.5	2.3
12	369, 60	7.1	2.5
13	400, 65	7.7	2.8
14	430, 70	8.3	3.0
15	461, 75	8.9	3.2

Advantages of Fibers in Slabs

Economic Advantages

- Elimination of traditional mesh or rebar with reduced labor and material costs
- Reduction in slab thickness
- Increased joint spacing possibilities
- Less complicated construction leading to earlier completion
- Lower maintenance costs

Technical Advantages

- Suppresses propagation of cracks and spalling
- Ensures a homogeneously reinforced product
- Increased toughness provides a high resistance to impact loading and abrasion
- Increase in fatigue resistance

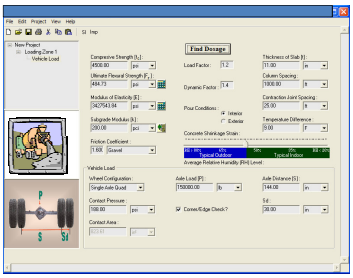
Same design question:
How much fiber do I need?

ACI 360 – Design of Slabs on Ground

10.2.2 Design Principles

The design principles for micro polymeric FRC are the same as those used for un-reinforced concrete.

Macro polymeric fibers provide increased post-cracking residual strength to concrete slabs-on-ground. The same design principles in 10.3.3 can be used for macro polymeric FRC.



Various fiber manufacturers are now supplying and developing software based design packages for providing optimum thickness : fiber dosage for specific job site requirements.

UL Approval



Some Macro Fibers have UL/ULC approval for deck design: 2 hour un-restrained fire rating @ 4 pcy (2.4 kg/m³).

What does this mean?
- approved material in elevated deck systems where engineer is requiring all materials be UL approved.
- Applications: schools, hospitals, mixed-use, banks, etc.

ANSI/SDI Language

New Code Provisions for Fibers to Replace WWF

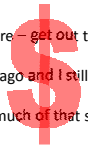
As of Nov 2006, the **ANSI/SDI-C1.0 Standard for Composite Steel Floor Deck** has changed the provisions in its design code relative to minimum reinforcing to the following:

2.4.B6 Reinforcement: *Temperature and Shrinkage reinforcement, consisting of welded wire fabric or reinforcing bars, shall have a minimum area of 0.00075 times the area of the concrete above the deck (per foot or meter of width), but shall not be less than the area provided by 6 x 6 - W1.4 x W1.4 welded wire fabric.*

Fibers shall be permitted as a suitable alternative to the welded wire fabric specified for temperature and shrinkage reinforcement. *Cold-drawn steel fibers meeting the criteria of ASTM A820, at a minimum addition rate of 25 lb/cu yd (14.8 kg/cu meter), or macro synthetic fibers "Coarse fibers" (per ASTM Subcommittee C09.42), made from virgin polyolefin, shall have an equivalent diameter between 0.4 mm ((0.016 in.) and 1.25 mm (0.05 in.), having a minimum aspect ratio (length/equivalent diameter) of 50, at a minimum addition rate of 4 lb./cu.yd (2.4kg/m3) are suitable to be used as minimum temperature and shrinkage reinforcement.*

Commentary: *Neither welded wire fabric or fibers will prevent cracking, however they have been shown to do a good job of crack control. The welded wire fabric must be placed near the top of the slab (3.4 to 1 inch cover (20 to 25 mm) at supports and draped toward the center of the deck span. If a welded wire fabric is used with a steel area given by the above formula, it will not be sufficient as the total negative reinforcement. If the minimum quantity of steel fibers, or macro synthetic fibers are used for shrinkage and temperature reinforcement, they will not be sufficient as a total negative reinforcement.*

Synthetic Fiber Typical Comments



"I've seen these fibers before – get out the lawnmower!"

"I used these twenty years ago and I still got cracks!"

"You want me to put how much of that stuff in my concrete?!"

In reality, the new synthetic fibers available on the market today are capable of competing directly with steel fibers, welded wire mesh and rebar in a wide variety of applications for primary reinforcing requirements.

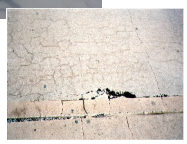
Issues: Higher reinforcing volumes than conventional synthetic fibers
Workability and slump of concrete – do not add water!

Pavements & Slabs on Grade

Can fibers be used to resist dynamic wheel loads, static rack loads and uniformly distributed loads? What about fork truck traffic and impact from falling loads or equipment? Fiber reinforced concrete, which is designed as a homogeneous material, can provide a solution.

Pavement Applications

- Airport pavements: runways, aprons and taxiways
- Highways and roads
- Parking areas
- Bridge decks
- Pavement repairs
- Overlays
- Canal and reservoir linings



Slab Applications

- Factories
- Warehouses
- Hangers
- Concrete Overlays

Finishing Expectations

- *Interior Finish: Power Trowel or Finishing Machines - burned in potential* (minimal to no fibers protruding; although they may be seen at surface below paste)
- *Interior Hand Finish:* Potential to see them increases

- *Exterior Finish: Bull float, light broom finish* (Broom Angle and timing determines likelihood of seeing fibers, unlikely to see cracks)

The Concrete Job

Every project has different requirements. Fiber dosages should always be selected on the basis of the required performance first.

Know the requirements, specifications and economics of the job.

Know use the proper tool for the Application

The Future in Fiber Reinforcement

• New Codes and design documents are coming forward detailing proper practices and procedures for using FRC – ACI 360, SDI.

• Fibers are proven to be a more economical and safe reinforcing alternative to conventional WWM and temperature steel.

• Ready mix suppliers and design build general contractors now have access to fiber dosage tools to ensure proper selection and use of macro-fibers.

• High volume macro-synthetic and steel fiber projects have the ability to enhance the concretes durability performance.

• Fiber R&D is continuing in markets to develop new reinforcement of structural members for seismic areas and dry shotcrete applications.

Thank you for your attention

Questions and Comments