A Comprehensive Guide to Fiber Reinforced Concrete (FRC) Applications

Date 08 March 2024

Author Jan Patrick Reboredo

Shervin Peñero

TOPIC OUTLINE

- MICROSTRUCTURE OF CONCRETE
- INTRODUCTION TO STEEL FIBER REINFORCED CONCRETE (SFRC)
- DESIGN APPROACH

TOPIC OUTLINE

MICROSTRUCTURE OF CONCRETE

INTRODUCTION TO STEEL FIBER REINFORCED CONCRETE (SFRC)

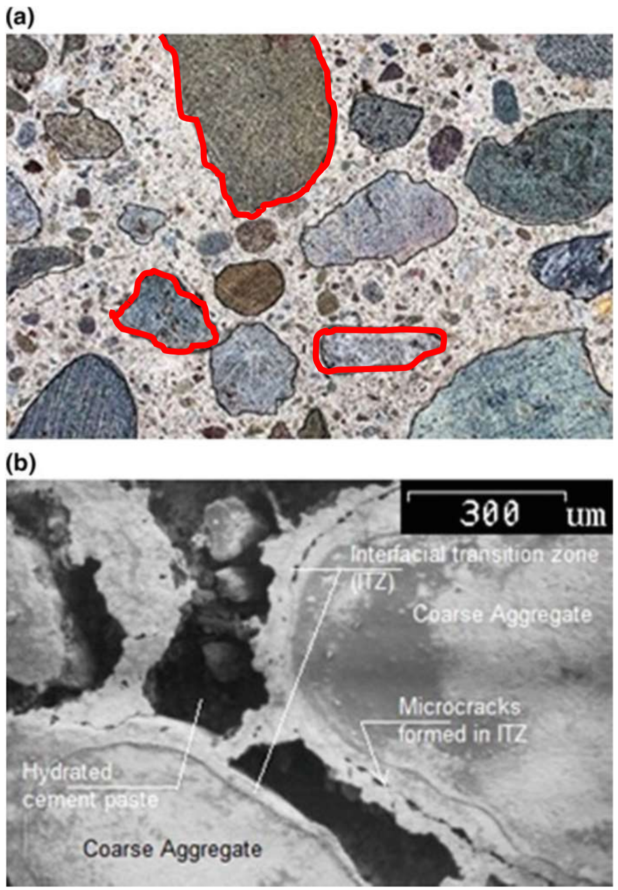
DESIGN APPROACH FOR SFRC

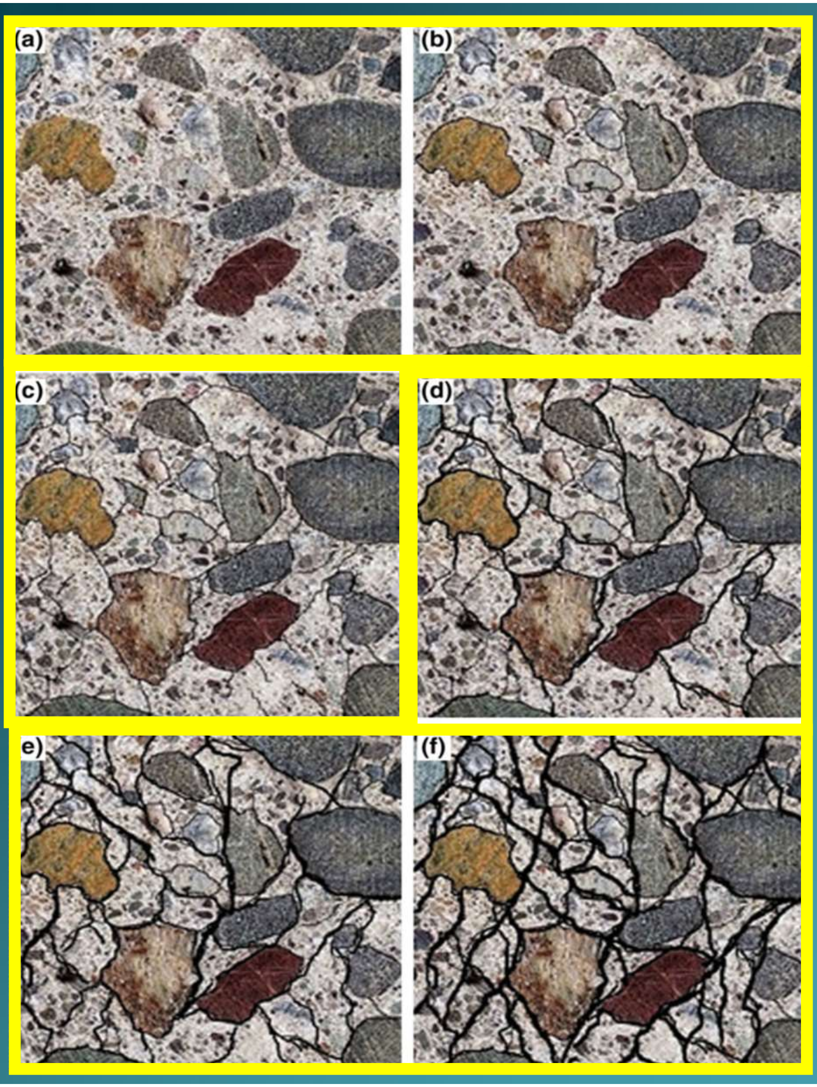
Concrete

Concrete in its hardened state consists of hydrated cement paste, fine aggregates, and coarse aggregates.

MICROSTRUCTURE OF CONCRETE

Interfacial Transition Zone (ITZ) is a distinct line observed around large particles, significantly impacting concrete strength. This zone exhibits larger voids than the rest of the cement due to increased water content near the surface of big particles, particularly flat and large round ones. Consequently, there's a higher concentration of crystalline compounds like calcium hydroxide and ettringite in this area, creating a weakened surface that limits overall concrete strength. The ITZ is both a vulnerability for strength and fluid permeation, characterized by high porosity affecting fluid movement through the concrete. Image a) displays a polished surface of a concrete sample, and b) is the view under a microscope.





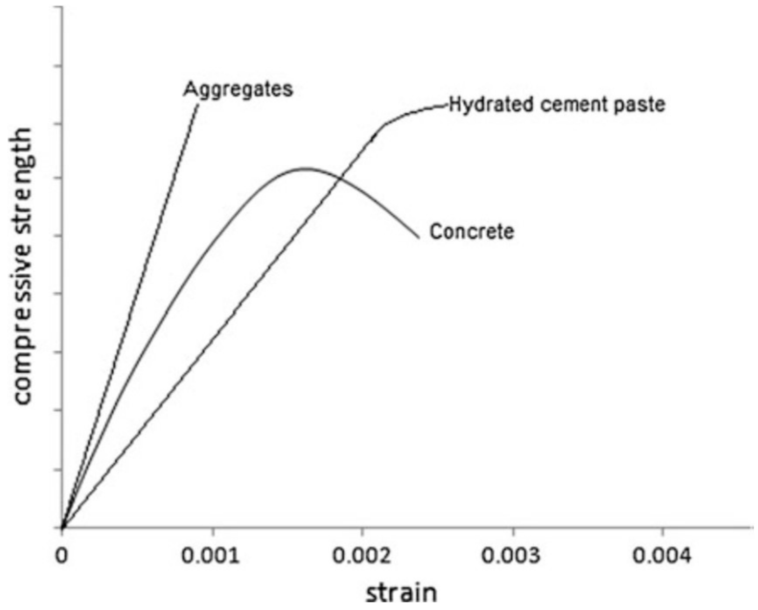
MICROCRACKS

- These pictures illustrate the step-by-step development of tiny cracks already present in the Interfacial Transition Zone of concrete under stress (a and b).
- These cracks then extend (c), widen, and progress into nearby areas in the concrete (d–f). A very thin separation layer around the surface of the coarse aggregates in concrete has been there from the day it was poured (about 10–50 µm thick, mostly invisible to the naked eye).
- When the concrete is stressed to around 30% of its ultimate strength, these tiny cracks get longer and wider but stay in the ITZ (c). Concrete acts almost like a spring under compression, behaving linearly.
- As the stress increases to 30–50% of the ultimate compressive strength, the cracks start going into the surrounding mortar but remain stable (d). The concrete's response starts changing from the linear one seen before.
- At 75% of the ultimate strength, these cracks grow, widen, and move into the mortar with the release of extra energy (e).
- At this point, the concrete has the highest volumetric strain. After this, it usually can't handle more pressure and starts to soften in its response.

INDIVIDUAL MATERIAL’S STRENGTH

“The aggregates and the hydrated cement paste exhibit a linear elastic response upon stressing, whereas the concrete does not. The presence of the interfacial transition zone around the surfaces of coarse particles in the concrete can be attributed to the non-linearity exhibited by concrete when it is strained beyond the elastic range. The interfacial transition zone did not exist in the case of the naturally occurring aggregates and the hydrated cement paste”

Singh, Harvinder. Steel Fiber Reinforced Concrete Behavior, Modelling and Design. Springer Science, 2017.

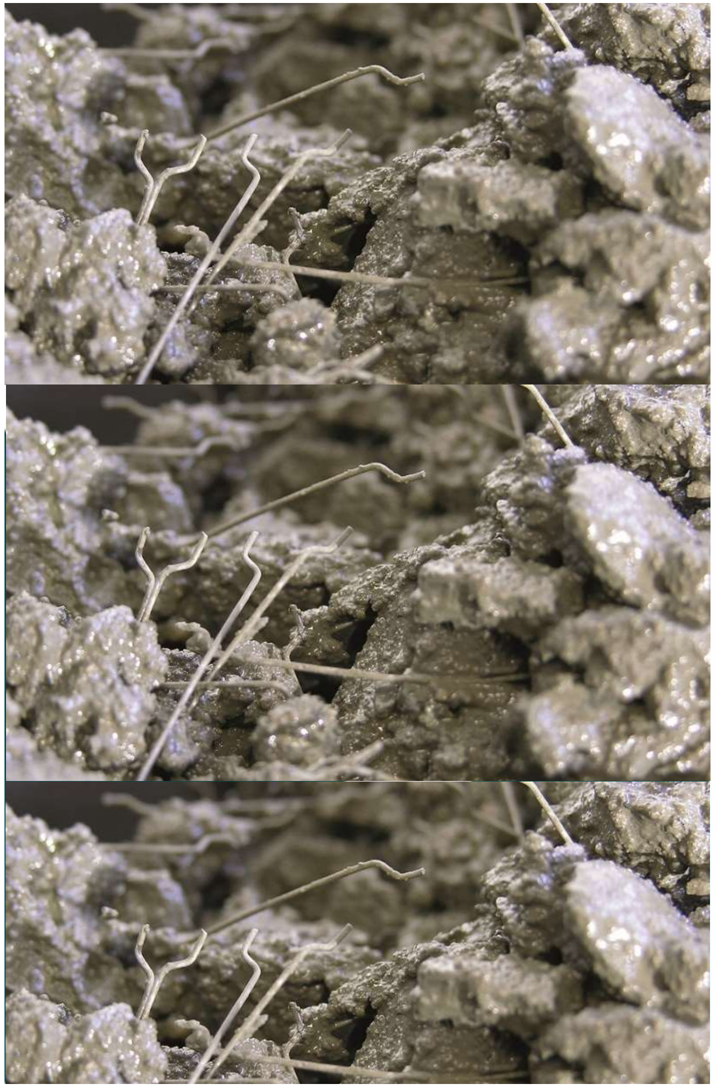


TOPIC OUTLINE

MICROSTRUCTURE OF CONCRETE

INTRODUCTION TO STEEL FIBER REINFORCED CONCRETE (SFRC)

DESIGN APPROACH FOR SFRC



ACI 544.3R - Steel Fiber Reinforced Concrete (SFRC)

Steel fiber reinforced concrete is a composite material made of hydraulic cements, fine and coarse aggregate, and a dispersion of discontinuous, small steel fibers. It may also contain pozzolans and admixtures commonly used with conventional concrete.

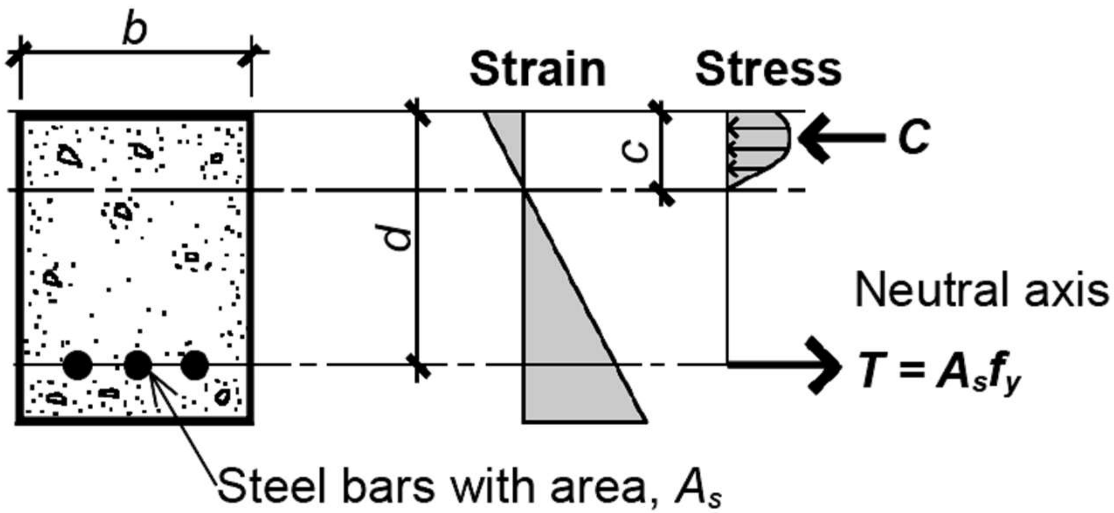
MACCAFERRI

Great Place To Work. Certified

DESIGN THE CHANGE

REINFORCED CONCRETE

Conventional reinforced concrete member relies on materials with high tensile strength, such as deformed steel bars, in its identified tensile zone to handle moments and are used as reinforcements. Adding rebars does not enhance the concrete's brittle characteristics, but it does change the overall flexural response of the concrete section.

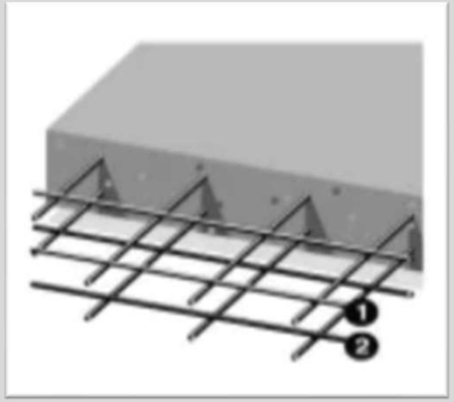


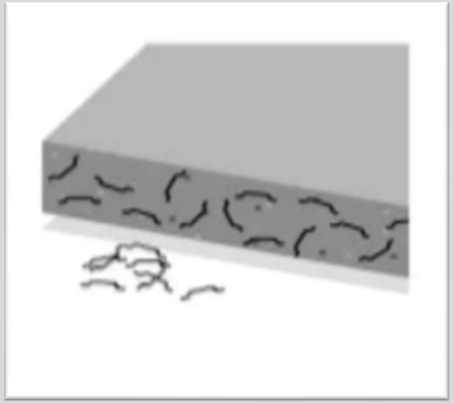
STEEL FIBER REINFORCED CONCRETE

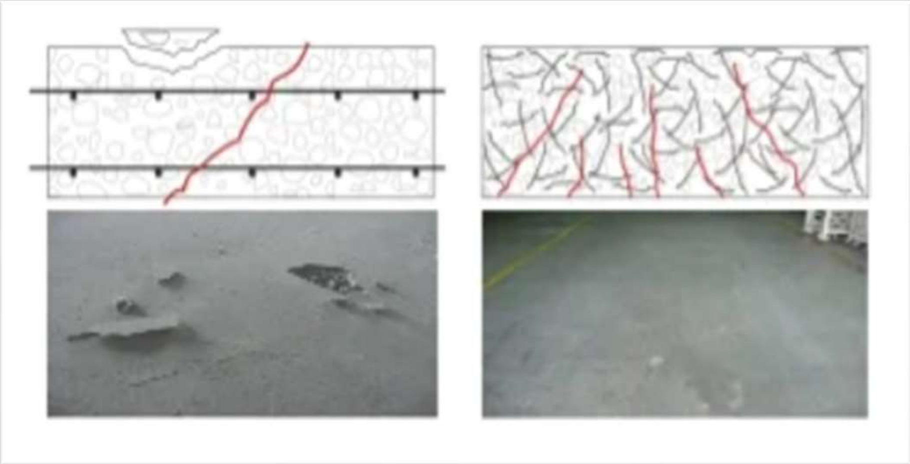
Steel fiber reinforced concrete contains short, discrete fibers dispersed randomly in the mix during the concrete's creation. These fibers form a network around coarse aggregates, acting like ties in imaginary 'space trusses.' The mortar mix supports compression and provides anchorage to the fibers. This arrangement enhances the concrete's strength by allowing stress transfer across discontinuities in the interfacial transition zone (ITZ) around coarse aggregates. The fibers also prevent the extension and widening of existing microcracks in the ITZ, improving the concrete's quasi-brittle characteristics and tensile straining capability.

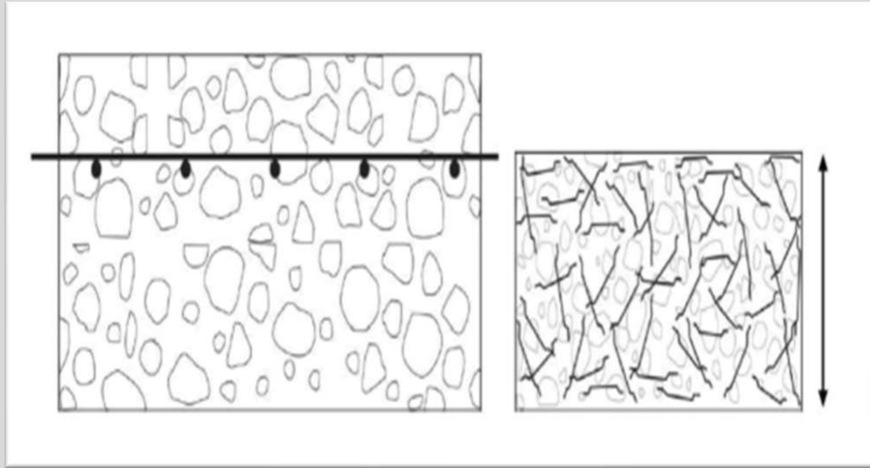
Conventionally Reinforced Concrete vs Fiber-reinforced

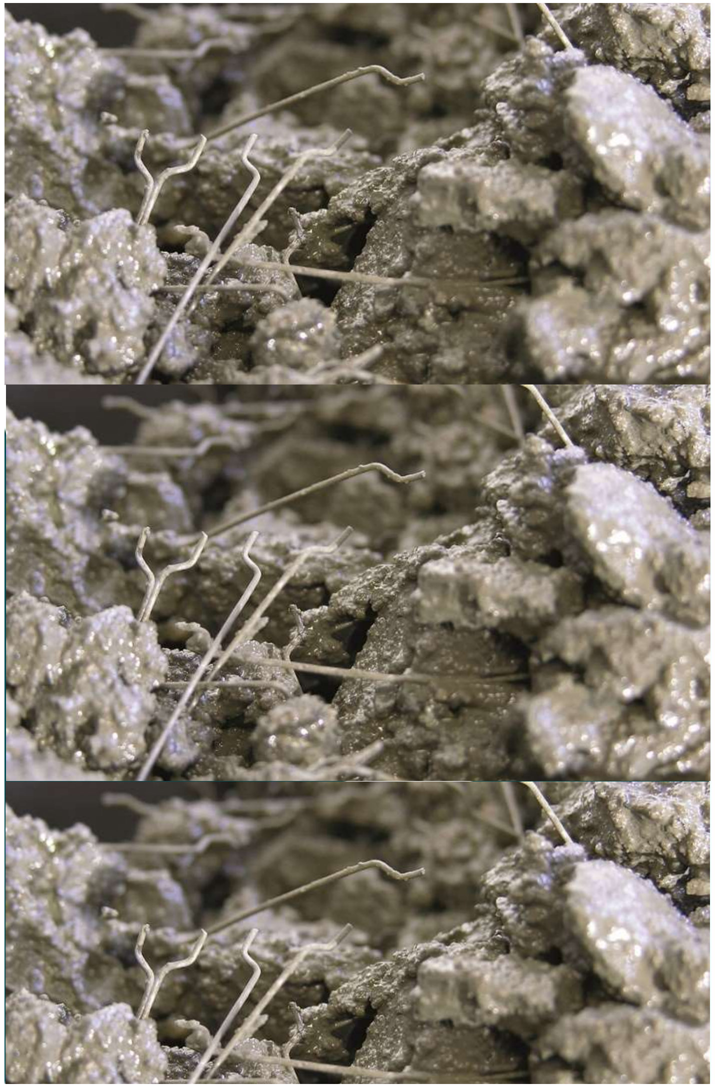
Homogenous reinforcement











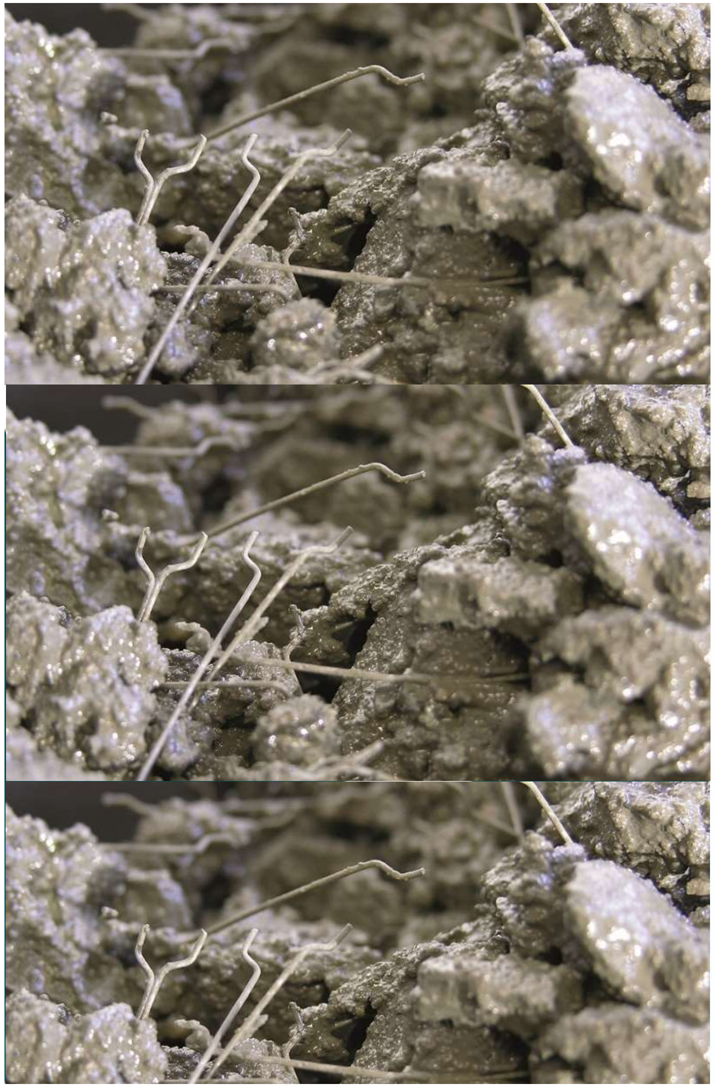
Dramix® Steel Fibers

- Cold-drawn Type 1 steel wire (ASTM-A820)
- Replaces traditional reinforcement in concrete
- 3-dimensional reinforcement throughout the concrete matrix

MACCAFERRI

Great Place To Work. Certified

DESIGN THE CHANGE



Dramix® Steel Fibers enhance the following properties of concrete :

- ☑ **Flexural strength**
- ☑ **Shear strength**
- ☑ **Stress distribution**
- ☑ **Durability**
- ☑ **Impact and abrasion resistance**
- ☑ **Fatigue resistance**
- ☑ **Fire resistance**
- ☑ **Crack control**

Dramix® Steel Fibers does not change these properties :

- ☑ Compressive strength
- ☑ Modulus of Elasticity
- ☑ Modulus of Rupture

MACCAFERRI

Great Place To Work. Certified

DESIGN THE CHANGE

Dramix® Steel Fibers reinforcement

Unique hooked ends, high tensile strength, and ductility.

Light Structural Requirements

Slabs – temperature and shrinkage crack control, flexural strength

Tensile Range : 1000 - 1200 N/mm^2

Strict Serviceability Requirements

Heavy duty slabs and pavements
Composite slab diaphragms
Jointless floors
Lightly reinforced floors

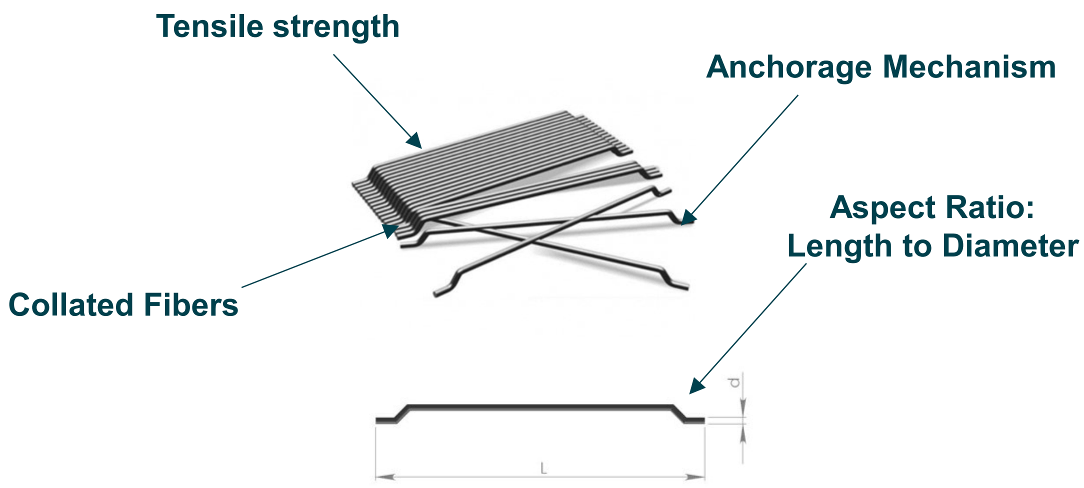
Tensile Range : 1650 - 1800 N/mm^2

Structural Reinforcement

Floors on piles
Structural mats
Structural members

Tensile Range : 2300 N/mm^2

4 FACTORS INFLUENCE THE PERFORMANCE OF STEEL FIBERS IN SFRC



INTEGRATION IN CONCRETE BATCHING PLANT

Utilization of dosing machine

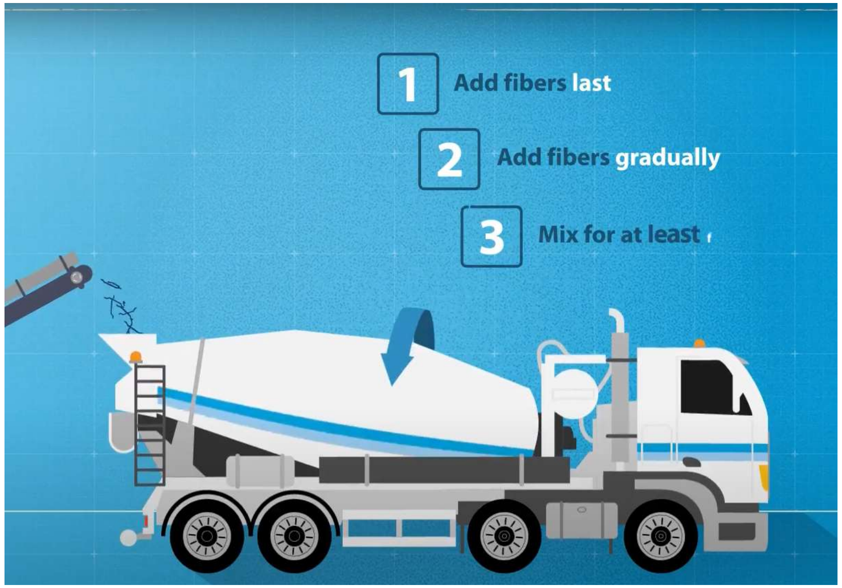
Concrete Batching Plant
(photo taken from gharpedia.com)

Steel fibre doser machine /
aggregate bin

DIRECT POURING IN CONCRETE MIXER

Traditional concrete mixing process

Concrete Batching Plant
(photo taken from gharpedia.com)



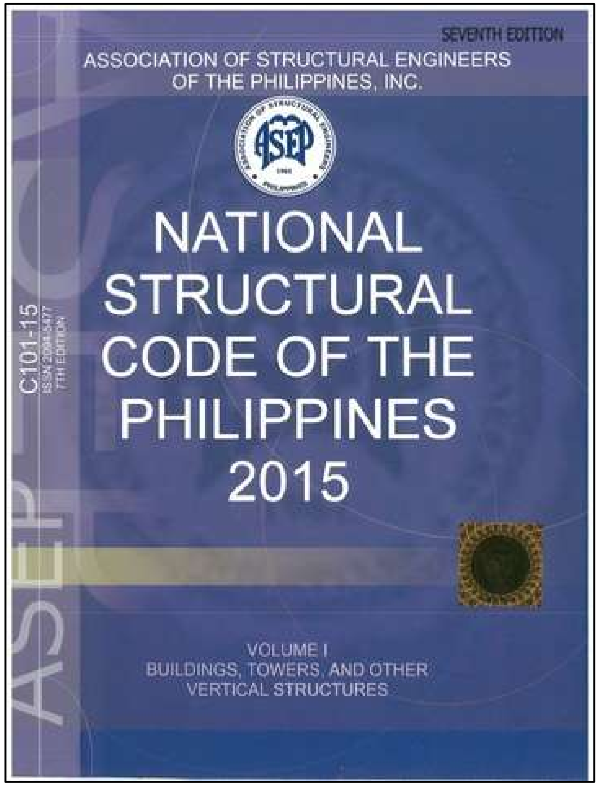
Mixing of steel fibres in concrete mixer

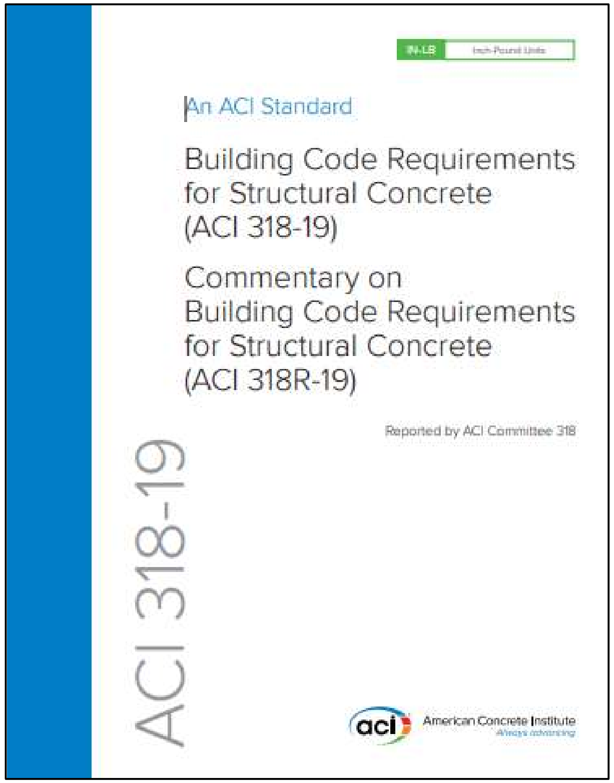
TOPIC OUTLINE

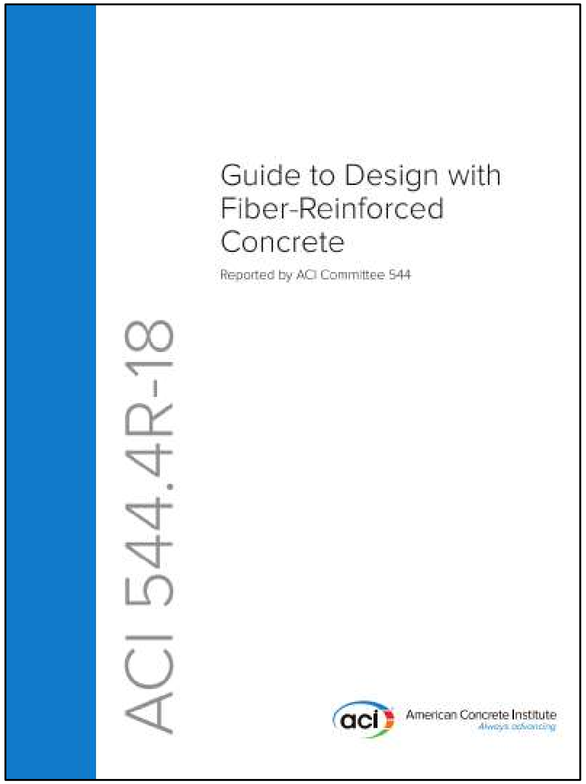
- MICROSTRUCTURE OF CONCRETE
- INTRODUCTION TO STEEL FIBER REINFORCED CONCRETE (SFRC)
- **DESIGN APPROACH FOR SFRC**

National Structural Code of the Philippines

American Concrete Institute - ASTM







GOVERNING DESIGN CONSIDERATIONS : CODES

ACI 544: ***Guide to Design with Fiber Reinforced Concrete (US)***

SS 812310 (2014) : *Fibre Concrete – Design of Fibre Concrete Structure* (Swedish)

DafStb (2015) : *Steel fibre reinforced concrete (German)*

Model Code 2010 (fib 2013) : *Final draft of the basis for future code (International)*

NZS3101 (2006) : *Concrete Structure Design (New Zealand)*

SS 674:2021 : Fibre concrete – Design of fibre concrete structures (Singapore)

DESIGN CONSIDERATIONS : TEST STANDARDS

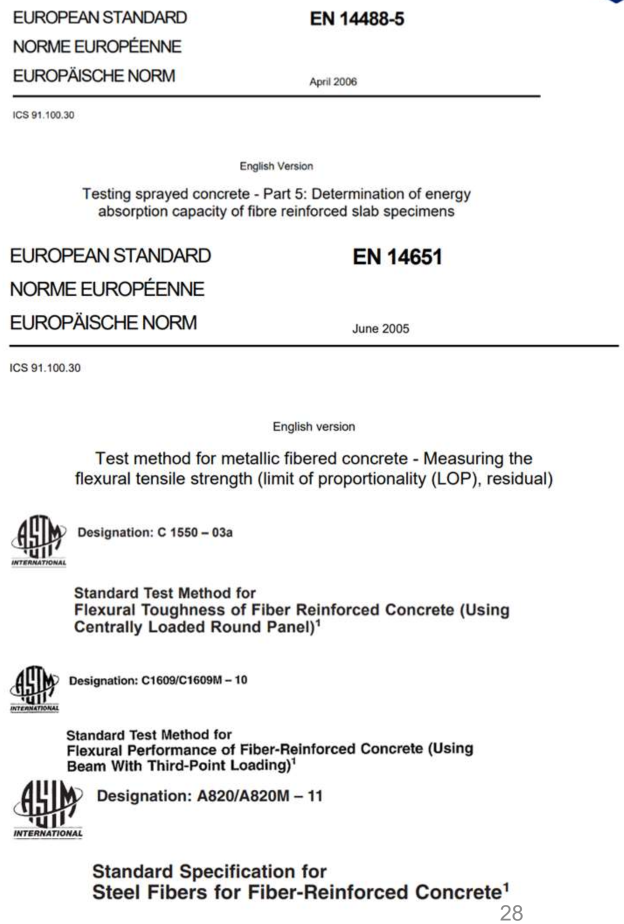
ASTM A820 – 11 *Standard Specification for Steel Fibers for Fiber-Reinforced Concrete*

BS EN 14651 : 2005 *Test method for metallic fibered concrete – Measuring the flexural tensile strength (limit of proportionality (LOP), residual)*

ASTM C1609 - 10 *Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading)*

BS EN 14488: 2006 *Testing sprayed concrete – Determination of energy absorption capacity of fiber reinforced slab specimens PRIMARY*

ASTM C1550 – 03A *Standard Test Method for Flexural Toughness of Fiber Reinforced Concrete (Using Centrally Loaded Round Panel)*


EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 14488-5

April 2006

ICS 91.100.30

English Version

Testing sprayed concrete - Part 5: Determination of energy absorption capacity of fibre reinforced slab specimens

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 14651

June 2005

ICS 91.100.30

English version

Test method for metallic fibered concrete - Measuring the flexural tensile strength (limit of proportionality (LOP), residual)

Designation: C 1550 – 03a

Standard Test Method for
Flexural Toughness of Fiber Reinforced Concrete (Using Centrally Loaded Round Panel)[1]

Designation: C1609/C1609M – 10

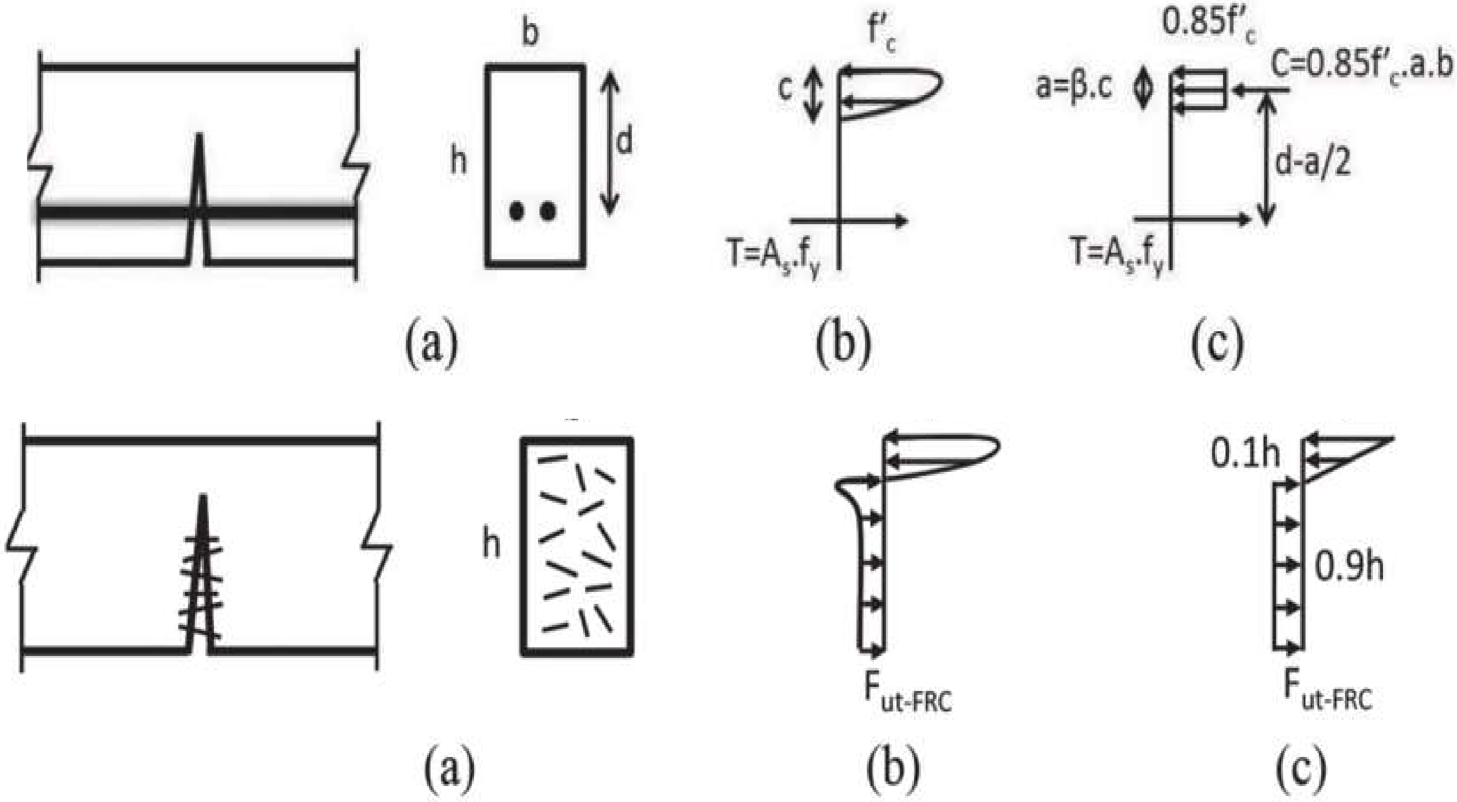
Standard Test Method for
Flexural Performance of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading)[1]

Designation: A820/A820M – 11

Standard Specification for
Steel Fibers for Fiber-Reinforced Concrete[1]

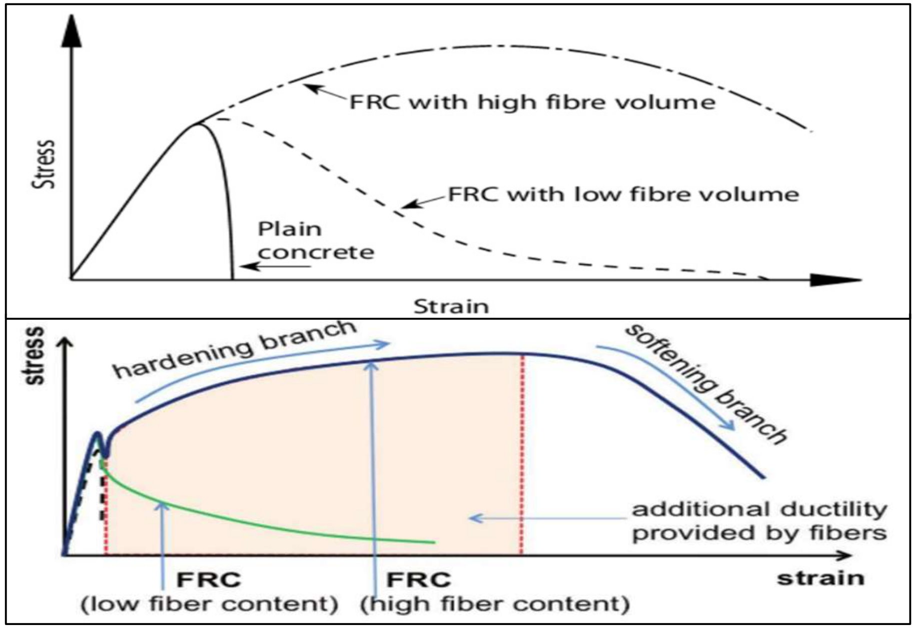
Design of FRC for flexure (ASTM C1609/C1609M)

RILEM TC 162-TDF 2003



ACI 544.4R Guide to Design with Fiber-Reinforced Concrete

Reported by ACI Committee 544

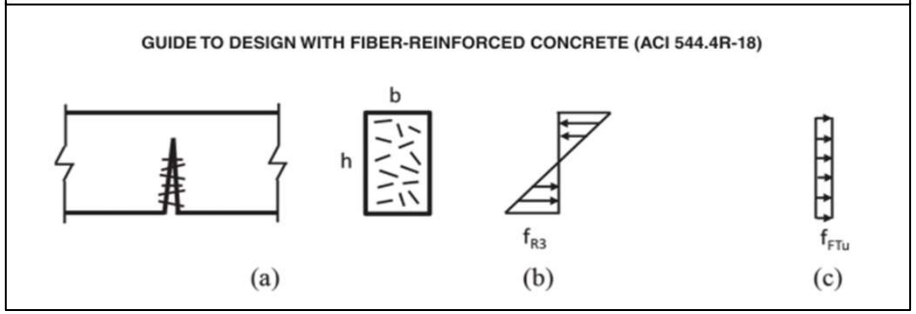


ACI 544.4R Section 3.4 Fiber contribution to tensile/flexural performance, obtained from flexural test, showing softening and hardening behaviors.

Using rigid-plastic model (for ULS only):

$$f_{Ftu\text{-}FRC} = \frac{f_{R,3}}{3}$$

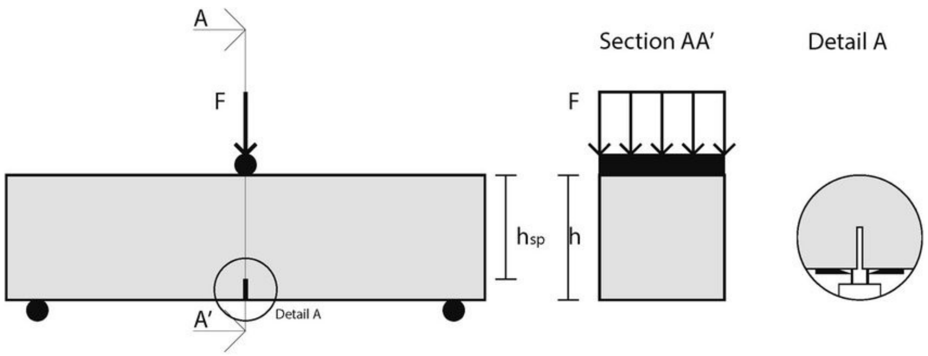
$$M_{nu\text{-}FRC} = f_{R,3} \cdot \frac{bh_{sp}^2}{6}$$

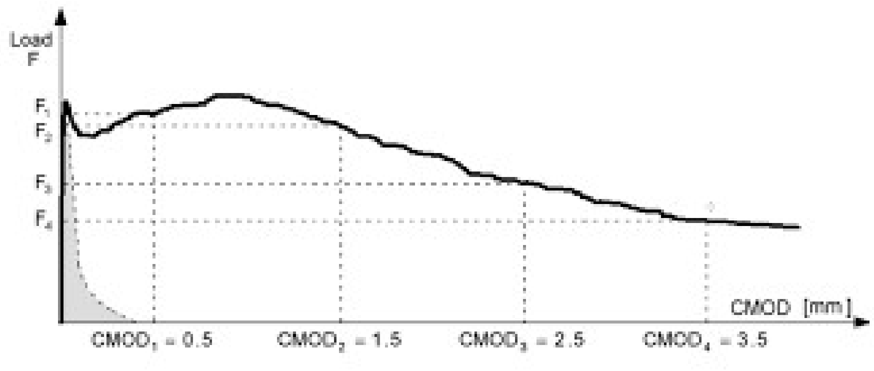


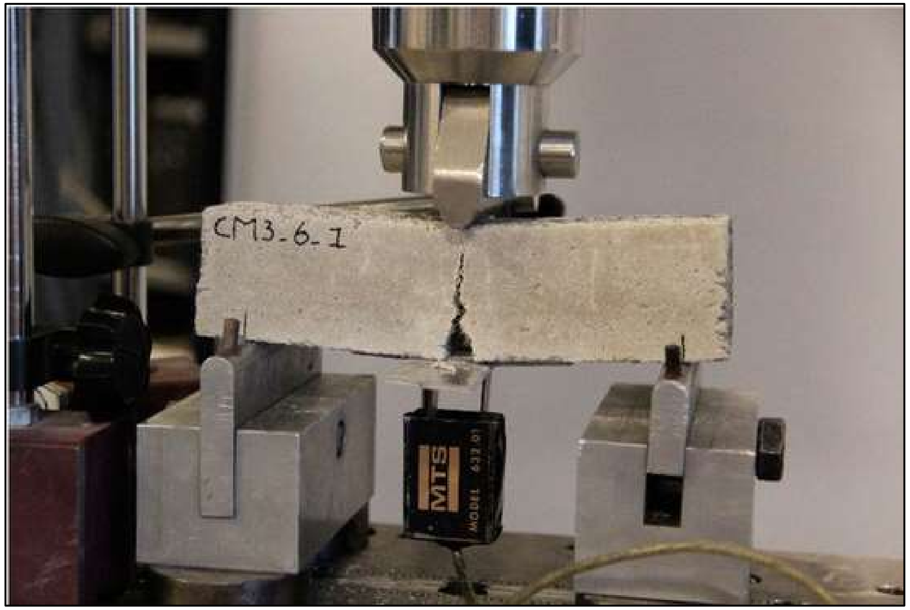
ACI 544.4R Section 4.6 Schematics of stress block for a cracked SFRC flexural member

Dramix® Steel Fibers Performance – Flexural Tensile Strength

Test method for metallic fibered concrete - Measuring the flexural tensile strength (limit of proportionality (LOP), residual)





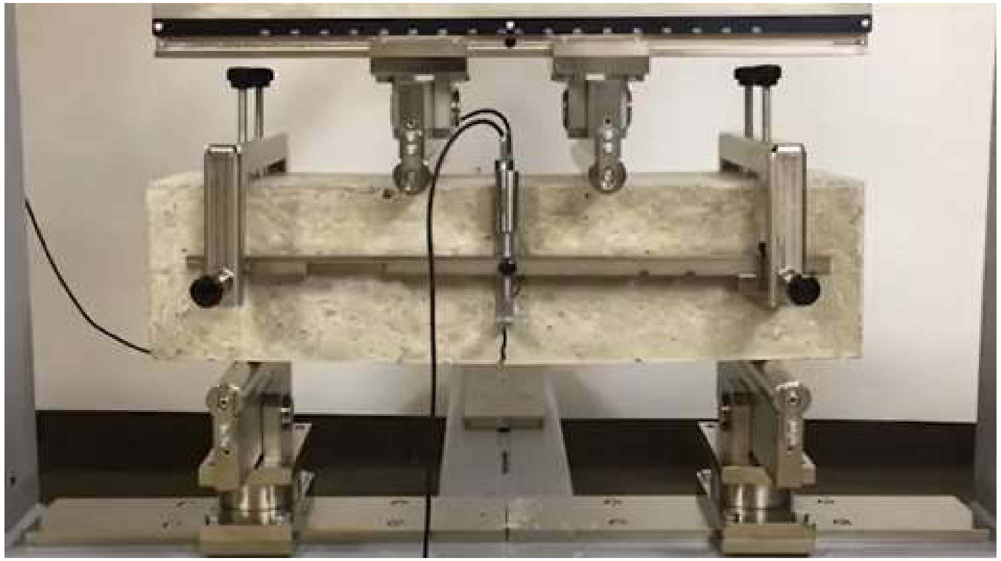


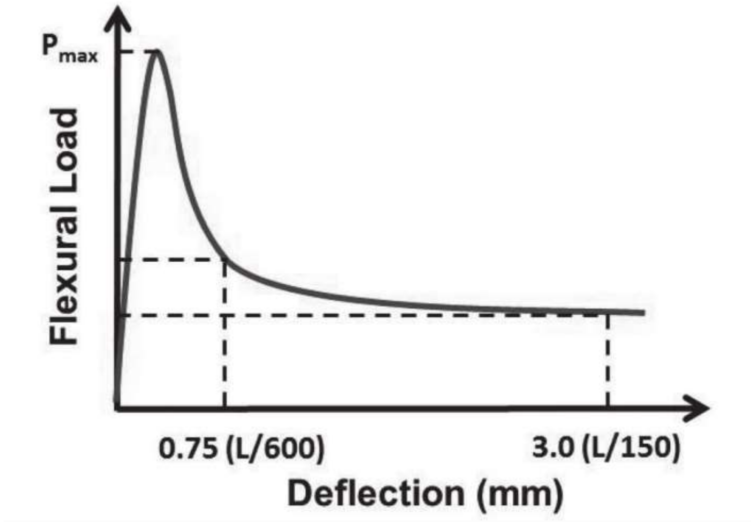
EN 14651

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

Flexural Behavior of FRC Beams to ASTM C1609

Flexural strengths (first peak, ultimate and residual) of fiber reinforced beam specimens





THANK YOU!

Jan Patrick D. Reboredo
j.reboredo@maccaferri.com

Maccaferri Philippines, Inc.

11/F, Asian Star Building, 2404
ASEAN Drive Filinvest City, Alabang,
Muntinlupa City 1781, Philippines

T: +63-2-8889 0623
E: info.ph@maccaferri.com

www. maccaferri.com

Maccaferri
Maccaferri World
Maccaferri World
@maccaferriworld
@maccaferriworld