Concrete is relatively brittle, and its tensile strength is typically only about one tenth of its compressive strength. Regular concrete is therefore normally reinforced with steel reinforcing bars. For many applications, it is becoming increasingly popular to reinforce the concrete with small, randomly distributed fibers. Their main purpose is to increase the energy absorption capacity and toughness of the material, but also increase tensile and flexural strength of concrete.
**FRC - Historical Perspective**

- BC horse hair
- 1900 asbestos fibers, Hatscheck process
- 1920 Griffith, theoretical vs. apparent strength
- 1950 Composite materials
- 1960 FRC
- 1970 New initiative for asbestos cement replacement
- 1970 SFRC, GFRC, PPFRC, Shotcrete
- 1990 micromechanics, hybrid systems, wood based fiber systems manufacturing
- techniques, secondary reinforcement, HSC ductility issues, shrinkage crack control.

**Areas of Application of FRC materials**

- Thin sheets
- shingles
- roof tiles
- pipes
- prefabricated shapes
- panels
- shotcrete
- curtain walls
- Slabs on grade
- precast elements
- Composite decks
- Vaults, safes.
- Impact resisting structures
Concrete Technology

Fiber-Reinforced Concrete

Fiber-Reinforced Concrete (FRC)

- Concrete containing a hydraulic cement, water, fine or fine and coarse aggregate, and discontinuous discrete fibers is called fiber-reinforced concrete (FRC).
- It may also contain pozzolans and other admixtures commonly used in conventional concrete.
- Fibers of various shapes and sizes produced from steel, plastic, glass, and natural materials are being used; however, for most structural and nonstructural purposes, steel fiber is the most commonly used of all the fibers.

Fiber-Reinforced Concrete (FRC)

- There is considerable improvement in the post-cracking behavior of concretes containing fibers. Although in the fiber-reinforced concrete the ultimate tensile strengths do not increase appreciably, the tensile strains at rupture do.
- Compared to plain concrete, fiber-reinforced concrete is much tougher and more resistant to impact.
Fiber-Reinforced Concrete (FRC)

- The steel fibers of different shapes and sizes are shown below:

Typical fiber types used in concrete: (a) straight, smooth, drawn wire steel fibers; (b) deformed (crimped) wire steel fibers; (c) variable-cross-section steel fibers; (d) glued bundles of steel fibers with crimped ends.
Fiber-Reinforced Concrete (FRC)

- Typical load-deflection curves for plain concrete and fiber-reinforced concrete are shown below:

  ![Load-Deflection Curve](image)

  **Area under the curve = Toughness**

  **Concrete Technology**

Fiber-Reinforced Concrete (FRC)

- Plain concrete fails suddenly once the deflection corresponding to the ultimate flexural strength is exceeded; on the other hand, fiber-reinforced concrete continue to sustain considerable loads even at deflections considerably in excess of the fracture deflection of the plain concrete.
Fiber-Reinforced Concrete (FRC)
- Examination of fractured specimens of fiber-reinforced concrete shows that failure takes place primarily due to fiber pull-out or debonding. Thus unlike plain concrete, a fiber-reinforced concrete specimen does not break immediately after initiation of the first crack.
- This has the effect of increasing the work of fracture, which is referred to as toughness and is represented by the area under the load-deflection curve.
- In FRC crack density is increased, but the crack size is decreased.

Fiber-Reinforced Concrete (FRC)
- The failure mechanism is by pull-out.
- you never exceed the tensile strength of the fiber. Bond is much weaker.
- Steel fiber in terms of durability is the best.
- The addition of any type of fibers to plain concrete reduces the workability.
- Concrete mixtures containing fibers posses very low consistencies; however, the placeability and compactability of concrete is much better than reflected by the low consistency.
Fiber-Reinforced Concrete (FRC)

Strength
- The most important contribution of fiber-reinforcement in concrete is not to strength but to the flexural toughness of the material.
- When flexural strength is the main consideration, fiber reinforcement of concrete is not a substitute for conventional reinforcement.
- The greatest advantage of fiber reinforcement of concrete is the improvement in flexural toughness (total energy absorbed in breaking a specimen in flexure).

Durability
- Fiber-reinforced concrete is generally made with a high cement content and low water/cement ratio.
- When well compacted and cured, concretes containing steel fibers seem to possess excellent durability as long as fibers remain protected by cement paste.
- Ordinary glass fiber cannot be used in portland cement mortars and concretes because of chemical attack by the alkaline cement paste.
Fiber-Reinforced Concrete (FRC)

- Mix Proportions:
  - High cement content
  - W/R admixtures (superplasticizers)
  - small MSA
  - Fibers (1-2% by volume)

- Properties:
  - Workability: tougher

- The $f'_c$ in compression and tension is not increased much.
- Fibers do not do anything to stop the first crack, it slows down the propagation of cracks.
- Toughness of material can be increased (15-30%)
- Creep results don't show much difference.
- Drying shrinkage show some difference.
- They use it for cavitation damage.
Fiber-Reinforced Concrete (FRC)

- Aspect Ratio = Length / Diameter
- Aspect ratio = \( l/d \) \( \uparrow \) 50 - 100
- For steel:
  - \( d = 0.01 \) in.
  - \( l = 1" \)
- Typical aspect ratios range from about 30 to 150.
- Maximum usage: 2% by volume.

Fiber-Reinforced Concrete (FRC)

- Polymeric and synthetic fibers alter the energy absorption properties of the composites significantly.
- Uniform fiber distribution at various size scales improves composite
- Small microfibers stabilize the microcracks and increase the strength – reducing the porosity of the cement paste as well increases the strength.