# An Overview of Fiber Reinforced Concrete, FRC and Fibers Properties and Current Applications

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**Abstract:** ***This paper focuses on the state-of-the-art research that has been done on Fiber-Reinforced Concrete (FRC) that are currently used in different applications to improve the concrete performance and provide new solution for concrete common problems. FRC is continually developed and many researches regarding to the enhancement of the concrete performance and strength. The past few years, concrete is considered as the most consumed construction material and the need of the properties development is necessary to mitigate the common problems of concrete. Different types of fibers will be described and discussed in this paper in addition to comparing the different types regarding to their efficiency, workability and cost. Furthermore, the structural behavior and mechanical of different types of FRC are going to be discussed and investigated as well as the FRC mixture components and placing methods. The various applications of FRC and current practices in the field of concrete industry prove the efficiency of FRC, but with considering the cost and high quality level of implementation.***

**Keywords:** Structural Engineering, Fiber-Reinforced Concrete, FRC Composite, Future Technology, Concrete Strength, Concrete Cracks

## 1. Introduction

Since the discovery of cement and the first concrete mix, most construction projects used concrete as the best material alternative due its properties, workability and relatively low cost. Conversely, concrete has some undesired properties that require development of concrete mix to produce concrete that has better performance in the different loading conditions and extreme exposure. Brittleness is one of the most critical issues related to concrete efficiency and it needs more attention due its significant importance if any failure could happen. The relatively low tensile strength of concrete is the cause of concrete brittleness which is assumed to be 1/10 of its compressive strength.

Reinforced concrete with steel bars has better performance as a composite material that can work properly against the different types of stresses. Increasingly, concrete is reinforced with small, randomly distributed fibers for many application in the field of concrete works. These fibers are added in order to increase the energy absorption capacity and toughness of the material in addition to enhance the tensile strength of concrete. [1-8]

High-modulus fibers can be used to substitute, partially or totally, conventional reinforcement to enhance concrete toughness for structural applications. Early applications of fibers in concrete include horse hair and the addition of asbestos fibers (se figure 1) in 1900 to reinforce pottery, straw to mud bricks, to reinforce plaster and asbestos.

**Figure 1:** Asbestos fibers

Modern practices include the use of Glass Fibers Reinforced Concrete (GFRC), Polypropylene Fibers Reinforced Concrete (PPFRC), Fibers Reinforced Concrete Steel Fiber Reinforced Concrete (SFRC) and the development continues to the use of micromechanics, hybrid systems, wood based fiber systems manufacturing in 1990. By the beginning of the 21st century and later on, various new structural applications and products with integration to the codes are widely used. [9-14]

## 2. Types of Fibers

Concrete Reinforcing Fibers are produced from various materials in different shapes and sizes. A fiber is a small discrete reinforcing material produced from various materials like steel, plastic, glass, carbon and natural materials in various shapes and size. (ACI Committee 440, 2008). The first use of fibers in reinforced concrete has been dated to 1870's. [15-17]There are some common typical fibers are currently used, the following are some types of the fibers:

### 2.1 Steel Fibers

Concrete cracking behavior could be improved by the addition of reinforcing steel. The reinforcing bars are placed at the surroundings of the concrete cracks to prevent the occurrence of cracks or stop their propagation. When concrete is cracked, it fails to transmit tensile stresses, however the reinforcing steel transmits the tensile force through the crack. In plain concrete the tensile stress drops to zero in the crack, but in steel fiber concrete the tensile stress drops and the cracked cross section is still able to transmit the tensile forces by using the steel fibers.[18-23]Figure 2 shows some types of Steel Fibers.[20]

**Figure 2:** Types of steel fibers [20]

Steel fibers can increase:
- Ductility of concrete
- Energy absorption
- Shear resistance of concrete
- Concrete Stiffness

The following are some typical steel fiber types used in concrete:
- Straight, smooth, drawn wire steel fibers;
- Deformed (crimped) wire steel fibers;
- Variable-cross-section steel fibers;
- Glued bundles of steel fibers with crimped ends.

Figure 3 shows some types of steel fibers.

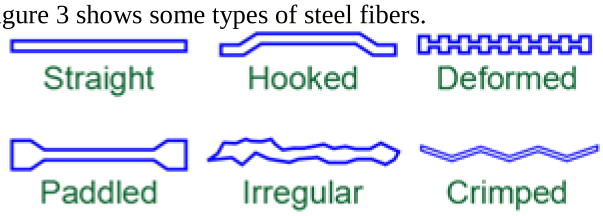


**Figure 3:** Typical steel fibers shapes

Round steel fibers are commonly used and they are produced by cutting round wire in to short length. The typical diameter lies in the range of 0.25 to 0.75mm. Steel fiber made from mild steel drawn wirewith the diameter of wire varying from 0.3 to 0.5mm. Round steel fibers are produced by cutting or chopping the wire. Deformed fiber, which are loosely bounded with water-soluble glue in the form of a bundle are also available. Since individual fibers tend to cluster together, their uniform distribution in the matrix is often difficult. This may be avoided by adding fibers bundles, which separate during the mixing process.[24-34]

There are some problems associated with the usage of steel fibers in concrete such as:
- Reducing the workability
- loss of workability is proportional to volume of fibers in concrete
- Higher Aspect Ratio results in reducing concreteworkability

### 2.2 Glass Fibers

Glass fibers are the most commonly used fibers for producing FRP composites. Glass fibers are made from molten glass spun from electrically heated platinum rhodium alloy bushings (or a furnace) at a speed of 200 mph.These filaments coolfrom a temperature of about 2300°F to room temperature within 10-5 seconds.Diameter ranges from 0.005 to 0.015mm (may be bonded together toform elements with diameters of 0.13 to 1.3mm). A protective coat is applied on individual filaments before they aregathered together into a strand and wound on a drum at speeds of up to 3.2 km per minute.A group of untwistedparallel strands wound in a cylindrical forming package is called a *roving*.[35-39]

The common types of glass fibers are:

a) Glass roving
b) Oven cloth roving
c) Bidirectional cloth
d) Chopped strand
e) Chopped strand mat
f) Braided glass fiber sleeve
g) Knitted glass fiber rope
h) Glass cloth
i) Woven glass cloth

Figure 4 illustrates the types of glass fibers mentioned above.

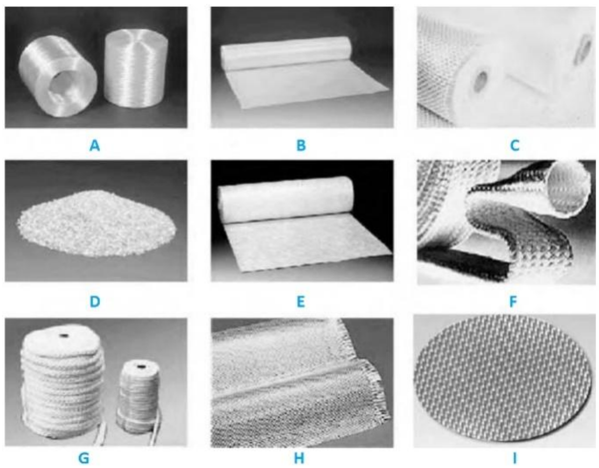


**Figure 4:** Types of glass fibers

There are some common types of commercial glass fibers, they are classified as the following types:
- **E glass:** E-glass is an Alumino-Borosilicate glass with a mass fraction of alkali ≤1 %, which is generally used in glass-reinforced. It has low alkali content and is the most common type of glass fiber in high-volume commercial

use. E-glass is used widely in combination with polyester and epoxy resins to form a composite. It is low susceptible to moisture and has high mechanical properties.

- **A glass:** It has high alkali content and is the most common type of glass fiber in high-volume commercial use. An alkali-lime glass with little or no addition of boron trioxide and a mass fraction of alkali ≥1 %, for special applications.
- **Z glass:** It is used for cement mortars and concretes due to its high resistance against alkali attack.
- **S glass:** It is an aluminosilicate glass without added calcium oxide but with a mass fraction of magnesium oxide of ca. 10 %
- **C-glass:** It is used for applications that require greater corrosion resistance to acids, such as chemical applications.

As a commonly used material in the recent years, glass fibers have many advantages and drawbacks, some of their advantages:

- It has low cost
- High tensile strength
- Higher resistance to chemicals;
- Glass insulation properties are excellent.

On the other hand, glass fibers have some drawbacks, such as:

- Low tensile modulus;
- Relatively High specific gravity;
- Sensitivity to abrasion from handling;
- High hardness;
- Relatively low fatigue resistance

Commercially available glass fibers have poor durabilityexcept acidic resistance and freeze-thaw resistance. They are notrecommendable for internal reinforcements. When glass fiber or is used as external reinforcements, care must be taken to the deterioration due to sustained load, fatigue load, alkali resistanceand ultra-violet rays and acidic environment must be considered.

### 2.3 Polypropylene Fibers

Polypropylene fibers (PP) are added to concrete to improve the strength and reduce spalling and cracking. Shape of PP fibers is shown in figure 5 below.

**Figure 5:** Shape of polypropylene fiber [48]

Although, PP fiber content increases flexural properties, there is no significant difference observed between 1% and 1.5%.[40-46]

On the other hand, PP fiber has some benefits when added to concrete such as:[47,48]

- Reducing the frequency of plastic cracking.
- Improving durability and reducing permeability.
- Decreasing the risk of plastic settlement cracking over reinforcement.
- PP fibers make concrete harder, and give more durable abrasion resistant surface of concrete.
- Improved flexural properties and enhance the resistance to spalling at higher temperatures and better fire resistance.

### 2.4 Carbon Fibers

Carbon fibers are a type of high-performance fiber available for structural engineering application. Carbon fiber consists of very thin strands of the element carbon. Carbon fibers have high tensile strength and are very strong for their size. In fact, carbon fiber might be the strongest material. Carbon fibers have high elastic modulus and fatigue strength than those of glass fibers. Considering service life, studies suggests that carbon fiber reinforced polymers have more potential than agamid and glass fibers. They also are highly chemically resistant and have high temperature tolerance with low thermal expansion. and corrosion resistance. [49-52]

Properties of carbon fiber:

- High Strength to Weight Ratio
- Very rigid
- Corrosion Resistant and Chemically Stable.
- Good resistant to fatigue.
- High Tensile Strength.
- High fire resistance as they are not flammable.
- Low coefficient of thermal expansion.

Tensile Strength of materials compare to Carbon Fibers are shown in table 1 in the next page.

**Table 1:** Tensile Strength of materials compare to Carbon Fibers

| *Material* | *Strength (MPa)* |
|---|---|
| Carbon steel 1090 | 3600 |
| Polypropylene | 19.7-80 |
| High density polyethylene | 37 |
| Stainless steel AISI 302 | 860 |
| Aluminum alloy 2014-T6 | 483 |
| E-Glass alone | 3450 |
| E-Glass in a laminate | 1500 |
| Carbon fiber alone | 4127 |
| Carbon fiber in a laminate | 1600 |

### 2.5 Natural Organic and Mineral Fibers

In addition to industrial fibers, natural organic and mineral fibers have been also investigated in reinforced concrete. [53-55]. Organic fibers are cheaper, because they are natural. Large volume of vegetable fiber may be used to obtain a multiple cracking composite. There are some types of natural fibers such as wood, asbestos, cotton, bamboo, and Rockwool. They come in wide range ofsizes. In some cases, the recycled carpet waste can be successfully used for concrete reinforcement by using the waste carpet fibers.See figure 6.


**Figure 6:** Natural Organic Fibers

FRC is classified according to the content of fibers as a percentage of the total volume of the concrete mix. The fibers content is an important factor in determining the behavior and the use of FRC in different applications. table 2 below gives the FRC classifications.

**Table 2:** Classification of FRC by Fibers content

| *Fibers Volume* | *Effects on Concrete* |
|---|---|
| *Low Volume < 1.00%* | Used in slab and pavement that have large exposed surface leading to high shrinkage cracking |
| *Moderate volume 1.00-2.00%* | Used in Construction method such as Shotcrete & in Structures which requires improved capacity against delamination, spalling & fatigue |
| *High volume 2.00%* | Used in making high performance fiber reinforced composites (HPFRC) |

The stress displacement relationship in concrete in accordance to fibers content added to concrete as percent of total volume is represented by the curve shown in figure 7 and fibers properties are shown in table 3 below.

**Table 3:** Typical Properties of Fibers used in concrete [54]

| Fiber | Diameter (μm) | Specific Gravity | Tensile Strength (GPa) | Elastic Modulus (GPa) | Fracture Strain (%) |
|---|---|---|---|---|---|
| *Steel* | 5–500 | 7.84 | 0.5–2.0 | 210 | 0.5–3.5 |
| *Glass* | 9–15 | 2.6 | 2.0–4.0 | 70–80 | 2.0–3.5 |
| *Fibrillated polypropylene* | 20–200 | 0.9 | 0.5–0.75 | 5–77 | 8.0 |
| *Cellulose* | — | 1.2 | 0.3–0.5 | 10 | — |
| *Carbon (high strength)* | 9 | 1.9 | 2.6 | 230 | 1.0 |
| *Cement matrix for comparison* | — | 2.5 | $3.7 \times 10^{-3}$ | 10–45 | 0.02 |

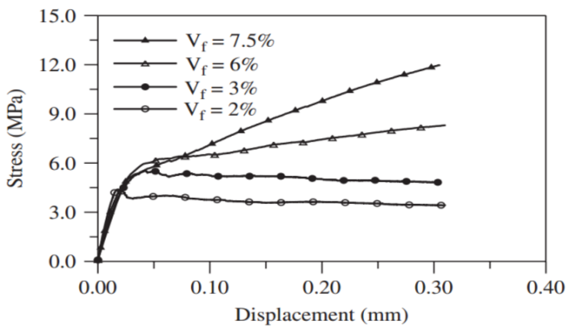


**Figure 7:** Tensile response of short steel fiber-reinforced concrete[55]

## 3. FRC Mixing, Placing and Finishing

Mixing of FRC can be carried out by various methods. The concrete mixture should have a uniform dispersion of the fibers in order to prevent segregation of the fibers while mixing. Most segregation occurs while addingfibers. Increase of aspect ratio, volume percentage of fiber, and size and quantity of coarse aggregate will increase the segregation tendencies and reduce the workability. To ensure coating of larger surface area of the fibers with cement paste, experience shown that a water to cement w/c ratio should be between 0.4 and 0.6, and the minimum cement content is to be not less than *400 kg/m*$^3$. Compared to regular concrete, FRC mixtures are generally characterized by higher cement factor, higher fine aggregate content, and smaller size coarse aggregate. FRC mixtures needs mechanical vibration to ensure the consultation of the mix. After concrete casting, FRC must be treated very well and finished appropriately using metal trowels and rotating power floats.

### 3.1 Mixing

ACI Committee 544.3R-08 recommends precautions such as: (ACI Committee 544 , Guide for Specifying, Proportioning, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete, 2008)

- Allow the project engineer to review and accept the equipment and methods used to add the fibers to the mix.
- Perform a full-scale trial at least 8 days before the first placement
- Do not allow fibers to pile up or slide down the blades of a partially filled drum.
- Do not use equipment with worn out mixing blades.
- Do not over mix, since this can cause wet fiber balls (composed of both fibers and the cement paste matrix)

### 3.2 Placing

FRC could be placed with the same conventional concrete equipment such as truck chutes, concrete buckets conveyors and pumps. All precautions used for conventional concrete must be taken into consideration so the equipment must be clean and in good conditions so the FRC can flow smoothly.

### 3.3 Finishing

Finishing FRC is similar to conventional concrete, but some additional procedures for finishing FRC should be considered while surface finishing of FRC such as:

- **Strike-off operations:** External vibration is useful to bring the paste to the surface and buries fibers located at the top surface so no fibers are exposed.
- **Bull-floating and straightening operations:** Wooden tools should not be used because they can tear the concrete surface. Also over work may bring the excessive fines of concrete to the surface which may result in concrete crazing. Timing of finishing of FRC does not differ from the conventional concrete.
- **Final floating operations:** Magnesium floats and power tools are used for final finishing. During power troweling pass, the steel fibers kicked out of the concrete surface by finishing blades. They should be removed from the surface of the slab before the next power troweling. The fibers should be kept from pulling up.
- **Saw-cutting:** All forms of saw-cutting equipment can be used with FRC at the correct timing.

## 4. FRC Characteristics

Concrete mechanical properties are influenced by the addition of fibers and that is significantly affected by the type and percentage of fibers. On the other hand, the fibers decrease the concrete workability.

The plain concrete fails suddenly when 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. (ACI Committee 440, 2008)

Mostly, fibers are added to concrete with small amounts ranging from 1-2% of the total volume of concrete and that does not increase the concrete compressive and tensile strength, however it enhances the other mechanical properties of concrete. Strength-Displacement relationship of FRC shown in figure 8 below.

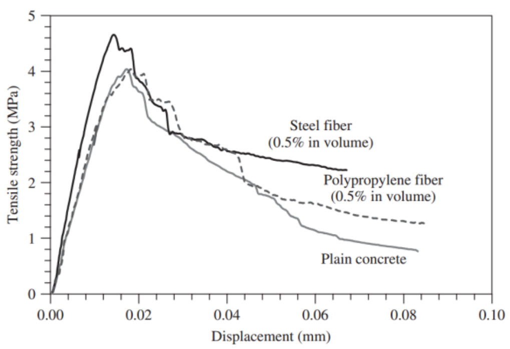


**Figure 8:** Load–displacement curves of FRC [54]

Investigating the effects of fibers on concrete priorities require studying the aspect ratio of fibers. The aspect ratio is defined as ratio of length of fiber to its diameter (L/d).

When the aspect ratio is increased up to 75, it results in increase ofrelative strength and toughness, but beyond 75 of aspect ratio there will be decrease in toughness.

When determining the mechanical properties of FRC, the same equipment and procedure as used for conventional concrete can also be used. The following are some properties of FRC that are influenced by fibers:

### 4.1 Modulus of Elasticity E

Modulus of elasticity of FRC increases slightly with an increase in the fibers content. It was found that for each 1 percent increase in fiber content by volume there is an increase of 3% in the modulus of elasticity.[56-61]Effects shown in figure 9 below.

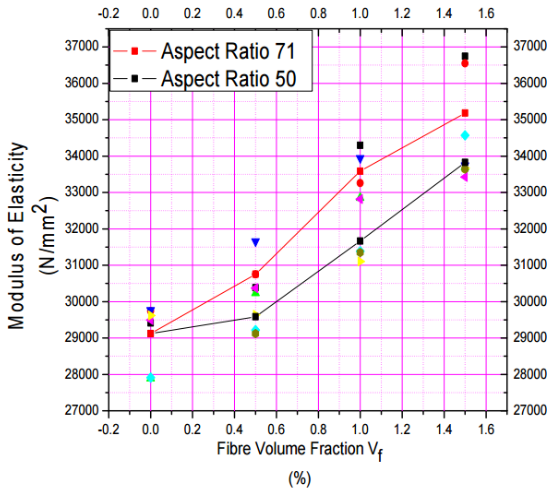


**Figure 9:** Effect of fiber volume fraction on the modulus of elasticity of SFRC at two different aspect ratios [60]

### 4.2 CompressiveStrength of Concrete

The main advantage of FRCimprovement is not to strength butto the flexural toughness of the material.When flexural strength is the main consideration, fiber reinforcement of concrete is not a substitute for conventionalreinforcement. Fiber reinforcement has sufficient strength and ductility to be used as a complete replacement to conventional steel bars in some types of structures; foundations, walls, slabs. For this to be a reality, the fibers must be distributed and oriented as expected, which is difficult. If fibers can be used without the need of steel reinforcement bars, the reinforcement part of the construction work will be eliminated. Hence, the construction costs will be significantly reduced.[62-68].Fibers effect on Compressive Strength are show in figure 10.

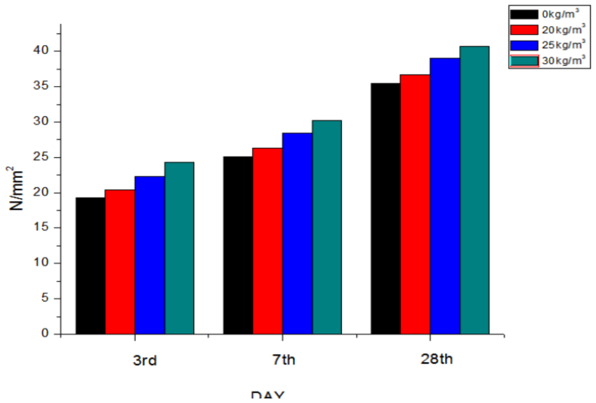


**Figure 10:** Fibers effect on Compressive Strength [64]

### 4.3 Flexural Strength of Concrete

FRC has higher toughness when compared to plain concrete and there is considerable improvement inthe post-cracking behavior ofconcretes containing fibers. Althoughin the fiber-reinforced concrete theultimate tensile strengths do notincrease appreciably, the tensile strains at rupture do. In addition, FRC continue to sustain considerable loads even at deflections considerably in excess of the fracture deflection of the plain concrete. In FRC, cracks density is increased, but the cracks size is decreased due to the exciting of fibers, so initial cracks are not prevented but the cracks propagation is slowed down by the fibers.[69-74]

The fibers do not fail under their ultimate tensile strength, because the bond is much weaker and it causes the splitting of fibers in FRC. Table 4 summarize impacts of fibers on concrete properties.

### 4.4 Fatigue Strength

Addition of fiber to conventionally reinforced beams increased the fatigue life and decreased the crack width under fatigue loading. SRFC has high fatigue strength resistance to impact, blast and shock loads. Fatigue strength can be increased by inclusion of macro-fiber in concrete. Essentially, it is the ability of concrete to withstand under cyclic load without failure when exposed to a load. Plain, un-reinforced concrete, when subjected to a bending load, will withstand that load with very little movement until the cyclic load exceeds its fatigue strength. [75-78]

### 4.5 Durability of Concrete

Fiber-reinforced concrete is generally madewith a high cement content and low water to cement (W/C) ratio.

When well compacted and cured, concretescontaining steel fibers seem to possessexcellent durability as long as fibers remainprotected by cement paste.

The addition of fibers increases fatigue strength of about 90% and 70% of the static strength at 2 x $10^6$cycles for non-reverse and full reversal of loading, respectively. [79-83]

**Table 2:** Improvement in the properties of fiber reinforced concrete [79]

| Property | | | Maximum improvement over plain concrete % | Optimum fiber parameters | |
|---|---|---|---|---|---|
| | | | | Volume function Vf | Aspect Ratio l/d |
| Compressive strength at failure (M20 mix) | | | 25 | 1.5 | - |
| Tensile strength (Direct) | | | 45 | 1.0 | 80 |
| Tensile Strength (Split Cylinder) | 40 | 1.5 | 80 | | |
| Modulus of Elasticity | 15 | 1.5 | 80 | | |
| Ultimate Strain | 300 | - | - | | |
| Flexural Strength At first crack | 40 | 1.5 | 80 | | |
| Flexural Strength tensile strain | 100 | - | - | | |
| Flexural Strength At failure | 60 | 1.5 | 80 | | |
| Flexural Strength tensile strain | 20 to 50 times | - | - | | |
| Modulus of Rupture | 10 | | | | |
| Energy Absorption | 500<br>1000 | 1.5<br>2.5 | 80<br>100 | | |

## 5. FRC Applications

FRC has many applications including different uses in industry. In construction field, FRC is mainly used for special requirements for concrete mix. The properties of concrete mix are important to the final results and performance of concrete elements such as slabs and pavement…etc.

FRC is also used in repairing and strengthening exciting structures using carbon fibers or other additives to concrete to have better performance of concrete for specific situations. Some applications of FRC are mentioned below:

### 5.1 SRF Shotcrete

Steel fiber-reinforced shotcrete (SFRS) is shotcrete (spray concrete) with steel fibers added. It has higher tensile strength than unreinforced shotcrete and is quicker to apply than weld-mesh reinforcement. It has often been used for tunnels. SFR Shotcrete is commonly used in Tunnels lining with short steel fibers and industrial floorings with long steel fibers. The addition of steel fibers into the concrete improves the crack resistance capacity of the concrete. [84-87]. Traditional steel bars are generally used to improve the tensile strength of the concrete in a particular direction, whereas steel fibers are useful for multidirectional reinforcement. This is one of the reasons why steel fiber reinforced shotcrete successfully replaced weld-mesh in lining tunnels. See figure 11

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**Figure 11:** Steel fiber-reinforced shotcrete (SFRS) [93]

### 5.2 FRC in Precast Concrete

FRC is used in precast concrete to improve the properties of precast elements used in different structures. Carbon fibers are used in precast concrete and started quantity-production from 2003. Now it is a very common material for precast elements in the USA and around the world. [88-91]

The carbon fibers are used to reduce the corrosion in precast concrete since it will not oxidize. In addition to the reduction in the amount of concrete cover and concrete weight generally. Another advantage of using carbon fibers in precast concrete is to improve the thermal efficiency, as the carbon fibers do not conduct heat or cold from outside. FIG. 12 below.


**Figure 12:** Segmental tunnel lining using steel-fiber-reinforced concrete [93]

Steel Fibers are also commonly lining to replace the conventional steel bars for small moments, as well as polypropylene fibers are added to enhance fire resistance of concrete segments.

### 5.3 Pipes and Pipeline trench

More efficient crack control is achieved using steel-fiber-reinforced concrete than with mesh because the first crack load is increased with fibers and at maximum load the crack width is typically smaller than it is for traditional reinforcement at similar loads.

GFRC is used for pipeline trench as box pads support electrical cabinets (FIG. 13). GFRC is used because of its strength and slenderness made the pads easy to handle. The impact strength of GFRC has a benefit in protecting the pads from damaging of cracking if dropped. [92-95]


**Figure 13:** GFRC pipeline trench application[93]

### 5.4 Repairs and Rehabilitation of Structures

Steel Fiber Reinforced Concrete SFRC is used for rehabilitation and repairing of marine structures such as concrete piling and caissons.

It shows good performance against severe conditions exposure to water and erosion. In addition, Repairs and new construction on major dams and other hydraulic structures to provide resistance to cavitation and severe erosion caused by the impact of large waterborne debris. (ACI Committee 544, 2002) See FIG. 15 in the next page.

### 5.5 Reinforcing and Strengthening of Concrete Structures by Carbon Fibers

Carbon fibers are used for reinforcing concrete members to increase its load capacity or to strengthen the weak, damaged, deflected or cracked members.

Strengthening using carbon fibers allows to avoid interference to the initial structure. Carbon fibers can be used for strengthening holes and cuts in the slabs and beams. Carbon fibers are used in the direction of tensile stresses. (see figure 14)


**Figure 14:** Fiber Reinforced Shotcrete in underground structures[94]

**Figure 14:** Concrete strengthening by carbon fibers[95]

Carbon Fiber Reinforced Polymer (CFRP) has over the past two decades become an increasingly recognized material used in structural engineering applications. Used with increasing effectiveness since their introduction in the aero-space industry in the early 1960's, composite materials offer a number of distinctive advantages for structural strengthening.

Retrofitting of concrete structures has become an increasingly dominant use of the material in structural engineering applications. Such uses include increasing the load capacity of existing structures (such as existing parking garages) that were designed to tolerate far lower service loads. Other uses include seismic retrofitting, and repair of damaged concrete structures. Retrofitting with CFRP in many instances can be a cost-effective method of structural concrete strengthening. CFRP is also widely used to strengthen concrete structures that have lost reinforcing steel mass due to corrosion and concrete deterioration.(Schnell Contractors, Inc., 2017)

Future researches could be dedicated to enhance the properties of FRC by testing new fibers with good performance and low cost and natural resources or recycled materials. In addition to the techniques of mass production of FRC and factors effecting the properties of FRC while production or placing processes.

## 6. Conclusions

Conventional concrete has limited ductility, low impact and abrasion resistance and little resistance to cracking because concrete has better resistance in compression while steel has more resistance in tension.

To improve the post cracking behavior, short discontinuous and discrete, fibers are added to the plain concrete with certain amounts and specification.

Addition of fibers improves the post peak ductility performance, pre-crack tensile strength, fracture strength, toughness, impact resistance, flexural Strength resistance, fatigue performance etc.

The ductility of fiber reinforced concrete depends on the ability of the fibers to bridge cracks at high levels of strain.

The total energy absorbed in FRC area under the load-deflection curve is at least 10 to 40 times higher for fiber-reinforced concrete than that of plain concrete.

Addition of fiber to conventionally reinforced beams increased the fatigue life and decreased the crack width under fatigue loading.

FRC has many applications when special properties of concrete are required. Strengthening concrete by carbon fibers and using different types of fibers such as steel, nylon and polypropylene fibers in concrete used in some structures such as pipes and precast concrete.

Ratio of fibers to total volume has direct effects on concrete properties as well as the aspect ratio of fibers. Fibers are produced from various sources and added to concrete as per standards and codes related to FRC specifications and applications.

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