

2. Literature Review

2.1 Fiber Reinforced Concrete

2.1.1 Introduction of Fiber Reinforced Concrete

Concrete is the most widely used material among construction materials due to its superior strength and durability (Koo et al., 2014). Generally, it is strong in compression and weak in tension (Johan, 2004). Concrete is very brittle in nature with the consequent low crack resistance which have limited its use only to absorbing compressive stresses. The idea of adding additives to concrete to improve its strength have been employed for many centuries. Concrete additives have been used since Roman and Egyptian times, when it was discovered that adding volcanic ash to the mix allowed it to set underwater, while adding horse hair made concrete less liable to crack and the adding of blood made it more frost-resistant. Conventional concrete has limited ductility, low impact and abrasion resistance and little resistance to cracking.

A good concrete must possess high strength and low permeability. Hence, alternative composite materials are gaining popularity because of ductility and strain hardening. To improve the post cracking behavior, short discontinuous and discrete fibers are added to the plain concrete.

Addition of fibers improves the post peak ductility performance, pre-crack tensile strength, fracture strength, toughness, impact resistance, flexural strength resistance, fatigue performance etc. More recent days additives started with asbestos until its cancer-related hazards were discovered. In the most recent times, many methods have been adopted to improve concrete properties, and one of such methods is the addition of fibers to concrete which have proved useful to controlling crack growth by inhibiting plastic and drying shrinkage from taking place thereby

reducing the permeability of concrete (Anthony and Abimbola, 2014; Anthony and Joshua, 2014).

Fiber is a small piece of reinforcing material possessing certain characteristics properties. They can be circular, triangular or flat in cross-section (Amit, 2013). It has been recognized that the addition of small Fiber, closely spaced and uniformly dispersed fibers to the concrete would act as crack arrester and would substantially improve its Compressive and flexural strength properties (Mr. Nikhil and Vidhale 2013).

Reinforcing the concrete structures with fibers is one of the possible ways to provide all the criteria of the durable repair material. This type of reinforcement is known as fiber reinforced concrete (R. Brown *et al.*, 2002).

It is significantly improves the crack control as it reduces the crack widths and crack spacing in the concrete which in turn reduces the ingress of water and chemicals that are known to be harmful to concrete thereby improving the long term serviceability and durability of built structures (Anthony and Abimbola, 2014). The reduction of crack growth through the adoption of fibers is a comforting news to the building industry as many infrastructures are beginning to age. This is of particular importance as infrastructures deteriorate and the built environment is grossly unable to sustain the service lives originally planned for most structures (Wang *et al.*, 1987).

• **Definitions of Fiber Reinforced Concrete (FRC)**

Fiber-reinforced concrete (FRC), sometimes called fibrous concrete, is defined by the American Concrete Institute as concrete containing dispersed randomly oriented fibers. Fibers are defined by the American Society of Testing and Materials (ASTM) as slender and

elongated filaments in the form of bundles, networks or stands of any natural or manufactured material that can be distributed throughout freshly mixed concrete (NPCA Fibers White Paper-National Precast Concrete Association, 2016).

The term fiber reinforced concrete (FRC) is defined by ACI Committee 544 as a concrete made of hydraulic cements containing fine and coarse aggregates and discontinuous discrete (James *et al.*, 2002).

Fiber reinforced concrete (FRC) is concrete made primarily of hydraulic cements, aggregates, and discrete reinforcing fibers (Brown *et al.*, 2002; James *et al.*, 2002). It is a cement-based composite material reinforced with randomly distributed fibers which have many shapes and sizes, produced from steel, synthetics, glass, and natural materials (Anette *et al.*, 2008). In FRC, thousands of small fibers are dispersed in the concrete during mixing, and thus improve concrete properties in all directions (R. Brown *et al.*, 2002).

Fibers are discontinuous and randomly distributed throughout the concrete matrix. This means they can distribute tensile stresses throughout the concrete better than conventional reinforcement. However, they may not handle the concentrated tensile forces of primary reinforcement and therefore proof of design testing should be performed to ensure the concentrated tensile forces can be handled. Fibers affect concrete on a more localized level, such as a small fraction of the concrete member. Conventional reinforcement affects the global capacity of the concrete.

Fibers are added during mixing, therefore they are usually easier to place and require less labor than conventional reinforcement (NPCA Fibers White Paper - National Precast Concrete Association, 2016).

- **History Background of Fiber Reinforced Concrete**

Since ancient times (BC), fibers have been used to reinforce brittle materials. Straw and horse Hair was used to reinforce sun-baked bricks, and horsehair was used to reinforce masonry mortar and plaster (James *et al.*, 2002).



Figure (3): Straw and horse Hair was used to reinforce old sun-baked bricks (James *et al.*, 2002).

A pueblo house built around 1540, believed to be the oldest house in the U.S., is constructed of sun-baked adobe reinforced with straw (James *et al.*, 2002). At 1900 asbestos fibers, Hatcheck process, and then composite materials discovered at 1950 (Kamran, 2015).

The concept of using fibers to improve the characteristics of construction materials is very old. Early applications include addition of straw to mud bricks, horse hair to reinforce plaster and asbestos to reinforce pottery. Use of continuous reinforcement in concrete (reinforced concrete) increases strength and ductility, but requires careful placement and labor skill. Alternatively the modern development of fiber reinforced concrete (FRC) started in the early sixties (Ramualdi, J.P and Batson, 1983; Fisal, 1990).

Historically there have also been used many types of fibers of natural origin in buildings. One of these is asbestos in 1970. Asbestos was used as reinforcement in fiber cement wallboards (eternite or asbestos cement) in the middle of the last century. This is forbidden today because the substance is carcinogenic (Ane, 2012).

Since 1970 SFRC, GFRC, PPFRC shown the light during seventies the commercial use of this material began to increase, particularly in Europe, Japan and USA (Clarke *et al.*, 2007). In 1990 micromechanics, hybrid systems, wood based fiber systems manufacturing techniques, secondary reinforcement, HSC ductility issues, shrinkage crack control. Further 2000 Structural applications and new products (Kamran, 2015).

For over half a century, extensive researches were undertaken to determine the appropriate qualities of fibers needed for various applications. The qualities of fibers needed for fiber reinforced concrete has been one of the major topics of interest because of the importance of concrete to the construction industries. Considerable research, development, and applications of FRC are taking place throughout the world. Industry interest and potential business opportunities are evidenced by continued new developments in fiber reinforced construction materials.

• Advantages and Disadvantages of Fiber Reinforced Concrete

Fiber reinforced concrete has started to find its place in many areas of civil infrastructure applications where the need for repairing, increased durability arises. Also FRCs are used in civil structures where corrosion can be avoided at the maximum. In addition, fibers reduce or relieve internal forces by blocking microscopic cracks from forming within the concrete (R. Brown *et al.*, 2002).

FRC having the equivalent strength of thicker plain concrete sections. When used in bridges it helps to avoid catastrophic failures. Also in the quake prone areas the use of fiber reinforced concrete would certainly minimize the human casualties.

Fibers benefit concrete by two primary means. First, fibers are strong in tension, in some cases as much as 10 times that of reinforcing steel. Second, fibers are distributed throughout a concrete matrix, which essentially means, fibers can benefit the entire concrete member. Of course, these are both dependant on many things including type, size, aspect ratio and concentration of the fibers as well as the mixture proportions of the concrete in almost all instances, in order for fibers to be effective, stress must transfer from the concrete into the fiber. This is achieved through bond, the same way it is achieved with conventional reinforcing steel. Bond is developed through physical deformations, such as crimping or texturing of the fibers, fiber geometry, aspect ratio and the orientation of the fibers within the concrete.

Fibers can improve cracking resistance. As concrete cracks, stress transfers into the fibers. The fibers essentially bridge the cracks, holding the concrete together. The stress is then redistributed into the surrounding area. Typically, fibers reduce the size of the cracks thereby increasing the durability of the concrete. This is very beneficial where shrinkage cracks or handling stresses are of concern. Without fibers, cracks may become large and allow moisture and chemicals quick access to the interior of the concrete and the reinforcing steel, which can result in degradation.

This same concept of distribution and crack bridging helps improve concrete's impact resistance. Since the fibers are located throughout the matrix, it becomes more difficult to fragment the concrete.

The fibers essentially help hold the concrete together. This attribute improves concrete's abrasion resistance as well. Fibers improve

concrete's fire resistance in a couple of ways. During a fire, moisture inside of concrete vaporizes and expands, increasing the internal pressure. Certain types of fibers assist in preventing fragments of concrete from exploding and becoming projectiles. Fire resistance can also be improved by synthetic fibers, which melt and provide channels for hot gases and moisture vapor to escape, thus reducing the internal pressure. Ultimately, fibers can help maintain the protective concrete cover over the reinforcing steel during a fire.

Also, since fibers are present throughout the concrete matrix, they improve the ductility of the concrete member. Concrete is a brittle material and fractures when its peak strain capacity is reached. After it cracks, it has no additional tensile capacity unless it has other reinforcement in it. Tests have shown that fibers increase concrete's residual flexural strength after cracking. The fibers hold the concrete together and take up the tensile forces, enabling the concrete to continue (NPCA Fibers White Paper - National Precast Concrete Association, 2016).

Fibers may also be used to replace secondary reinforcement as required for temperature and shrinkage. However, this typically applies only to non-structural products and, therefore, may have limited opportunities for use. Currently, neither ACI 318 nor AASHTO Specifications for Highway Bridges, which are the two most common standards for structural concrete design, have any provision for the use of fiber in lieu of reinforcing steel. The replacement of reinforcing steel (primary or secondary) with fibers should be evaluated by a structural engineer to ensure that the product complies with all applicable codes and specifications and also to ensure that the structural integrity of the product is not degraded in any way. Steel fibers and synthetic macro fibers have received third party review, from entities like ICCES

(International Code Council Evaluation Service) and Uniform ES (Uniform Evaluation Service), for primary and secondary reinforcing steel replacement and code compliance. Stamped engineering designs, that follow accepted design documents, such as ACI 544.4R and include proof testing in accordance with the applicable ASTM Standards noted Section VI (NPCA Fibers White Paper - National Precast Concrete Association, 2016).

Their main purpose is to increase the energy absorption capacity and toughness of the material, but also increase tensile and flexural strength of concrete (Kamran, 2015).

The main disadvantage associated with the fiber reinforced concrete is fabrication, it have special criteria to add , the process of incorporating fibers into the cement matrix is labor intensive and cost. The real advantages gained by the use of FRC overrides this disadvantage.

- **General Requirements for the Fiber**

For the fibers to work efficiently in a concrete mix, a good fiber is the one which possess the following qualities (Anette *et al.*, 2008):

- Economic, an accessible price, taking into account the proportion within the mix.
- Being sufficiently short, fine and flexible to permit mixing, transporting and placing.
- Being sufficiently strong, yet adequately robust to withstand the mixing process.
- Good adhesion within the matrix, the bond between the matrix and the fibers must have a strength of at least then same order as that of the matrix, compatibility with the binder, to prevent fracturing of the fibers due to abrasion or

bending which should not be attacked or destroyed in the long term.

- Good properties, the Poisson ratio and the coefficient of thermal expansion of the fibers should be about the same order as that of the matrix.
- In addition, the fibers must be durable and able to withstand the alkaline environment in the concrete matrix.
- Behavior and Mechanism of Fibers.

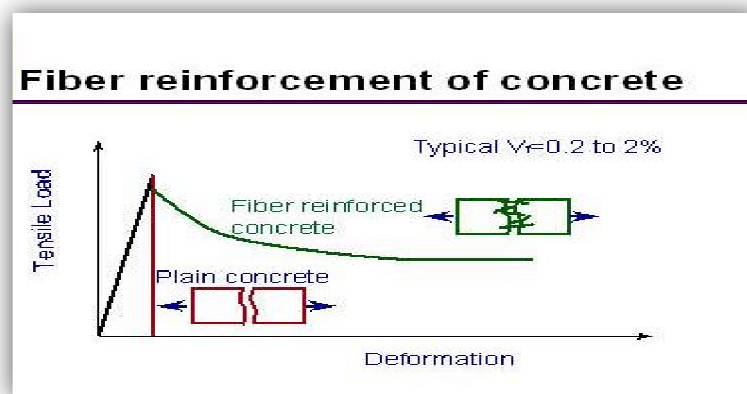


Figure (4): Tensile load versus Deformation for Plain and Fiber Reinforced (R. Brown, 2002)

Brittle materials are considered to have no significant post-cracking ductility. The elastic response is followed by micro cracking localized, and finally fractures (James *et al.*, 2002). Crack control plays a crucial role in the performance life of concrete construction. This is because the settlement and shrinkage cracks may pass through fresh concrete, thus forming planes of weakness and lowering the integrity of the concrete constructions. Further, the service loads may overstress hardened concrete for cracking, leading from cracking to substantial failure in concrete. Concerning the crack control, the incorporating of discrete fibers into the vulnerable concrete is useful and effective.

Addition of fibers to concrete makes it a homogeneous and isotropic material, it becomes more ductile and increases the resistance against

crack growth. When concrete cracks, the randomly oriented fibers start functioning, arrest crack formation and propagation, and thus improve strength (Faisal, 1990).

After the initial cracking has started, the fibers across the cracks will often be able to carry more load than other weak zones in the matrix. Therefore new cracks will continue to form in the brittle matrix. When many cracks have formed the fibers will have plastic deformations by being drawn out of the concrete matrix. The ultimate failure will happen when the fibers get completely drawn out of the concrete. This way the FRC will have a much more ductile behavior than regular concrete, and will have some residual capacity after the stress-strain diagram has reached its peak.

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. Examination of fractured specimens of fiber-reinforced concrete shows that failure takes place primarily due to fiber pull-out or deboning.

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 toughness.

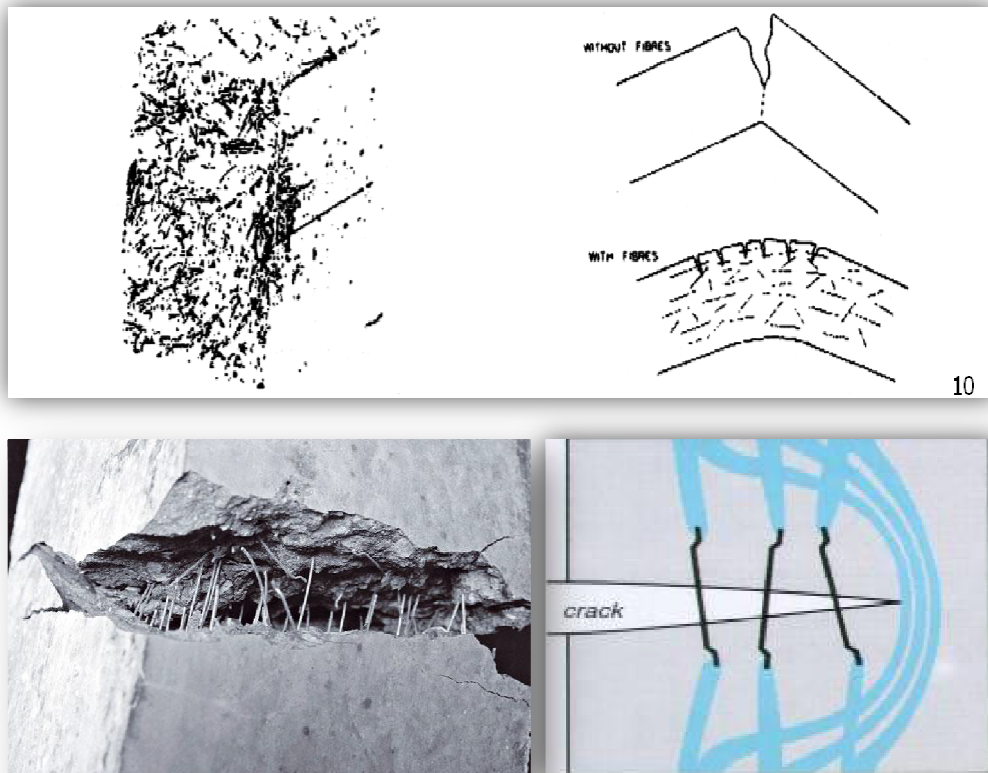


Figure (5): Fiber Reinforced Concrete failure.

Fiber work with concrete utilizing two mechanisms: the spacing mechanism and the crack bridging mechanism.

➤ **Fiber Matrix Interaction (Spacing Mechanism)**

The tensile cracking strain of cement matrix is much lower than the yield or ultimate strain of fibers. As a result when a fiber reinforced composite is loaded the matrix will crack long before the fibers can be fractured. Once the matrix is cracked composite continues to carry increasing tensile stress.

The spacing mechanism requires a large number of fibers well distributed within the concrete matrix to arrest any existing micro crack that could potentially expand create a sound crack. For typical volume of fractions of fibers utilizing small diameter of fibers or micro fibers can ensure the required no of fibers for micro crack arrest.

➤ Bridging Action

Fibers are acting as bridges between the concrete matrix to distribute the stresses uniformly thus making the whole matrix resists the deformation. This mechanism requires larger straight fibers with adequate bond to concrete.

Pullout resistance of fibers is important for efficiency; Pullout strength of fibers significantly improves the post-cracking tensile strength of concrete. Fibers bridge the cracks such bridging action provides the FRC specimen with greater ultimate tensile strength and more importantly, larger toughness and better energy absorption (P.Sampathkumar *et al.*, 2016).

Secondly we can say that the fibers are acting as bridges between the concrete matrix to distribute the stresses uniformly thus making the whole matrix resists the deformation.

The decreased amount of aggregates content in the concrete mix resulted in lesser bridging action moreover the increased cement content ratio could not bond with fibers as polypropylene fibers are hydrophobic and resulted in even loss of strength from cement bond resulting in strength loss of concrete matrix (P.Sampathkumar *et al.*, 2016).

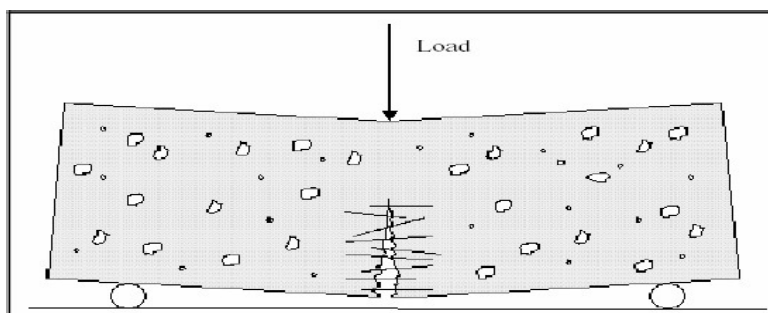


Figure (6): Pullout Mechanism.

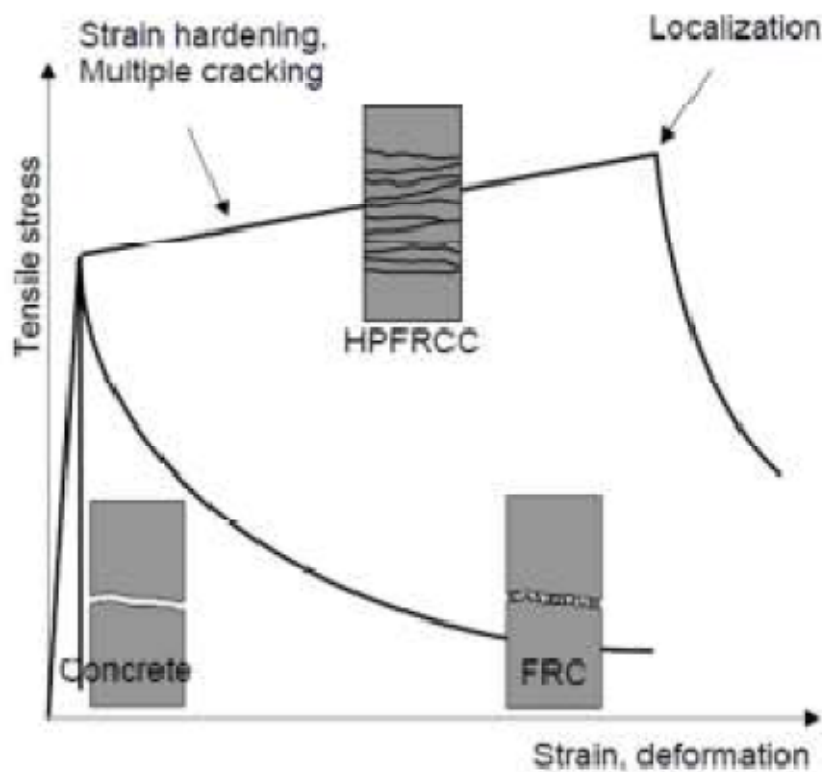


Figure (7): Schematic stress-strain behavior of cementitious matrix in tension (Shehnil Fatima, 2013).

- **Orientation and Distribution of Fibbers**

The orientation of fibers in FRC is important for the capacity and mechanical performance. For randomly dispersed fibers the placement depend on the method of adding fibers, the casting equipment used and the fresh concrete properties among others. A problem when casting fiber reinforced concrete is that the fibers may clot together and prevent a good flow of the concrete. This can cause a less fortunate dispersing of the fibers. Another problem that may occur is separation, which can cause the fiber especially steel fibers to sink to the bottom of the formwork and make corrosion.

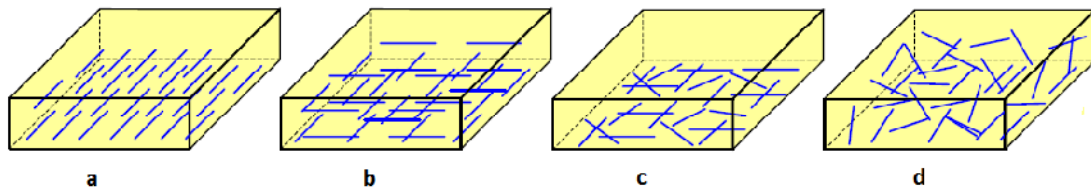


Figure (8): Different distributions of discontinuous fibers (Anette *et al.*, 2008).

- a) Biased 1-D fiber orientation
- b) Biased 2-D fiber orientation
- c) Plane random fiber orientation
- d) Random fiber orientation, (Anette *et al.*, 2008).

• Mixture Compositions and Placing

The influence of fibers in improving the strength of the matrix depends on whether concrete is used. Mixing of FRC can be accomplished by many methods at (ACI 544, 1982). The mix should have a uniform dispersion of the fibers in order to prevent segregation or balling of the fibers during mixing. Most balling occurs during the fiber addition process. Increase of aspect ratio, volume percentage of fiber, and size and quantity of coarse aggregate will intensify the balling tendencies and decrease the workability. To coat the large surface area of the fibers with paste, experience indicated that a water cement ratio between 0.4 and 0.6, and minimum cement content of 400 kg/m are required (Naaman A.E, 1985). Compared to conventional concrete, fiber reinforced concrete mixes are generally characterized by higher cement factor, higher fine aggregate content and smaller size coarse aggregate (Amit and Dr. Y.P Joshi, 2014).

A fiber mix generally requires more vibration to consolidate the mix. External vibration is preferable to prevent fiber segregation. Metal

trowels, tube floats, and rotating power floats can be used to finish the surface (Faisal, 1990).

The production technique to ensure that a sufficiently fiber can be dispersed in the max:

- Premix process: In this method the fiber are combined with the cementitious matrix in a mixer. They are treated simply as an extra ingredient in the most common method to producing a cementations mix. However because the fiber reduce the workability , only to 2% fiber volume can be introduced in the mix by these method of mixing
- Spray up process: This technique is used for glass fiber volume up to 6%, chopped fiber and cement slurry are sprayed simultaneously on to the forming surface to produce thin.
- Shotcret: it has been found possible to produce steel and polypropylene fiber, with this method, too, relatively high volume of fiber can be added to the mix.
- Pulp type processes for asbestos replacement, the fiber are dispersed in a cement sully which is then dewatered to produce thin sheet material. these process contents of typically from 9& to over 20% by volume
- Hand lay up: In this method, layers of fibers in the form of mats or fabrics can be placed in moulds, impregnated with a cement slurry, and then vibrated or compressed to produce dense materials with very high fiber contents (Arnon and Sidney, 2007).

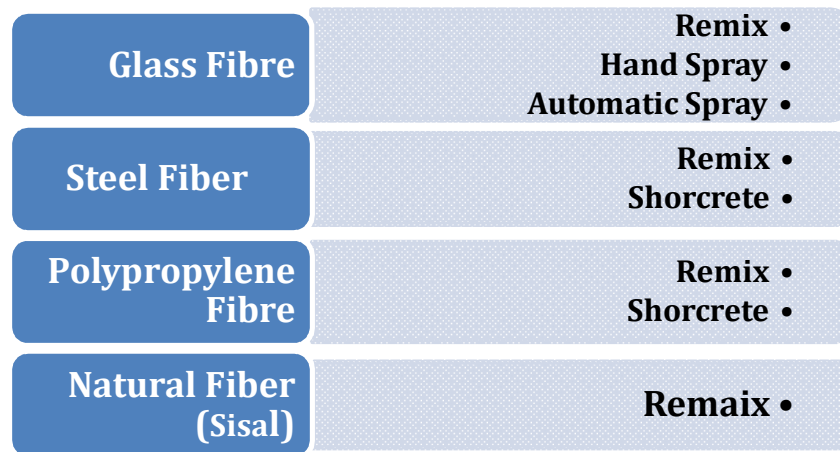


Figure (9): Typical Production method for FRC (Arnon and Sidney, 2007).

• **Factors Affected on Properties of Fiber Reinforced Concrete**

Properties of concrete is affected by many factors like properties of cement, fine aggregate, coarse aggregate. Other than this.

The fiber reinforced concrete is affected by following factors:

- Type of fiber.
- Aspect ratio.
- Quantity of fiber.
- Orientation of fiber.

➤ **Aspect ratio:**

Aspect ratio is defined as the ratio of length to width of the fiber. The value of aspect ratio varies from 30 to 150. Generally the increase in aspect ratio increases the strength and toughness till the aspect ratio of 100. Above that the strength of concrete decreases, in view of decreased workability and reduced compaction.

➤ **Fiber quantity:**

Generally quantity of fibers is measured as percentage of cement content. As the volume of fibers increase, there should be increase in toughness and may be increase of strength concrete.

➤ **Orientation of fiber:**

The orientations of fibers play a key role in determining the capacity of concrete. In RCC the reinforcements are placed in desired direction. But in FRC, the fibers will be oriented in random direction. The FRC will have maximum resistance when fibers are oriented parallel to the load applied (Kamran, 2015).

2.1.2 Studies of Properties of Fiber Reinforced Concrete

Several different types of fibers have been used to reinforce the cement-based matrices. The choice of fibers varies from synthetic organic materials such as polypropylene or carbon, synthetic inorganic such as steel or glass and natural organic, the selection of the type of fibers is guided by the properties of the fibers (Daniel *et al.*, 1998).

Below are cited some properties of FRC determined by different researchers (Faisal, 1990):

- Fibrous composites have been developed to provide improved mechanical properties to otherwise brittle materials. FRC composite properties, such as crack resistance, reinforcement and increase in toughness are dependent on the mechanical properties of the fiber, bonding properties of the fiber and matrix, as well as the quantity and distribution within the matrix of the fibers which are being developed to provide improved mechanical properties to otherwise brittle materials (Amit, 2013). The mechanical properties of FRC are much improved by the use of hooked fibers than straight fibers.

- Fibers can prevent the occurrence of large crack widths that are either unsightly or permit water and contaminants to enter, causing corrosion of reinforcing steel or potential deterioration of concrete (Shah, S. P., 1991). Fibers are usually used in concrete to control cracking due to both plastic shrinkage and drying shrinkage (Amit, 2013). The resulting fiber-reinforced concrete exhibits satisfactory resistance to crack formation and propagation. That is mean, fibers do not do anything to stop the first crack, it slows down the propagation of cracks (Kamran, 2015). In ordinary concrete, where vibration is necessary, the best and most acceptable method for preventing cracks formations caused by paste contract is by using fibers, particularly thin artificial ones with the volume of less than 0.5% (Saeid *et al.*, 2012) have shown that fiber reinforcement effectively controls cracking and deflection, in addition to strength improvement. In conventionally reinforced concrete beams, fiber addition increases stiffness, and reduces deflection.
- They also reduce the permeability of concrete and thus reduce bleeding of water (Amit, 2013).
- The fibers in FRC have a large impact on the moment capacity. The increase in moment capacity is highly dependent on the amount of fibers and the fiber type. When the concrete has cracked the tensile zone may still carry a stress equal to the residual tensile strength. Simplified the tensile zone may be characterized as a uniform stress distribution with the stress equal to the design residual tensile strength. This residual tensile strength may work together with the regular reinforcement if the latter is present. The fibers will also reduce the crack width of the moment cracks by spreading the moment to several smaller cracks (Ane, 2012).

- Addition of fibers increases shear capacity of reinforced concrete beams up to 100 percent. Addition of randomly distributed fibers increases shear-friction strength, the first crack strength, and ultimate strength (Mohd Hashmat and Mohammed Rafi, 2015).
- Generally, fibers into the concrete mix have proved to considerably improve the ductile behavior of concrete materials. Under pure compressive loads and low tensile stress, the addition of fibers has little effect (Amit Rai and Dr. Y.P Joshi, 2014). Generally the addition of fiber leads to substantial increases in the ductility of concrete (Wasan *et al.*, 2013). Fibers help to improve the post peak ductility performance, pre-crack tensile strength, fatigue strength, impact strength and eliminate temperature and shrinkage cracks (Khatere *et al.*, 2012). The increase of fiber content slightly increases the ductility of axially loaded specimen. The use of fibers helps in reducing the explosive type failure for columns. Behavior (Abdul-Wahab *et al.*, 1986; Craig *et al.*, 1984).
- Addition of fiber had no effect on the compressive strength values. However, the brittle mode of failure associated with concrete was transformed into a more ductile one with the increased addition of fibers (Faisal, 1990). The percentage of fiber volume content has practically no influence on the compressive strength of concrete either at early or later stage of its life. Present a comparison of the strength for hooked and straight fibers which indicates that the fiber types and content have little effect on the compressive strength (American Concrete Institute, 1982; Naaman, 1985). Other results of the tests conducted by researchers showed that the compressive strength, tension strength and bending strength increased with higher fiber volume, while concrete liquefaction decreased (Saeid *et al.*, 2012). The increase of fiber content slightly

increases the ductility of axially loaded specimen. The use of fibers helps in reducing the explosive type failure for columns (Abdul-Wahab *et al.*, 1986; Craig *et al.*, 1984).

- The important effect fibers have on concrete tensile strength is on the tensile fracture behavior. In concrete the tensile load carrying abilities of the concrete will decrease a lot after crack widths of about 0.3 mm. The FRC will be able to carry considerable loading after cracking (Anette *et al.*, 2008). The presence of 3 percent fiber by volume was reported to increase the splitting tensile strength of mortar about 2.5 times that of the unreinforced one. (Faisal, 1990). Earlier experiments has indicated that the fibers have a great effect on the shear capacity and can increase the capacity up to 60% of the compressive capacity for regular concrete with low or moderate dosages of fibers The effect increases with higher fiber volume fractions (Anette *et al.*, 2008).
- The addition of any type of fibers to concrete reduces the workability (Kamran, 2015). Other research conclusion that straight fibers produce balling at high fiber content and require special handling procedure, recognized that the effect of fiber content on both slump and inverted cone time clearly seen that as the fiber content increased from 0.0 to 2.0 percent, the slumps value decreased from 230 to 20mm (Faisal, 1990).
- The addition of fibers increases fatigue strength of about 90 percent and 70 percent of the static strength at 2×10^6 cycles for non-reverse and full reversal of loading, respectively (Faisal, 1990).
- The use of fibers in reinforced concrete flexure members increases ductility, tensile strength, moment capacity, and stiffness. The fibers improve crack control and preserve post cracking structural

integrity of members. Fibers increase the ductility of high strength concrete. The use of high strength concrete and steel produces slender members. Fiber addition will help in controlling cracks and deflections (Abdul-Wahab *et al.*, 1986; Craig *et al.*, 1984).

- (Kamran, 2015) result that toughness of material can be increased (15-30%) in fiber addition.
- The impact strength for fibrous concrete is generally 5 to 10 times that of plain concrete depending on the volume of fiber used (American Concrete Institute, 1982; Faisal, 1990). Some types of fibers produced greater impact, abrasion and shatter resistance in concrete (Amit, 2013).
- The uses of fibers eliminate the sudden failure characteristic of plain concrete beams. It increases stiffness, tensional strength, ductility, rotational capacity, and the number of cracks with less crack width (Abdul-Wahab *et al.*, 1986; Craig *et al.*, 1984).
- A ten-year exposure (American Concrete Institute, 1982) of steel fibrous mortar to outdoor weathering in an industrial atmosphere showed no adverse effect on the strength properties. Corrosion was found to be confined only to fibers actually exposed on the surface
- Data from three studies (Aitcin *et al.*, 1985; Dahl, 1985) show that the fibers had little or no effect on unit weight of the concrete.
- The increase of formability and bending strength are the extra advantages of adding the fibers to the concrete. Two kinds of fiber that very often used in the concrete are: steel fiber and polypropylene fiber (Saeid *et al.*, 2012).
- In addition to crack control and serviceability benefits, use of fibers at high volume percentages (5 to 10 percent or higher with special production techniques) can substantially increase the matrix tensile strength (Shah, 1991).

- The chemical properties of the fiber in terms of their inertness or reactivity with the surrounding environment plays an important role in determining the bonding characteristics of the fiber and the composite as they may or may not form a chemical bond between the fiber and matrix (R. Brown, A. Shukla 2002).
- Performance of the composites materials are affected with factors physical properties of the reinforced concrete and matrix, the strength of the bond between fibers and matrix. The chemical properties of the fiber in terms of their inertness or reactivity with the surrounding environment plays an important role in determining the bonding characteristics of the fiber and the composite as they may or may not form a chemical bond between the fiber and matrix (R. Brown, A. Shukla 2002).

Table (1): The characteristics of different fibers (Wang *et al.*, 2008).

Type	Specific gravity (gr/cm ³)	Tensile strength (MPa)	E (GN/m ²)	Elongation at failure (%)	Common V (%)
Polypropylene	0.91	550-700	3.5-6.8	21	<2
Steel	7.86	400-1200	200	-3.5	<2
Glass	2.7	1200-1700	73	-3.5	4-6
Asbestos	2.55	210-2000	159	2-3	7-18
Polyester	1.4	400-600	8.4-6	11-3	0.065
Concrete, for comparison	2.4	2-6	20-50	-	0

2.1.3 Applications of Fiber Reinforced Concrete (FRC)

The application of fiber reinforced concrete are indispensable in all concrete constructions under mixed and heavy loadings and where tensile stresses are common such as roadways, warehouses, driveways, sidewalks, runways, taxiways, dams, storm-water structures, mining and tunneling structures, storage structures, etc. Researchers have proved that the impacts of overloads on road pavements can be very devastating (Anthony, 2014). Common applications today are pavement, industrial floors, precast elements and various kinds of repairs (Carlsward, 2006).

The main area of FRC applications (Henger, 1981 and Williamson, 1966) are:

- Runway, Aircraft Parking, and Pavements.
- Tunnel Lining and Slope Stabilization.
- Blast Resistant Structures.
- Thin Shell, Walls, Pipes, and Manholes.
- Dams and Hydraulic Structure.
- Other Applications (Faisal, 1990).

2.1.4 Types of Fiber Reinforced Concrete (American Concrete Institute, 1982; James, 2002):

Fibers are produced from different materials in various shapes and sizes. Typical fiber materials (American Concrete Institute, 1982; Naaman, 1985) are: these fiber types are broken into four main categories, as described in ACI 544.1R. These categories are steel, glass, synthetic and natural fibers.

- **Steel Fibers**

Straight, crimped, twisted, hooked, ringed, and paddled ends.

Diameter range from 0.25 to 0.76mm.

- **Glass Fibers**

Straight Diameter ranges from 0.005 to 0.015mm (may be bonded together to form elements with diameters of 0.13 to 1.3mm).

- **Natural Organic and Mineral Fibers**

Wood, asbestos, cotton, bamboo, and Rockwool. They come in wide range of sizes.

- **Synthetic Fibers**

Kevlar, nylon, polyester, Polypropylene and Other Synthetic Fibers. Diameter ranges from 0.02 to 0.38mm.

A convenient parameter describing a fiber is its aspect ratio (L/D), defined as the fiber length divided by an equivalent fiber diameter. Typical aspect ratio ranges from about 30 to 150 for length of 6 to 75mm (Faisal, 1990).

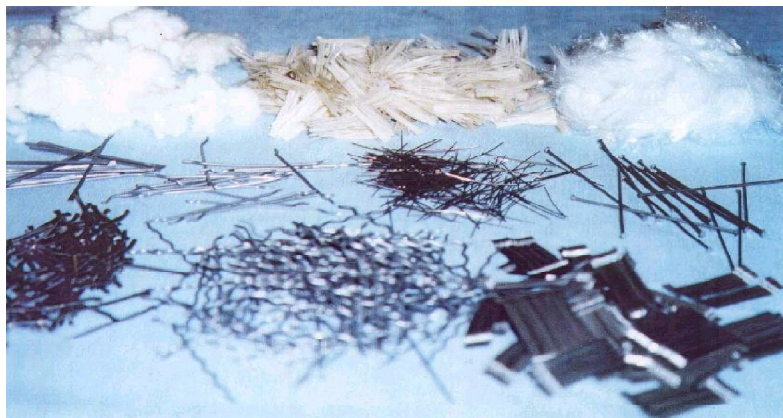


Figure (10): Type of Fiber Reinforced Concrete (Ane, 2012).

2.1.4.1 Steel Fiber Reinforced Concrete (SFRC)

Steel fiber reinforced concrete (SFRC) is concrete made of hydraulic cements containing fine or fine and coarse aggregate and discontinuous discrete steel fibers. In tension, SFRC fails only after the steel fiber breaks or is pulled out of the cement matrix.



Figure (11): Steel Fiber Reinforced Concrete SFRC.

The properties of SFRC in its freshly mixed state are influenced by the aspect ratio of the fiber, fiber geometry, its volume fraction, the matrix proportions, and the fiber-matrix interfacial bond characteristics (Ramakrishnan, 1987). Steel fiber is the fiber type with the most extensive use which has a tensile strength between 200 and 2600 MPa, but typically the fibers that are used have a tensile strength typically 2-3 times that of traditional reinforcement. They have typical diameters from 0.5 to 1 mm and length between 25 and 60 mm (The Concrete Society, 2007).

The fibers are classified after which basic materials they are produced from (COIN Concrete Innovation Center, 2011):

- Cold-drawn wire
- Cut sheet
- Melt extracted
- Shaved cold drawn wire
- Milled from blocks

For conventionally placed SFRC applications, adequate workability should be insured to allow placement, consolidation, and finishing with a minimum of effort, while providing uniform fiber distribution and minimum segregation and bleeding. For a given mixture, the degree of consolidation influences the strength and other hardened material

properties SFRC has advantages over conventional reinforced concrete for several end uses in construction. The applications of SFRC will depend on the ingenuity of the designer and builder in taking advantage of the static and dynamic tensile strength, energy absorbing characteristics, toughness, and fatigue endurance of this .Present applications of SFRC are discussed in the: Applications of cast-in-place SFR , Applications of precast SFR

One example is the use of steel fiber reinforced concrete (SFRS) for tunnel lining, rock slope stabilization, and as lagging for the support of excavation.

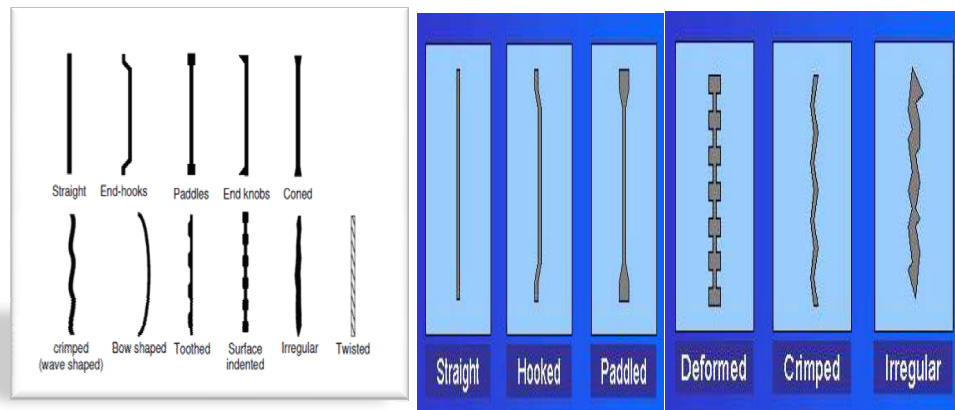


Figure (12): Typical Fiber Geometry (Anette *et al.*, 2008).



Figure (13): SFRC shapes (Kamran, 2015).

The steel fibers have a disadvantage when it comes to the aesthetic prospect. Since fibers get spread out in the matrix some of them will be at the surface of the structure. These might rust so that the surface gets discolored by rust stains (Ane, 2012).

2.1.4.2 Glass Fiber Reinforced Concrete (GFRC)

This work used conventional borosilicate glass fibers (E-glass) and soda-lime-silica glass fibers (A-glass). Glass compositions of E-glass and A-glass, used as reinforcement, were found to lose strength rather quickly due to the very high alkalinity (pH 12.5) of the cement-based matrix. Consequently, early A-glass and E-glass composites were unsuitable for long-term.

Continued research, however, resulted in the development of a new alkali resistant fiber (AR-glass fiber) that provided improved long-term durability. This system was named alkali resistant-glass fiber reinforced concrete (AR GFRC) (John and Thomas, 1977).

Mechanical properties of GFRC composites depend upon fiber content, polymer content (if used), water-cement ratio, porosity, sand content, fiber orientation, fiber length, and curing (John and Thomas, 1977).



Figure (14): Fiber glass.

It can replicate virtually any surface detail and reproduce the appearance of materials such as stone, slate, terracotta and marble.

By far, the single largest application of GFRC has been the manufacture of exterior building facade panels. Another large application of GFRC is surface bonding. Use of GFRC continue increase such as electrical utility product, trench systems and distribution boxes.

2.1.4.3 Natural Fiber Reinforced Concrete (NFRC)

Concretes reinforced with naturally occurring fibers are generally termed natural fiber reinforced concrete (NFRC). Many natural reinforcing materials can be obtained at low levels of cost and energy using locally available manpower and technical know-how. Such fibers are used in the manufacture of low fiber content FRC and occasionally have been used in the manufacture of thin sheet high fiber content FRC.

These fibers are typically referred to as unprocessed natural fibers (UNF). However, other natural fibers are available that have been processed to enhance their properties. These fibers are derived from wood by chemical processes such as the Kraft process. Kraft pulp fibers are used in sophisticated manufacturing processes, such as the Hatschek process, to produce thin sheet high fiber content FRC.

Although historically many fibers have been used to reinforce various building materials, straw-reinforced, sun-dried mud bricks for wall construction, and horse hair in mortar, are typical examples of how natural fibers were used long time ago, until recently little scientific effort has been devoted to the use of natural fibers for reinforcement. The use of some of the best known natural fibers such as sisal, coconut, sugarcane bagasse, plantain (banana), palm, etc., have mostly been limited to the production of fabrics, ropes, mats, etc.

In Africa, sisal fiber reinforced concrete has been used extensively for making roof tiles, corrugated sheets, pipes, silos, and gas and water tanks (Rakesh *et al.*, 2013). Elephant grass fiber reinforced mortar and cement sheets are being used in Zambia for low-cost house construction

(Rakesh *et al.*, 2013), while wood and sisal fibers are being used for making cement composite panel lining, eaves, soffits, and for sound and fire insulation.

Kraft pulp fiber reinforced cement has found major commercial applications in the manufacture of flat and corrugated sheet, non-pressure pipes, cable pit, and outdoor fiber reinforced cement paste or mortar products for gardening (James *et al.*, 2002).

2.1.4.4 Synthetic Fiber Reinforced Concrete (SNFRC)

A variety of fiber materials other than steel, glass, or natural fibers have been developed for use by the construction industry for fiber reinforced concrete. These fibers are categorized as synthetic fibers for use in synthetic fiber reinforced concrete, SNFRC. Synthetic fibers are man-made fibers consequential of petrochemical and textile industries activities. Synthetic fibers used for reinforcing concrete derives from assortment of formulations of organic polymers (American Concrete Institute, 1996). Synthetic fiber that have been experimented in Portland cement concrete matrices include acrylic, aramid, carbon, nylon, polyester, polyethylene and polypropylene.

SNFRC is a rapidly growing FRC technology area due to the availability of a wide spectrum of fiber types and a wide range of obtainable composite enhancements. To date, the largest use of synthetic fibers is in ready-mix applications for flat slab work to control bleeding and plastic shrinkage cracking. This application generally uses 0.1 percent by volume of relatively low modulus synthetic fibers.

Higher volume percentages (0.4 to 0.7 percent) of fibers have been found to offer significant property enhancements to the SNFRC, mainly increased toughness after cracking and better crack distribution with reductions in crack width (American Concrete Institute, 1996).

With the emergence of new areas of application, research interest has moved to higher fiber contents where toughness index and other factors are design considerations. Toughness index is an indication of the load-carrying capabilities of the fibers within the concrete matrix after first crack. Basically, cast-in-place concrete will accommodate up to 0.4 percent by volume of synthetic fibers with minimal mix proportion adjustments. Wet mix concrete with up to 0.75 percent by volume will provide major increases in toughness index values (DR. Morgan *et al.*, 1989). Fiber length and fiber configuration are important factors at this fiber content. In slab-on-grade applications, with collated fibrillated polypropylene fiber contents up to 0.3 percent by volume, the fatigue strength has increased dramatically (James *et al.*, 2002). The use of synthetic fibers in the form of layered mesh is similar in concept to the system known as fibrocement. Progress in research and in the development of commercial products has been rapid and has been reported in publications on fibrocement in the U.S. and in publications on fiber reinforced concrete principally in Europe.

The synthetic fibers are usually divided into two classes:

- Class I: Micro fibers
 - Class Ia: Micro fibers < 0.30 mm in diameter, monofilament.
 - Class Ib: Micro fibers < 0.30 mm in diameter, fibrillated.
- Class II: Macro fibers > 0.30 mm in diameter, (The Concrete Society, 2007).

The Class I micro fibers have been used since the mid 80s as a means to modify the properties of fresh concrete. Their primary goal is to control plastic shrinkage cracking. They may also affect the bleeding of the concrete and more recently they are used to reduce spalling of

concrete exposed to fire. However, their contribution to load-bearing capacity post cracking is insignificant.

The Class II macro fibers has similar dimension as steel fibers used in concrete structures. These provide the concrete with some post cracking load-bearing capacity when added in large enough doses (up to about 1.35% of the volume). They are mainly used to increase the residual flexural strength in concrete (Ane, 2012).

2.1.4.4.1 Types of Synthetic Fiber Reinforced Concrete (SNFRC)

Twentieth century interest in synthetic fibers as a component of construction materials was first reported in 1965 (George *et al.*, 1965). It was also discovered that the addition of what then was considered small quantities, 0.5 percent by volume, of synthetic fibers to concrete resulted in a composite with increases in both ductility and impact resistance (Williamson, 1966). However, it was another fifteen years before large scale development activities began with synthetic fibers. It has been shown to better distribute cracking, reduce crack size, and improve other properties of concrete.

The earlier applications of synthetic fibers first used in the late 1970s, with low volume applications appeared at 0.1 to 0.3 percent by volume

Synthetic fibers for concrete are made from a wide range of organic polymers, and there is an increasing amount of examples where these are used in practice. Earlier these fibers have not been very good for post cracking load capacity for concrete as the polymers often have very high Poisson's ratio which result in poor bonding. However, recent interest in polymer fibers has resulted in research and development of materials with

E-modulus up to 10 000 MPa and production techniques that enables the manufacturers to create fibers with good anchoring mechanisms.

Synthetic fibers are man-made fibers resulting from research and development in the petrochemical and textile industries. SNFRC utilizes fibers derived from organic polymers which are available in a variety of formulations. Fiber types that have been tried in Portland cement concrete based matrices are: acrylic, aramid, carbon, nylon, polyester, polyethylene and polypropylene. The fibers indicated below have generally performed well in Portland cement matrices.



Figure (15): Synthetic Fiber Reinforced Concrete Types.

2.1.4.4.1.1 Acrylic

Acrylic fibers contain at least 85 percent by weight of acrylonitrile units. Generally, acrylic fibers used in the textile industry (James *et al.*, 2002).

2.1.4.4.1.2 Aramid

Aramid (aromatic polyamide) is a high-modulus, manmade polymeric material that was first discovered in 1965. Attempts to incorporate this fiber into concrete as a form of reinforcement began by the late 1970s. It has been concluded that the mechanical properties of a cement matrix reinforced with aramid fibers are sufficiently attractive to warrant further studies (James *et al.*, 2002). However, the high cost of aramid fibers has been a limitation to commercial acceptance.

Aramid fibers have relatively high tensile strength and a high tensile modulus. It has two and a half times as strong as E-glass fiber and five times as strong as steel fibers per unit weight (James *et al.*, 2002).

2.1.4.4.1.3 Carbon

Carbon fibers were developed primarily for their high strength and stiffness properties for applications within the aerospace industry. Compared with most other synthetic fiber types, carbon fibers are expensive else it has limited commercial development. However, laboratory research has continued to determine the physical properties of carbon fiber reinforced concrete (CFRC). It has been shown that carbon fibers can be made from petroleum and coal pitch, tows are commonly pre-spread prior to incorporation in CFRC to facilitate cement matrix penetration and to maximize fiber effectiveness. Polyacrylonitrile (PAN) based carbon fibers are manufactured by carbonizing polyacrylonitrile yarn at high temperatures while aligning the resultant graphite crystallites by a process called “hot-stretching.” They are manufactured as either HM (high modulus) fibers or HT (high-tensile strength) fibers and are dependent upon material source and extent of hot-stretching for their physical properties. They are available in a variety of forms. Pitch based fibers are also manufactured in two types: General purpose (GP) fibers are made from isotropic (non-oriented fiber structure) pitch and are low in tensile strength and elastic modulus. High performance (HP) fibers are made from mesophase (highly oriented fibers) pitch which produces fibers with high tensile strength and high elastic modulus (James *et al.*, 2002). Carbon fibers have high tensile strength and elastic modulus. They are also inert to most chemicals.

2.1.4.4.1.4 Nylon

Nylon is a generic name that identifies a family of polymers characterized by the presence of the amide functional group CONH (Goldfein, 1965). Various types of nylon fibers exist in the marketplace for use in apparel, home furnishings, industrial, and textile applications. A nylon fiber's properties are impacted by the base polymer type (molecular weight, end groups, residual monomer, etc.), addition of different levels of additives (light and heat stabilizers, delusterants, etc.), manufacturing conditions (spinning, drawing, texturing, etc.), and fiber dimensions (cross-sectional shape and area, fiber length, etc.). Currently, only two types of nylon fiber are marketed for fiber reinforced concrete. They are nylon 6 and nylon 66.

Nylon fibers are available as multifilament yarns, monofilament, staple, and tow. For concrete applications, high tenacity (high tensile strength) heat and light stable yarn is spun and subsequently cut into shorter lengths. Nylon fibers exhibit good tenacity, toughness, and excellent elastic recovery. Nylon is very heat stable and is readily used in commercial applications requiring this property, such as tires (James *et al.*, 2002).

2.1.4.4.1.5 Polyester

To date, polyester fibers available to the concrete industry belong to the thermoplastic polyester sub grouping. This type of polyester exhibits physical and chemical characteristics that depend on manufacturing techniques (James *et al.*, 2002). There is no consensus on the long-term durability of polyester fibers in Portland cement concrete.

2.1.4.4.1.6 Polyethylene

Polyethylene has been produced for use as concrete reinforcement (S Mukhopadhyay and S Khatana, 2015). It has been reported that

polyethylene fibers could be easily dispersed in concrete mixtures in volume percentages of up to 4 percent using conventional mixing techniques. Polyethylene in pulp form has also been applied in concrete mixtures. In this application the pulp, a fine irregular form of fiber, acts to retain cement fines by acting as filter fibers (James *et al.*, 2002) and its use is intended as an alternate to the use of asbestos fibers.

2.1.4.4.1.7 Polypropylene (Pp)

Polypropylene is hydrophobic, meaning it does not absorb water. Polypropylene fibers are not expected to bond chemically in a concrete matrix, but bonding has been shown to occur by mechanical interaction (Rice *et al.*, 1988). Polypropylene fibers are produced from homo polymer polypropylene resin. The melting point and elastic modulus, which are low relative to many other fiber types, may be limitations in certain processes such as autoclaving (James *et al.*, 2002). However, refractory product manufacturers use polypropylene fibers for early strength enhancement and because they disappear at high temperatures. Most common is polypropylene (PP), usually in the form of a fibrillated film made from splitting and stretching PP sheets or extruded tapes. (C. L. Page and M. M. Page).

2.1.4.4.2 Properties of Synthetic Fiber Reinforced Concrete (SNFRC)

Design methods for particular applications using low volume synthetic fibers have not yet been developed. Depending on the intended application, different manufacturers may suggest different volume content and fiber geometry. Acceptance criteria are prescribed in the ASTM Standard Specification C 1116 1989.

Reports on compression strength, splitting tensile strength, and flexural strength tests generally result in the conclusion that significant

improvement in these strength properties will not be observed in mature specimens when synthetic fibers are applied at relatively low (0.1 to 0.2) volume percentages (Zollo, 1984). However, synthetic fibers have been shown to be effective in the early lifetime of the composite when the matrix is itself weak, brittle, and of low modulus. For mature concrete, improved material toughness is dependent on the fiber volume content and fiber durability in the matrix.

Improved toughness and crack control properties with SNFRC have been demonstrated for some fiber types (Zollo *et al.*, 1986). Test methods used for flexural strength and toughness testing of FRC have been published (American Society for Testing and Materials, 1978). These methods have been applied to SNFRC as have other specialized tests, such as for shrinkage and crack control. Work on standard test procedures to evaluate shrinkage and crack control is presently being undertaken by ASTM Subcommittee C09.42.

The bonding of current commercially available synthetic fibers (nylon, polyester, and polypropylene) within the concrete matrix is mechanical. There is no chemical bond. The modulus of elasticity and Poisson's ratio of each material will have an effect on bonding properties as will the fiber geometry and type derived from monofilament or fibrillated tape. Tests like the drop weight impact test and the toughness index test will show the bonding potential of various fiber types as well as the effect of other parameters such as fiber volume, fiber configuration, and fiber length.

Most common polymers have a modulus of elasticity rather lower than that of a cementations matrix and thus their use in frc is normally limited to providing toughness, strength or impact resistance. However, since these are all very useful properties, wide use is made of various polymer fibers (C. L. Page and M. M. Page).

2.1.4.4.3 Applications of Synthetic Fiber Reinforced Concrete (SNFRC)

In current commercial and industrial bulk concrete applications, synthetic fibers are added to concrete in the low range of fiber additions, approximately 0.1 percent based on the volume of concrete. In these applications, the strength of the concrete is considered to be unaffected and crack control characteristics are sought. Fiber additions of two or three times the volume above are being tested and flexural strength and toughness increases are being reported when concrete placement can be accomplished without compaction difficulties (James *et al.*, 2002).

The application of these fibers in construction increased largely because addition of fibers in concrete improves the tensile strength, flexural strength, toughness, impact strength and also failure mode of concrete (Dr. T.Ch.Madhavi *et al.*, 2014).

There is an increasing worldwide interest in utilizing fiber reinforced concrete structures for civil infrastructure applications. Only a few of the possible hundreds of fiber types have been found suitable for commercial applications (R. Brown *et al.*, 2002).

SNFRC has found its largest commercial uses to date in slabs on grade, floor slabs, and stay-in-place forms in multi-story buildings. Recent research in fibers and composites has opened up new possibilities for the use of synthetic fibers in construction elements. Thin products produced with synthetic fibers can demonstrate high ductility while retaining integrity.

Commercial use of SNFRC currently exists worldwide, primarily in applications of cast-in-place concrete (such as slabs-on-grade, pavements, and tunnel linings) and factory manufactured products (such as cladding panels, siding, shingles, and vaults) (James *et al.*, 2002). Currently, there

are two different synthetic fiber volume contents used in applications today, they are 0.1 to 0.3 percent, which is referred to as low volume percentage, and 0.4 to 0.8 percent, which is referred to as high-volume percentage. Most synthetic fiber applications are at the 0.1 percent by volume level to control plastic shrinkage cracking. Uses include precast products, concrete, and cast-in-place elements.

To date, most commercial applications of polypropylene FRC (James *et al.*, 2002) and nylon FRC have used low denier, low volume percentage (0.1 percent), monofilament (in the case of polypropylene and nylon) or fibrillated fibers (in the case of polypropylene). These fibers have been applied to nonstructural and non-primary load bearing applications.

Current applications include residential, commercial, and industrial slabs on grade, slabs for composite metal deck construction, floor overlays, concrete for slope stabilization and pool construction, precast units, slip form curbs, and mortar applications involving sprayed and plastered Portland cement stucco.

Today steel and synthetic fibers are used for both non-structural and structural purposes. Although it has been found that adding fibers to concrete mainly enhances the post-cracking properties in terms of a more ductile behavior and reduced crack widths (e.g. Anette *et al.*, 2008) which including : Thin sheet , shingles, roof tiles , pipes , prefabricated shapes , panels , concrete , curtain walls, Slabs on grade ,precast elements, Composite deck , Vaults, safes., Impact resisting structures (Kamran, 2015).



Figure (16): GFRG project at Trillium Building (Woodland Hills, Californi).



Figure (17): Application of PPFRG in Roof Screeding, Creek Vista, DHA Karachi, Pakistan (Shehnil Fatima, 2013).



Figure (18): Application of PpFRC in Jam Sadiq Bridge Deck and Expansion Joint at KPT Interchange, Karachi, Pakistan (Shehnil Fatima, 2013).



Figure (19): Application of PPFRC in steel free pavements at Shaheen Air, Jinnah Airport, Karachi, Pakistan (Shehnail Fatima, 2013).

2.2 Polypropylene Fiber Reinforced Concrete (PpFRC)

2.2.1 Polypropylene (Pp)

Polypropylene fibers are new generation chemical fibers. They are manufactured in large scale and have fourth largest volume in production after polyesters, Polyamides and acrylics. Polypropylene fibers were first suggested for use in 1965 as an admixture in concrete for construction of blast resistant buildings meant for the US Corps of Engineers (Goldfein, 1965; Williamson, 1966).

Polypropylene fiber derive from synthetic hydrocarbon polymer through extrusion processes of hot drawing the material through a die in the production process and based on the properties required, copolymerization among the monomers is necessary for the desired properties to be achieved (Anthony *et al.*, 2014).

These fibers are manufactured using conventional melt spinning. Polypropylene fibers are thermo plastics produced from Propylene gas.

Propylene gas is obtained from the petroleum by products or cracking of natural gas feed stocks. Propylene polymerizes to form long polymer chain under high temperature and pressure. However, polypropylene fibers with controlled configurations of molecules can be made only using special catalysts (James *et al.*, 2002).

Polypropylene (PP) is thermo plastic polymer used in a wide variety of applications such as textiles (rope and carpets), packaging, labeling, stationary, containers, automotive parts and banknotes (James *et al.*, 2002) which is produced by polymerizing monomer units of polypropylene molecules into very long polymer molecules or chains in the presence of a catalyst under carefully, controlled heat and pressure. Propylene is an unsaturated hydrocarbon, containing only carbon and hydrogen (R. Brown *et al.*, 2002).

Polypropylene fibers were formerly known as Stealthe. These are micro reinforcement fibers and are 100% virgin homo polymer polypropylene graded monofilament fibers. They contain no reprocessed Olifin materials. The raw material of polypropylene is derived from monomeric C₃H₆ which is purely a hydrocarbon (T.Ch.Madhavi *et al.*, 2014).

Polypropylene is an extremely hard, stiff, but brittle material at very low temperature, gradually becomes softer, more flexible, and tougher as the temperature increases and finally softens beyond the range of usefulness. It is also stated that the stiffness of polypropylene varies with temperature. The normal temperature range within which PP is most commonly used is limited by the crystalline melting point T_m on the high side and by the glass transition temperature T_g on the low side 'high crystallinity PP' results in higher bulk properties of the material such as softening point, stiffness, tensile strength, modulus and hardness (R. Brown *et al.*, 2002). Polypropylene fibers have hydrophobic levels,

which protect them against wetting with cement paste. The hydrophobic nature of polypropylene has no effect on the amount of water needed for concrete (Kolli.Ramujee, 2013).

Polypropylene fibers are available in three different forms; Monofilaments, Multifilament and Fibrillated (R. Brown *et al.*, 2002). Monofilaments are used in weaving stiffer products such as rope or twine. Ropes thus produced have high wear resistance, do not absorb water, float due to the low density and they retain strength when they are wet. Monofilament fibers are characterized by highly reflective and translucent surface, limited absorption capacity, high stiffness and good tensile strength (R. Brown *et al.*, 2002). Polypropylene fibers are also produced as continuous cylindrical monofilaments that can be chopped to specified lengths or as films and tapes that can be fibrillated to form the fibrils of rectangular cross-section (Daniel *et al.*, 1998). Fibrillated means the polypropylene film is slit so it can be expanded into an open network of fibers (Hannant, 1978).

Subsequently, the polypropylene fiber has been improved further and is now used as short discontinuous fibrillated material for production of fiber reinforced concrete or as a continuous mat for production of thin sheet components (James *et al.*, 2002).



Figure (20): Polypropylene Fiber.

2.2.2 Properties of Polypropylene

Monofilament polypropylene fibers can be used in much lower content than steel fibers (R. Brown *et al.*, 2002). The tensile strength and other mechanical properties are enhanced by subsequent multi stage drawing. These fibers have low density of (0.9 g/cc). They are highly crystalline, with high stiffness and excellent resistance to chemical and bacterial attack (Hamed *et al.*, 2016).

• Mechanical Properties of Polypropylene

The mechanical properties of polypropylene are strongly dependent on time, temperature and stress. Furthermore, it is a semi-crystalline material, so the degree of crystallinity and orientation also affects the mechanical properties. Also the material can exist as homo polymer, block copolymer and random copolymer it can be extensively modified by fillers, reinforcements and modifiers. These factors also affect the mechanical properties (Brown, *et al.*, 2002).

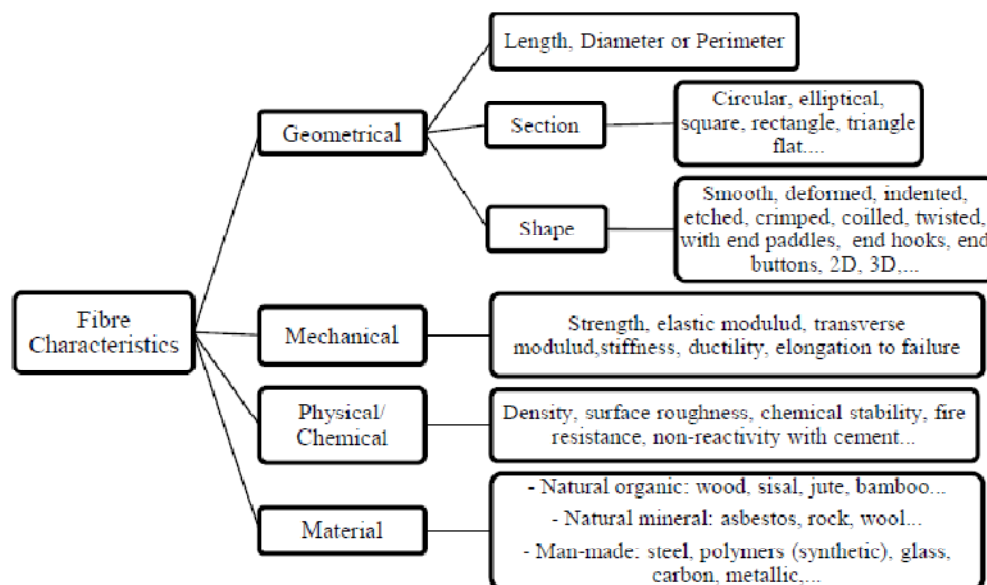


Figure (21): Main characteristics of Fibers (Shehnil Fatima, 2013).

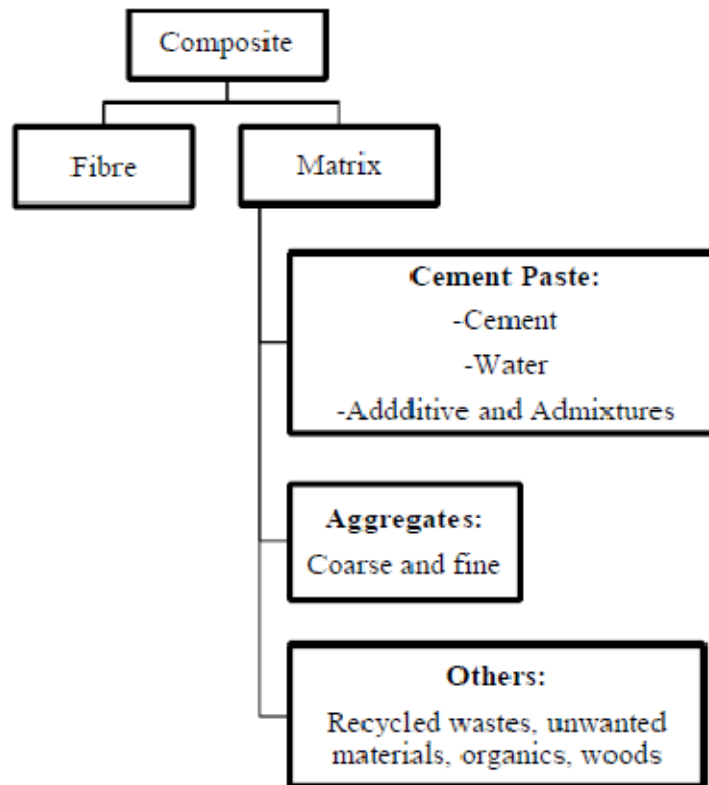


Figure (22): Composite model of FRC (Shehnil Fatima, 2013).

**Table (2): A summary of the mechanical properties are given below
(R. Brown *et al.*, 2002):**

Tensile Strength	25-33 Mpa
Flexural Modulus	1.2-1.5 Gpa
Strain at yield	150-300%
Strain at yield	10-12%

- **Physical Properties of Polypropylene.**

Table (3): The physical properties of the PP fibers are summarized as follows (R. Brown *et al.*, 2002).

Thermal conductivity	0.95 Btu-in/ft².hr.oF
Coefficient of linear thermal expansion	4.0 x 10⁻⁵/Of
Decomposition temperature range	328-4100 C
Specific gravity	0.9

Polypropylene is more susceptible to oxidation by oxidizing agents and by air at elevated temperature (R. Brown *et al.*, 2002). Normally all polypropylenes are stabilized against oxidation by adding stabilizers. Copper, manganese, cobalt and carbon black additives decrease resistance of polypropylene to heat ageing (R. Brown *et al.*, 2002).

- **Chemical Properties of Polypropylene**

Chemical resistance is excellent at room temperature (R. Brown *et al.*, 2002). Chemical resistance refers to inertness and compatibility with other ingredients present within the compounded polymer as well as resistance to external environment. It is often associated with heat stability because reaction may take place during high temperature processing (R. Brown *et al.*, 2002).

Polypropylene has a high resistance to chemical attack due to its non-polar nature. The term non-polar refers to the bond between atoms. The atoms of each element have specific electro-negativity values of the atoms in a bond. If the electro-negativity value is greater the polarity of the bond will be higher. When this difference is small the material is said

to be non-polar. In other words, the solubility of a polymer is related to the forces holding the molecule together, and one measure of this is the solubility parameter. Vulnerability is said to occur when the solubility parameter of the polymer and solvent are similar. It is understood that lower the value of the solubility parameter, the more resistant will be the polymer (R. Brown *et al.*, 2002).

They don't absorb water because of hydrophobic nature. It has excellent abrasion resistance due to the surface smoothness (R. Brown *et al.*, 2002). Also the water absorption is very low and this is again because of the non-polar nature of the material (R. Brown *et al.*, 2002).

In general, polypropylene is resistant to alcohols, organic acids, esters and ketones. It is swollen by aliphatic and aromatic hydrocarbons, and by halogenated hydrocarbons but is highly resistant to most inorganic acids and alkalis.

2.2.3 Polypropylene Fibers Reinforced Concrete (PpFRC)

2.2.3.1 Introduction of Polypropylene Fibers Reinforced Concrete.

Polypropylene is widely used in the production of fibers, for use in carpeting, rope and twine, automobile interiors, textiles and in other applications (R. Brown *et al.*, 2002).

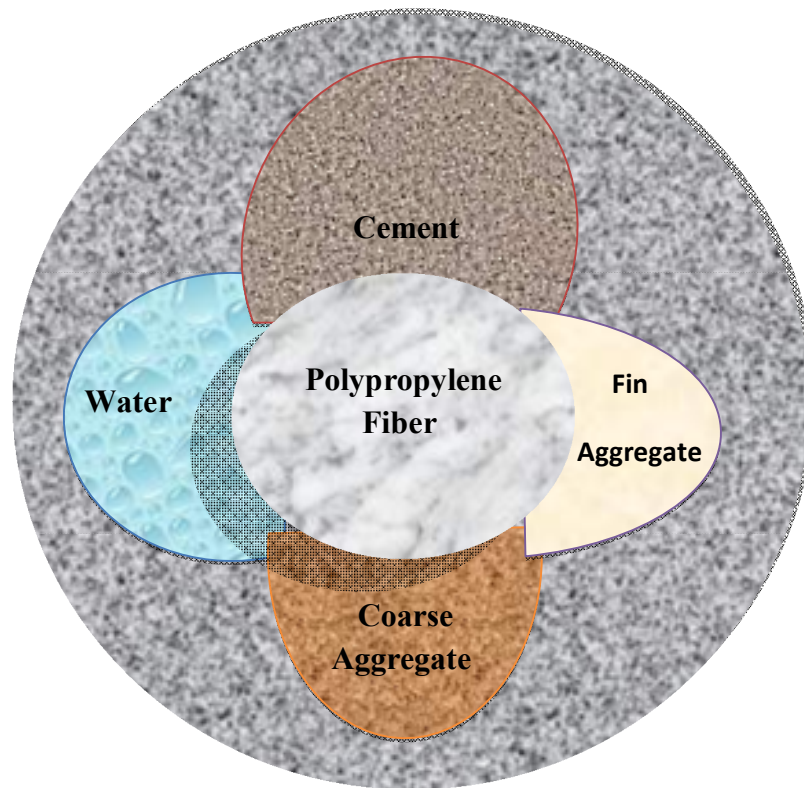


Figure (23): Explained the components of Polypropylene Fiber Reinforced Concrete (PpFRC).

Polypropylene Fiber Reinforced Concrete (PFRC) is an embryonic construction material which can be described as a concrete having high mechanical strength, stiffness and durability. By utilization of polypropylene fibers in concrete not only optimum utilization of materials is achieved but also the cost reduction is achieved. Concrete has better resistance in compression while steel has more resistance in tension. Conventional concrete has limited ductility, low impact and abrasion resistance and little resistance to cracking. A good concrete must possess high strength and low permeability. Hence, alternative composite materials are gaining popularity because of ductility and strain hardening. To improve the post cracking behavior, short discontinuous and discrete fibers are added to the plain concrete.

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. Addition of polypropylene fibers decreases the unit weight of concrete and increases its strength (Zollo, 1984; Zollo, *et al.*, 1986; Rice *et al.*, 1988; American Concrete Institute, 1989).

By utilization of polypropylene fibers in concrete not only optimum utilization of materials is achieved but also the cost reduction is achieved (Hamed *et al.*, 2016).

The ductility of fiber Polypropylene Fiber Reinforced Concrete (PFRC) is an embryonic construction material which can be described as a concrete having high mechanical strength, stiffness and durability. By utilization of polypropylene fibers in concrete not only optimum utilization of materials is achieved but also the cost reduction is achieved.

Good concrete must have high strength and low permeability. Inclusion of polypropylene fibers reduces the water permeability, increases the flexural strength due to its high modulus of elasticity (Dr.T.Ch. Madhavi *et al.*, 2014). PpFRC come to overcome some shortcomings of conventional concrete.

Addition of polypropylene fibers decreases the unit weight of concrete and increases its strength (Zollo, 1984; Rice *et al.*, 1988). Other benefit of PpFRC is impact loads, placements where all materials must be nonmetallic and areas requiring materials that are resistant to alkalis and other chemicals (Polypropylenefibers in concrete) (W. R. Malisch, 1986).

Fiber-reinforced concrete (FRC) is concrete containing fibrous material which increases its structural integrity. The character of fiber-reinforced concrete changes with varying concretes fiber materials, geometries, distribution, orientation, and densities. (Divya *et al.*, 2016).

Polypropylene fibers are new generation chemical fibers. They are manufactured in large scale and have fourth largest volume in production after polyesters, Polyamides and acrylics. Polypropylene fibers were first suggested for use in 1965 as an admixture in concrete for construction of blast resistant buildings meant for the US Corps of Engineers (Goldfein, 1965; Williamson 1966).

Monofilament polypropylene fibers can be used in much lower content than steel fibers. The tensile strength and other mechanical properties are enhanced by subsequent multi stage drawing. These fibers have low density of (0.9 g/cc). They are highly crystalline, with high stiffness and excellent resistance to chemical and bacterial attack. The crystalline of these fibers is about (70%) while the molecular weight is (80,000 to 300,000 gm/mole) (James *et al.*, 2002).

• **Advantages and Disadvantages of Polypropylene Fiber Reinforced Concrete**

- Polypropylene fibers are Non-Magnetic, rust free, Alkali resistant, safe and easy to use abundantly available and is of consistent quality.
- Polypropylene fibers are also compatible with all concrete chemical admixtures and can be handled with ease. The high molecular weight of polypropylene, gives it many useful properties.
- Polypropylene fibers are chemically inert and hence, any chemical that will not attack the concrete constituents will not have any effect on the fiber also. When more aggressive chemicals come in contact, the concrete will always deteriorate first before fibers.

- It reduces the settlement and bleeding in concrete. The resistance to abrasion, freeze and thaw, Impact is improved.
- Presence of Pp fibers reduces the appearance of cracks during shrinkage in the early age of concrete, during first 12 hours, by increasing strength and strain capacity of cement paste.
- Cracking control is essential for the development of more durable and long-lasting structures.
- It has increase the tensile strength, toughness and to improve the deformation characteristics of the composite.
- Polypropylene fibers reduces the water permeability, increases the flexural strength due to its high modulus of elasticity.
- Polypropylene has a hydrophobic surface that prevents it from being wetted by the cement paste (R. Brown *et al.*, 2002).
- Perfectly isotactic Polypropylene has a high melting point of 171°C (Dr.T.Ch.Madhavi1 *et al.*, 2014).
- The addition of PP fibers could prevent micro cracks in concrete. Control of micro cracks could prevent the development of macro cracks when a dynamic load is imposed directly on the surface of the concrete. This idea has been applied to improve the strength of the building structure (beams, slabs and columns) through the addition of PP fibers (A. Saadun *et al.*, 2016).
- Polypropylene fiber is a light weight synthetic fiber. It prevents crack formation and provides reinforcement to the concrete structure (Divya S Dharan and Aswathy La, 2016).
- The emergence of polypropylene Fibers has introduced to the world the possibility of having a high-performance and more cost-effective product in the market place. Polypropylene fibers also possess better durability as plastic does not rust. It also contributes

to the ease in handling as it weight about one-fifth of an equivalent steel fiber (Salahaldein Alsadey and Muhsen Salem, 2016).

- Concrete reinforced with polypropylene mono-filament fiber may be used as secondary reinforcement but cannot replace the primary (Salahaldein Alsadey and Muhsen Salem, 2016).
- Polypropylene fibers should not be used for structural reinforcement. These fibers should not be used to produce thinner sections and also to increase joint spacing than those suggested for unreinforced masonry (Dr.T.Ch.Madhavi *et al.*, 2014).
- Exacting of production technology. Pp Fiber want special method of adding which effect in fiber bonding, distributed and other fresh and hard Properties of concrete specially with increases of percentage of volume.

- **Mix Method and Production of Polypropylene Fiber Reinforced Concrete**

(State of the Art Report on Fiber Reinforced Concrete) Currently, there are two different synthetic fiber volume contents used in applications today. They are 0.1 to 0.3 percent, which is referred to as low volume percentage, and 0.4 to 0.8 percent, which is referred to as high-volume percentage. There are also two different physical fiber forms. They are monofilament and fibers produced from fibrillated tape. Most synthetic fiber applications are at the 0.1 percent by volume level to control plastic shrinkage cracking (James *et al.*, 2002).

Generally, Mix designs and production procedures must be carefully adjusted before placing into full production. Follow the manufacturer's recommendations regarding material handling and safety procedures. The addition of fiber to concrete requires modifications to your mix designs. More slurry or paste is required to coat the fiber just as the aggregates are coated in a well-graded mix. There are three ways to

achieve this: first by adding more cement and water, second by adjusting the ratio of the coarse aggregates and third by adjusting the ratio of fine to coarse aggregates. Mix times may increase when fibers are introduced into the mix. The mix time depends on when the fibers are introduced and the efficiencies of the equipment being used.

Once mix designs are dialed in, the production process for fiber-reinforced concrete does not differ much from traditional concrete. The transporting, placing, vibrating and curing processes are all the same. The difference is in the mixing process, how and when to add the fiber to the mix. Fiber can be added manually or by using an automated system (R. Brown *et al.*, 2002)

Most synthetic fiber companies package their products in pre-weighed bags that dissolve in water. This feature is ideal for adding fiber to the mix, is safer, and lends itself to custom automation for plant-by-plant situations (NPCA Fibers White Paper - National Precast Concrete Association, 2016).

James *et al.*, (2002) Polypropylene fibers have been incorporated into concrete using several methods. They may be mixed as short discrete fibers of monofilament or fibrillated form. It has been reported that polyethylene fibers could be easily dispersed in concrete matrices in volume percentages of up to 3 percent using conventional mixing techniques (James *et al.*, 2002)

Concrete panels with monofilament polypropylene fiber have been produced using a spray suction dewatering technique (James *et al.*, 2002) Monofilament fibers also have been used in a pressing technique (Brown *et al.*, 2002).

(Daniel *et al.*, 1998) state that (Brown *et al.*, 2002) produced concrete panels reinforced with chopped mono-filament polypropylene fiber by a ‘*spray suction de-watering*’ technique. Fiber volume content up

to 6% can be achieved by using the spray suction de-watering techniques. Composites incorporating chopped monofilament and chopped fibrillated polypropylene film are produced using a mixing, dewatering and pressing technique.

Fiber volumes up to 11% have been obtained by mixing chopped fiber directly into the matrix at high water-cement ratios and then removing the excess water through suction and pressing. A hand lay-up technique was used to produce composites with continuous network of polypropylene fibrillated films (Hannant, 1978) Woven polypropylene mesh can be incorporated into a cement matrix using a hand lay-up technique.

High volume percentage of fibers (up to 12%) in the cement matrix can be obtained by using continuous polypropylene film networks or woven mesh with the hand lay-up technique (Daniel *et al.*, 1998)

With the hand lay-up technique, higher fiber volume percentages (up to 12 percent) can be obtained than with conventional batch mixing techniques (up to about 1 percent). Spray suction dewatering techniques can produce composites with as high as 11 percent fiber by volume (James *et al.*, 2002).

When chopped polypropylene fibers are incorporated into conventional ready mix concrete, volume percentages of fibers must be kept relatively low. This indicates that special mixing conditions are needed for high fiber volumes. The practical implication of this is that low fiber volumes should be specified for placement. Several researchers have acknowledged that the addition of polypropylene fiber to concrete has a marked effect on the concrete slump, which is a measure of how concrete flows. A low slump rate is undesirable as molds will not fill efficiently leaving voids. Fiber reinforced concrete slump is dependent on fiber length and fiber concentration (Daniel *et al.*, 1998).

Conventional ready-mixed concrete can easily be produced using monofilament or fibrillated fibers at 0.1 percent volume with little loss of consistency as measured by slump. However, slump loss will increase more rapidly beyond this point (Hannant, 1978). The slump loss is dependent upon the fiber length as well. Slump is often, though improperly, used as a measure of workability, and it is often said that the workability of concrete is reduced in the presence of fibers. However, with standard placement practices, fiber concrete will work, place, and pump readily. No additional mixing water is required and none should be added. Since the conventional slump test is an inappropriate measure of workability for FRC, it is recommended that the inverted slump cone test (ASTM C 995) or the Vebe Test (American Concrete Institute 211.3) be used to evaluate workability.

Synthetic fibers are usually added to ready-mix concrete at the batch plant (Hannant, 1978). Conventional placement methods are applicable, including batch placement and pumping (James *et al.*, 2002).

2.2.3.2 Studies on General Polypropylene Fibers Reinforced Concrete Properties

- **Static Modulus and Pulse Velocity**

Electrical resistivity of concrete samples with fibers ratios of 1 and 1.5 kg m³ had higher values in comparison with other samples. It has direct effect on the corrosion reduction of rebar that the addition of fibrillated polypropylene fibers with fiber contents ranging from 0.1 to 2.0 in quantities varying from 0.1 to 2.0 percent by volume had no effect on the static modulus of elasticity (Ramakrishnan *et al.*, 1987; Ramakrishnan, *et al.*, 1989). The results showed that there was little or no effect on the measured pulse velocities due to the addition of fibers to the

control concrete indicating that concrete matrix qualities were not compromised by the addition of fibers.

- **Shrinkage and cracking**

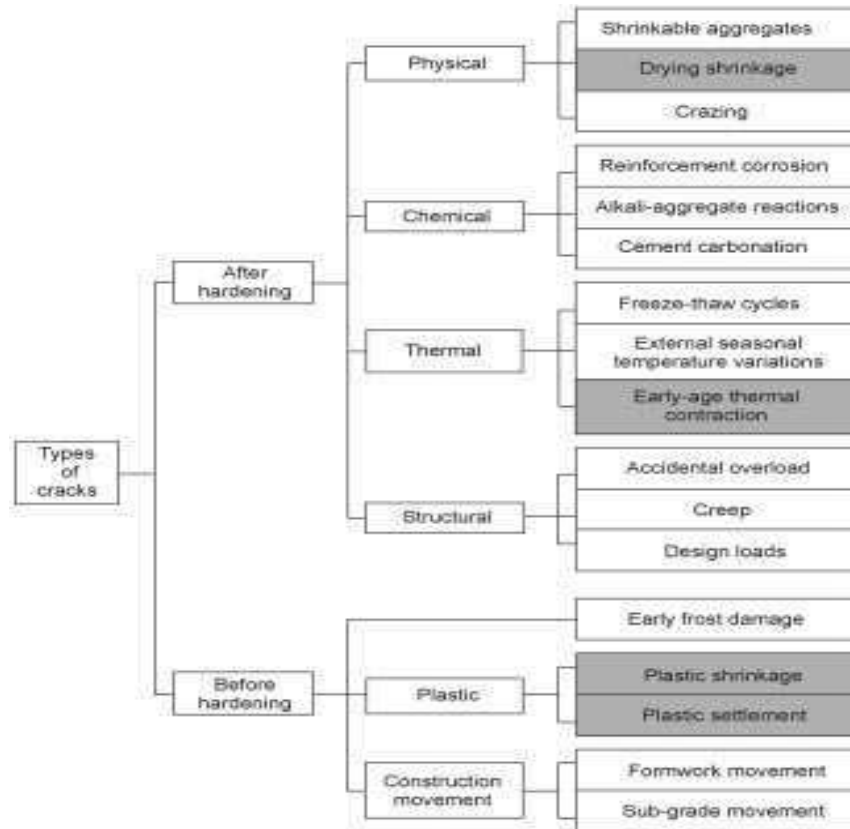


Figure (24): Types of crack (The Concrete Society, 2007).

One possible method to reduce these adverse effects of cracking due to restrained shrinkage is addition of short and randomly distributed fibers (S.R.R. Senthilkumar and S.C. Natesan, 2004).

The best and most acceptable method for preventing cracks formations caused by paste contract is by using fibers, particularly thin artificial ones with the volume of less than 0.5% (S.R.R. Senthilkumar and S.C. Natesan, 2004).

Addition of fibers is known to considerably reduce the width of cracks resulting from restrained shrinkage it has effectively control the maximum extent of plastic shrinkage cracking and crack width in any of the concrete mixes. Fiber parameter "specific fiber surface" seems to be

very effective in describing the use of fibers in controlling the restrained plastic shrinkage cracking in concrete (S.R.R. Senthilkumar and S.C. Natesan, 2004).

Thinner and longer fibers are more streamlined than thicker and shorter ones, while more effective control is achieved with fibrillated rather than monofilament fibers (S.R.R. Senthilkumar and S.C. Natesan, 2004).

Beneficial effect of polypropylene fibers on reducing the crack width is positively reflected on the value of restrained shrinkage (American concrete institute, 2010; Marijana *et al.*, 2015).

➤ Plastic Shrinkage

Plastic shrinkage is the contraction of the concrete due to water evaporation from the mixture. This causes the concrete to weaken and can lead to cracks, internal warping and external deflection (Ahmed *et al.*, 2006).

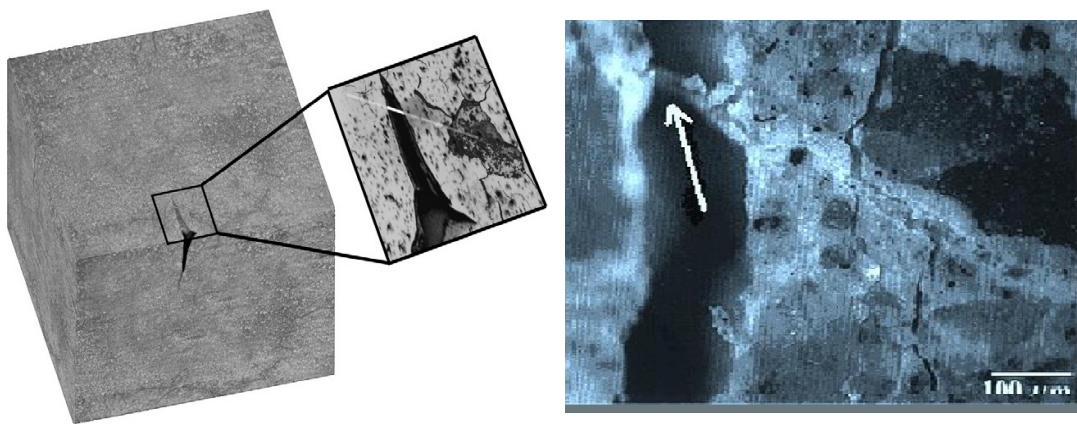


Figure (25): Microscopic picture of the intersections of fiber and crack formed on the concrete surface (Saeid *et al.*, 2012).

Plastic shrinkage cracks are so-called because they form while the concrete is still plastic, i.e. has not set. Rapid drying of the surface of the

plastic concrete causes it to shrink and crack, but the cracks are total ways evident during finishing operations and may not be discovered until the next day. Plastic shrinkage cracks may form in a random manner or be roughly parallel to each other. The cracks are often almost straight, ranging in length from 25 mm to 2 m but are usually 300 to 600 mm.

They rarely occur near the edges of a slab as at those locations the concrete is usually free to move. They can be up to 3 mm wide at the surface but usually taper quickly over their depth but may penetrate right through a concrete element. These cracks form a weakness in the concrete and will be widened and/or extended by subsequent drying shrinkage and the movement.(plastic shrinkage Cracking,june2005Simplistically, plastic shrinkage cracking occurs when the rate of evaporation of moisture from the surface exceeds the rate at which moisture is being supplied to it (via bleeding from the concrete). The concrete surface dries out and shrinks at a time at which it has little strength and hence it cracks. It can be likened to the cracking that occurs in clay soil as it dries. Water is lost from the concrete mass in two main ways. Drying from the top moisture rises to the top surface of a concrete element during placement a process known as bleeding. Bleed water dries out mainly from evaporation; when the rate of evaporation exceeds the rate of bleeding, the surface dries and tends to crack. Drying from the base Water in a concrete slab may be absorbed into the sub grade or ground below. In addition to affecting bleeding this could significantly increase settlement of concrete and the risk of associated cracking. The rate of evaporation from the surface is dependent on environmental factors such as temperature, relative humidity and wind speed. It is not just a hot weather phenomenon, as the combination of these factors may provide the worst conditions in cool weather with low humidity and wind. Mix design sets the bleed capacity of the concrete. This may be changed from hot to cold conditions to suit

the finishing operations and crack-control requirements. Concretes with low bleed potential (e.g. those containing a high proportion of fine material such as silica fume, fine aggregate, low slump) are more prone to plastic shrinkage cracking. However, mixes with high bleed characteristics are not recommended as a solution as they give rise to other problems (e.g. increased risk of plastic settlement cracking, crazing, delays in finishing processes, greater long-term shrinkage). PpFRC concrete is also more prone to plastic shrinkage cracking because it change the concrete to brittle material and stop generation of crack

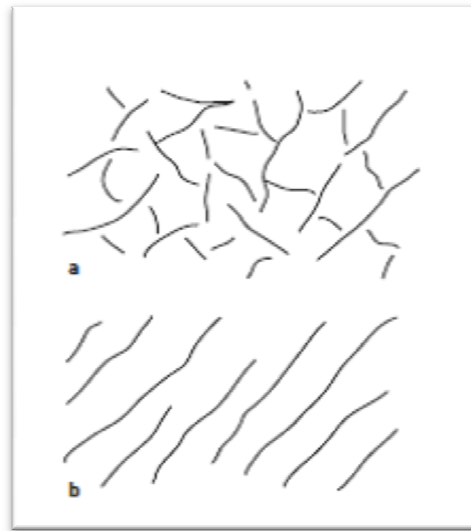


Figure (26): Plastic shrinkage crack.

Concrete shrinkage could be challenging during construction, especially for the flat structural elements for example the floors and slabs (G.M. Sadiqul and Sristi, 2016). Plastic shrinkage cracks are typically observed in thin concrete elements with a high surface area to volume ratio (G.M. Sadiqul and Sristi, 2016).

Plastic shrinkage is due to a very rapid loss of moisture from the freshly laid concrete within a few hours of placement while the concrete is still plastic and before it gains any significant strength (S.R.R. Senthilkumar and S.C. Natesan, 2004).

Fresh concrete is susceptible to plastic shrinkage cracking especially during hot, windy, and dry weather conditions (National Ready Mixed Concrete Association (NRMCA), 2015; G.M. Sadiqul and Sristi, 2016). If the evaporation rate becomes significantly higher than bleeding rate, it can cause high tensile stresses to develop in the capillary pores in the surface zone of concrete that may be sufficient to exceed the tensile strength of concrete, especially at early ages (G.M. Sadiqul and Sristi, 2016). In case of the surface cracks that develop as a result of plastic shrinkage remain unnoticed, they become channels for passage of external deteriorating agents and reduce long-term durability (G.M. Sadiqul and Sristi, 2016).

If an appropriate volume fraction (0.2%) and diameter of fibers are used, it is possible to reduce the total amount of plastic shrinkage cracking to 10% of control (American Concrete Institute 544 10, 2010).

The addition of non-metallic fiber (polypropylene) has been reported to provide adequate tensile strength to concrete in addition to controlling shrinkage cracks (G.M. Sadiqul and Sristi, 2016).

Presence of Pp fibers reduces the appearance of cracks during shrinkage in the early age of concrete, during first 12 hours, by increasing strength and strain capacity of cement paste (Marijana *et al.*, 2015).

Plastic shrinkage cracks were reduced by 50–99% compared to the control concrete by addition of 0.1–0.3% fiber. With an increase in the non-metallic fiber (polypropylene) content, the crack width significantly reduced by 72–93% for up to 0.25% fiber and cracks almost eliminated with 0.3% fiber addition (G.M. Sadiqul and Sristi, 2016). Other research has shown that low volume contents, 0.1 percent, of low effective diameter polypropylene fiber significantly limit crack size for plastic shrinkage cracks that occur within the first few hours after casting (Saeed

et al., 2006). The shrinkage cracking is reduced by 83 to 85% by addition of fibers up to 0.35% and 0.50 %.

Unrestrained drying shrinkage tests conducted at an early age and using accelerated drying conditions (Zollo *et al.*, 1986) “Plastic and Drying Shrinkage in Concrete Containing Collated Fibrillated Polypropylene Fibre,” Third International Symposium on Developments in Fiber Reinforced Cement and Concrete, RILEM Symposium FRC 86, indicated reductions of 18, 59, and 10 percent for fiber volumes of 0.1, 0.2, and 0.3 percent. These same authors also reported plastic shrinkage reductions of 12 to 25 percent for polypropylene contents ranging from 0.1 to 0.3 percent by volume.

In there strained condition, shrinkage strains translate into tensile stresses in concrete. After cracking, polypropylene fibers are believed to transfer tensile stress across cracks and act to arrest or confine crack tip extension so that many fine (hairline) cracks occur instead of fewer larger cracks (Vondran, 1987) Making More Durable Concrete With Polymeric Fibers (Mather International Conference, SP-100, American Concrete Institute), (James *et al.*, 2002).

Other research has shown that low volume contents, 0.1m percent, of low effective diameter polypropylene fiber significantly limit crack size for plastic shrinkage cracks that occur within the first few hours after casting (S.R.R. Senthilkumar and S.C. Natesan, 2004). The Relationship of Polypropylene Fiber Reinforced Concrete to Permeability, SP 108, American Concrete Institute and Padron and Zollo, R. F. (1990) from ACI Materials Journal showed that effect of Synthetic Fibers on Volume Stability and Cracking of Portland Cement Concrete and Mortar.

➤ **Drying Shrinkage**

Reductions in drying shrinkage (or volume change) in unrestrained specimens have been reported using polypropylene fibers at 0.1 percent by volume (Zollo, *et al.*, 1986). Unrestrained drying shrinkage tests conducted at an early age and using accelerated drying conditions indicated reductions of 18, 59, and 10 percent for fiber volumes of 0.1, 0.2, and 0.3 percent, respectively. Some studies did show potential beneficial effect on drying shrinkage when 0.1% of PP fibers by volume (Marijana *et al.*, 2015).

➤ **Autogenous shrinkage**

The autogenous shrinkage is due to the self-desiccation as the hydration of cement goes on and the cement paste starts hardening. Investigation on influence of different PP fibers volumes show that for 0.25, 0.5, and 0.75% of fibers autogenous shrinkage decreases progressively for 5, 15, and 26%, respectively (Marijana *et al.*, 2015).

Additional decrease of deformation due to the early autogenous shrinkage can be achieved with usage of pre moistened PP fibers and corresponding reduction of added water (Marijana *et al.*, 2015).

• **Environmental Effects**

The environmental effects on the polypropylene fibers used for reinforcement can change in the properties of the polypropylene fibers such as: affects the bonding characteristics of the fibers with the matrix, which subsequently alters the performance of the FRC loaded conditions (R. Brown *et al.*, 2002).

• **Elevated Temperatures**

The results showed that there was little or no effect on the measured pulse velocities due to the addition of fibers to the control concrete indicating that concrete matrix qualities were not compromised

by the addition of fibers (Nemkumar *et al.*, 2012). PpFRC increased resistance of composites to spalling during fire (C.J. Hookham, 1995).

Full scale fire testing of metal deck composite slabs, utilizing fibrillated polypropylene fibers and no other reinforcement, has been reported (Vondran, 1988) Test results indicated that the presence of fibers had no adverse effect and that a two-hour fire rating could be achieved for unprotected steel deck composite slab system and a three-hour fire rating could be achieved for a protected steel deck composite slab system. Matthias *et al.*, (2006). The results of research project have been shown that a great influence of the amount of polypropylene (PP) fibers on the spalling behavior of concrete under fire loading. Starting from the identification of the permeability as the parameter with the greatest influence on spalling.

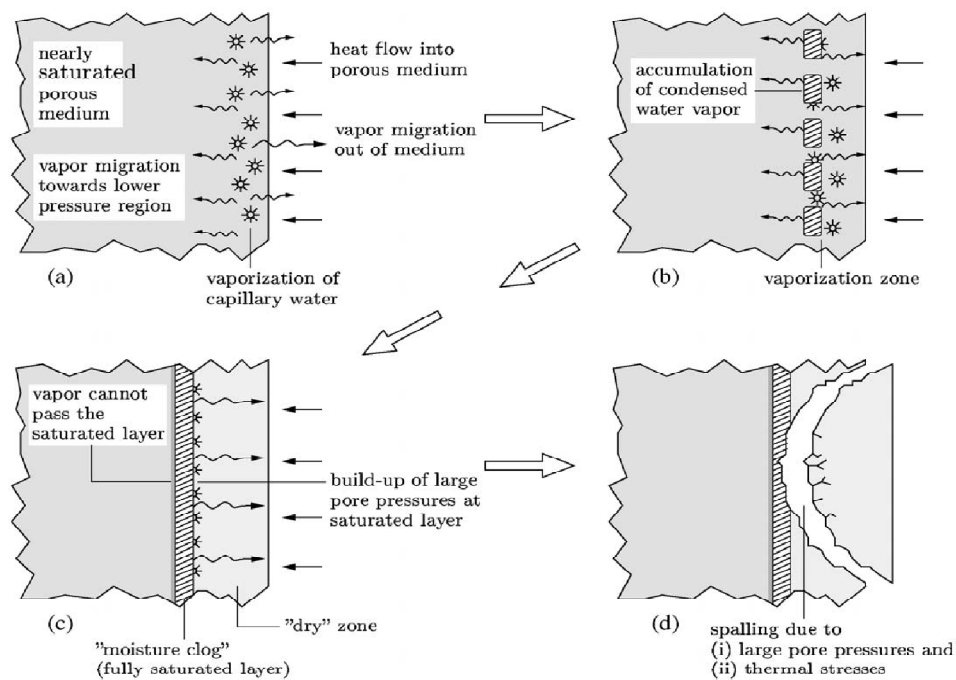


Figure (27): lustration of mechanism of spalling of concrete as a result of fire loading according (Matthias *et al.*, 2006).

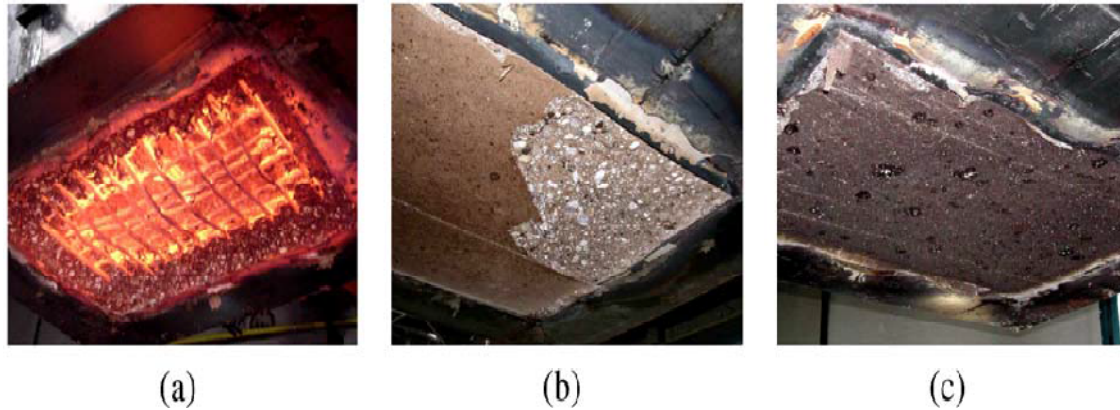


Figure (28): Spalling depth for concrete with (a) 0, (b) 1.5, and (c) 3.0 kg/m³ PpFRC (heated surface after 120 min of fire loading).

Matthias *et al.*, (2006) Motivated by recent results from large-scale fire experiments showing a great influence of the amount of polypropylene (PP) fibers on the spalling behavior of concrete, permeability and mercury-intrusion-porosimetry (MIP) experiments were conducted on in-situ concrete. Based on the obtained results, the following conclusions can be drawn: For pre-heating temperatures lower than 140 °C, the permeability of concrete with 1.5 kg/m³ PP-fibers was three to four times larger than the permeability of concrete without fibers with decreasing difference for increasing temperature.

- **Bond Strength**

Generally, the effectiveness of polypropylene fibers in fiber reinforced concrete depends upon the mechanical bond between the fiber and cement paste.

Polypropylene is chemically inert and hydrophobic, thus eliminating the potential for chemical bonding. As a result, the mechanical bond of fibrillated polypropylene fibers can be greater than monofilament polypropylene fibers. The fibrillated polypropylene fiber exhibits improved mechanical bonding as a direct result of cement matrix

penetrating the fibrillated network that anchors the network in the matrix (Hannant, D. J., 1978). The chemical bond between polypropylene fiber and the cement paste is very poor (Daniel *et al.*, 1998; R. Brown *et al.*, 2002).

However, the improved bond is almost entirely physical and is a direct result of cement matrix penetration into the network of individual fiber filaments created by fibrillation (Hannant, D. J., 1978).

Polypropylene fiber having non-polar nature and thus inhibits adhesion to concrete that can further improved by its surface treatment (Saman *et al.*, 2015).

2.2.3.2.1 Studies on Fresh Properties of Polypropylene Fibers Reinforced Concrete

- **Workability**

Generally, when fibers are added to the concrete slump will decrease (Malisch, W. R, 1986). The Reduction of slump is noticed with increase in fiber content, especially beyond 1.5% dosage, the mix becomes fibrous which results in difficulty in handling (Kolli, 2013). According to one fiber manufacturer's representative, the reduction in slump depends on the length of fiber used; longer fibers cause a greater slump reduction. Adding water improve workability but will reduce strength and increase shrinkage (Malisch, W. R, 1986).

Satisfactory workability was maintained even with a relatively high fiber content (2.0 percent by volume) with the addition of an appropriate amount of high-range water reducer to maintain equal strength and water-cement ratio (Shende .A.M and Pande .A.M, 2011) high quantities of fiber (2.0 percent by volume) produced concrete with poorer workability, more bleeding and segregation, relatively higher entrapped air (13.9 percent), and lower unit weight. This resulted in a

decrease in the compressive strength. This observation indicates the importance of adjusting aggregate proportions when high quantities of fibers are used (Shende .A.M and Pande .A.M, 2011) “Flexural Fatigue Strength, Endurance Limit, and Impact Strength of Fiber Reinforced Concrete,” *Transportation Research Record* 1226, National Research Council, n Washington D. C., 1989.

Workability of concrete decreased with increase in polypropylene fiber volume fraction (Dr.T.Ch.Madhavi *et al.*, 2014), reported that the workability of concrete decreased with the addition of polypropylene fibers but it can be overcome by addition of High Range Water Reducing Admixtures(Dr.T.Ch.Madhavi *et al.*, 2014), reported that the workability of concrete reduced with higher polypropylene fiber content. Vee Bee time indicated that at 0.5% of fiber content workability is high while at 1% it is medium.

Salahaldein and Muhsen, (2016) The reduction of slump is noticed with increase in polypropylene fiber content, especially beyond 2 % dosage, the mix become fibrous which results in difficulty in handling.

A. Saadun, (2016) sample 1kg/m³ has a 60 mm slump, and the addition of 2 kg/m³ PP reduced the slump to 23 mm.

There is a reduction in slump with the increase in fiber content, especially beyond 1.5% dosage (Kolli, 2013).

Workability decreases due to more addition of fibers, there is increases in amount of entrapped air voids due to the presence of fibers and therefore increase in air content attributes in reducing workability (Divya S and Aswathy, 2016).

Polypropylene fibers dose not disperse properly in the mixing water. Fiber volume fraction – 0%, 0.5%, 1%, 1.5%and 2 %.using Super plasticizer (Dr. T.Ch.Madhavi *et al.*, 2014) observed that Polypropylene fibers dose not disperse properly in the mixing water.

Workability of concrete decreases with increase in polypropylene fiber volume fraction. However, higher workability can be achieved with the addition of HRWR admixtures even with w/c ratio of 0.3. (T.Ch.Madhavi *et al.*, 2014).

When polypropylene fibers are used in concrete as secondary reinforcement, they are added in such low levels (0.1 to 0.2 percent by volume) that the reduction in workability is small, despite significant changes in slump. Because fibers affect the slump of concrete much more than they do its actual workability, ASTM Committee C09.03.04 is now considering adoption of an inverted slump cone test to replace the conventional slump test for fiber concretes.

Polypropylene fiber reinforced concrete is reported to respond well to vibration. It flows satisfactorily when kept moving, and segregation is reduced. Special attention should be given, though, to good vibration; closer than normal spacing of vibrator insertions is recommended. If improved workability is still required, the amount of air entraining agent can be increased or a water reducer, super plasticizer or up to 10 percent fly ash can be added.

Polypropylene fibers do not absorb water, so more water should not be added (S.K.Singh. Propylene Fiber Reinforced Concrete: An overview).

Dr.T.Ch.Madhavi *et al.*, (2014) used monofilament polypropylene fibers in self compacting concrete with fly ash and studied the workability and Mechanical properties. The materials used in this study showed no workability or segregation problems.

Kolli, (2013) concluded to The Reduction of slump is noticed with increase in fiber content, especially beyond 1.5% dosage, the mix becomes fibrous which results in difficulty in handling.

- **Bleeding**

According to the researches, the increase of formability and bending strength are the extra advantages of adding the fibers to the concrete (Saeid *et al.*, 2012).

Although fibrillated polypropylene fibers, cement, and aggregates were added to the mixer simultaneously, no balling occurred even at higher quantities of fibers. The fresh concrete with fibrillated polypropylene fibers had no surface bleeding and no segregation (James *et al.*, 2002).

2.2.3.2.2 Studies on Hardened Properties of Polypropylene Fibers Reinforced Concrete

- **Ductility**

The fiber diameter and length also can have a direct effect on post-peak ductility behavior of FRC (Seong *et al.*, 2015).

Dr.T.Ch.Madhavi *et al.*, (2014), also reported that polypropylene fibers can be utilized to control fresh and hardened properties of concrete and that PpF can decrease the plastic shrinkage.

- **Compressive Strength**

Compressive strength of concrete is one of the most important properties of concrete. It is a qualitative measure of concrete. Failure of concrete under compression is a mixture of crushing and shear failure.

The compressive strength varies as a function of both cement paste and fibers. Higher binder ratio gives higher compressive strength.

The effect of polypropylene fiber on the compressive strength of concrete has been discussed in some studies and they showed that polypropylene fiber either decrease or increase the compressive strength of concrete (Roohollah *et al.*,2012) that compressive strength increased

by about 25% at 0.5% volume fraction of PP fibers in the concrete mixture design

Dr.T.Ch.Madhavi *et al.*, (2014), found that the compressive, split tensile and flexural strength improved on addition of 1.5 % of polypropylene fiber in the concrete.

Compressive strength increases for all dosages of fibers due to confinement provided by fiber increases bonding characteristics of concrete. Compressive strength of 1.5% of blended length polypropylene fiber reinforced concrete has found to be 17% increase in strength, when compared to that of Conventional concrete. Strength enhancement in split tensile strength is 22%, flexural strength is 24% and modulus of elasticity is 11% compared to that of Conventional concrete. The experimental studies proved to be the best method or way in providing strong and durable concrete. It is observed 1.5% fiber in concrete yields max strength (Divya *et al.*, 2016).

The M25 and M30 grades of concrete mixes and polypropylene mono-filament macro-fibers of length 35mm at volume fractions of 0.0%, 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% were used so we can say that the increased compressive strength due to fiber percentage is due to fiber and aggregate bonding and not due to cement paste bonding. The fibers are acting as anchors between the cement paste and the fine and coarse aggregates which results in increased durability of concrete before failure (Saman *et al.*, 2015).

The compressive strength, split tensile strength, flexural strength and modulus of elasticity increase with the addition of fiber content as compared with conventional concrete (T.Ch.Madhavi *et al.*, 2014).

In general, the samples with fibers content of 1.5 kg/m³ showed optimum results in comparison with other samples in this study.

(James *et al.*, 2002) shown that there was no reduction in compressive strength when 0.1 to 1.0 percent by volume of fibers were added .

Salahaldein and Muhsen,(2016) observed that The compressive strength tests reveal that, the strengths were increased proportionately with the increase in volume ratios of polypropylene fiber with reference to the control mix without fiber. The percentage increase of compressive strength of polypropylene fiber concrete mixes compared to the mix without fiber is observed from 4 to 12 %. The samples with polypropylene fiber content of 2 % showed optimum results in comparison with other samples in this study.

According to the results of compressive strength tests, the concrete compressive strength increased proportionately with the increase in volume ratios of propylene fibers, the highest strength values were seen in the volume ratios of 1.5 kg/m³ and 2 kg/ m³ (Saeid *et al.*, 2012).

Researchers have shown a significant increase in the compressive strength of fiber reinforced concrete (Sabir *et al.*, 2013), concluded that polypropylene fibers have a relatively small favorable effect on compressive strength of concrete when 12 mm (1/2 in.) long fibers were used.

A. Saadun *et al.*, (2005), noted an enhancement of approximately 6% when using polypropylene fibres with a fibre content of 0.6 kg/m³ (0.037 lb/ft³).

Mtasher *et al* .,(2011) noted a 22% increase in the compressive strength of concrete due to the presence of fibers in the concrete mix; the results of their study showed that the addition of polypropylene fiber in the amount of 0.4% and 1.5% increased the compressive strength up to 11% and 56% respectively (A. Saadun *et al.*, 2016).

The optimum percentage of polypropylene to be added to the concrete mix to increase the compressive strength lies around 0.25%. Polypropylene fibers increased the 28 days compressive strength of concrete by about 9%. Polypropylene fiber addition greater than the optimum percentage (0.25%) showed a slight increase for 0.50% and then decreased for higher values (Anthony and Oluwabambi, 2014).

Dr.T.Ch.Madhavi *et al.*, (2014) used fibrillated polypropylene fiber of length 12mm and diameter 34 micron and low density of 0.9 kN/m³, in percentages of 0.5%, 1% and 1.5% in high strength concrete. Super plasticizer Conplast-Sp430 was used. They observed that the compressive strength of concrete increased with addition of fibers.

Dr.T.Ch.Madhavi *et al.*, (2014) studied the effect of polypropylene fibers in fly ash concrete. Fiber volume fraction of 0.15%, 0.2%, 0.25% and 0.3% was used in fly ash concrete with class C fly ash of specific gravity 1.96, obtained from NLC. Fly ash content was varied as 30%, 40% and 50%. 12 mm (40%) and 20 mm (60%) coarse aggregate with specific gravity of 2.7 were used. The compressive strength gained maximum strength at early age as observed for all fly ash and polypropylene fiber concrete. It is also observed that the compressive strength increased gradually from 0.15% to 0.3% fiber content.

The Compressive strength and splitting tensile strength tests reveals that, the strengths were increased proportionately with the increase in volume ratios of Polypropylene Fibers with reference to the controlled mix without fibers. The maximum increase in Compressive strength was 34% and split tensile strength was 40% compared to the mix without fibers. The samples with fibers content of 1.5 % showed optimum results in Comparison with other samples in this study (Kolli, 2013).

Dr.T.Ch.Madhavi *et al.*, (2014) appears that at low dosage rates (0.5% to 1%) the addition of polypropylene fibers does not significantly detract from, and even improve the compressive strength. Higher dosage rates however decrease the strength of concrete matrix due to higher volumes of fibers interfering with the cohesiveness of the concrete matrix.

Other researchers have concluded that there are no significant compressive strength differences between mixes with and without polypropylene fibers. Others have found a modest increase in compressive strength when fibers are added, Some increase in compressive strength is possible when fibers are added to concrete and an increase in fatigue resistance (Malisch, W. R, 1986), notable increase in compressive strength is reported with addition of polypropylene fibers (T.Ch.Madhavi *et al.*, 2014).

Higher dosage rates however decrease the strength of concrete matrix due to higher volumes of fibers interfering with the cohesiveness of the concrete matrix (Hamed and Abdulkader, 2016).

(Hamed and Abdulkader, 2016) observed that the compressive strength decreased up to 1.5 % fiber content. The cube compressive strength was observed as 40.21 MPa for 0.5% of fibers, 39.23 MPa for 1% of fibers and 37.61 MPa for 1.5% fiber content in the concrete at 28 days.

Addition of 0.3%, 0.6%, 0.9% and 1.2% resulted in a decrease of compressive strength relative to concrete by 9%, 19%, 1%, and 18% respectively (Mustapha, 2014).

Many researchers reported that polypropylene fiber in small volume fraction (between 0.05% to 0.5%) has no or very small effect on

the compressive strength of fiber reinforced concrete (A. Saadun *et al.*, 2016).

The comparison between the different values of compressive strength of concrete for (7 and 28 days) shows a decrease gradually due to the addition of polypropylene fiber from 0.00% to 1.5%. There is a decrease in compressive strength as compared with normal plain concrete (without fibers). Thus the percentages of compressive strength decreases are: (152.8, 58.6, 57.2, and 71.5), for fiber content percent (0.00%, 0.50%, 1.00%, and 1.50%).

A. Saadun *et al.*, (2016) suggested that compressive strength decreases but flexural properties are improved with increasing fiber content. That, for a specific concrete mix used for both control concrete and fiber concrete, high quantities of fiber (2.0 percent by volume) produced concrete with poorer workability, more bleeding and segregation, relatively higher entrapped air (13.9 percent), and lower unit weight. This resulted in a decrease in the compressive strength (Shende. A.M and Pande. A.M, 2011). Optimum mixture proportions should be obtained by trial mixes when using higher fiber volumes. (Optimum mixture proportions should be obtained by trial mixes when using higher fiber volumes. This was demonstrated in another investigation by (Faisal Fouad wafa, 1990; ShashwatSharda *et al.*, 2016). It was shown that there was no reduction in compressive strength when 0.1 to 1.0 percent by volume of fibers were added with the addition of polypropylene fiber (0.1–0.3%) the compressive strength of the concrete decreased by 2–10% which is minor compared to the control concrete. The optimum fiber content for the compressive strengths is 0.1% for which reduction of compressive strength of this content is about 2 % (G.M. Sadiqul, Sristi, 2016).

Compressive strength of material increases within creasing fiber content. Strength enhancement ranges from 8% to 16% for PFRC (A P Sathe, 2014) when it observed Fiber volume fraction – 0%, 0.5%, 1%, 1.5% and 2 %. With super plasticizer .

- **Flexural Strength**

(Dr.T.Ch.Madhavi *et al.*, 2014.) reported that the flexural strength increases with addition of fiber content.

The compressive strength, split tensile strength, flexural strength and modulus of elasticity increase with the addition of fiber content as compared with conventional concrete (Dr.T.Ch.Madhavi *et al.*, 2014.)

When it observed fiber volume fraction 0%, 0.5%, 1%, 1.5% and 2 %. With super plasticizer .The flexural strength increases with increasing fibre content. The maximum increase in flexural strength of PFRC is 36%. The flexural strength of the mix with the dosage of 0.5% and 2% are increased by 16% and 36% respectively.

Anthony and Abimbola, (2014), the flexural strength of concrete increases by as much as 65% when low percentage fractions (0.25%) are added it is observed that the optimum dosage of polypropylene fiber is between 0.25% and 0.5% both for compressive strengths and for flexural strengths.

Dr.T.Ch.Madhavi *et al.*, (2014.) reported that the flexural strength increases with addition of fiber content (Murahari and Rama Mohan, 2013) tested 500 x 100 x 100 mm specimens under three point loading in accordance with ASTM C78. It is observed that the flexural strength increased with content up to 0.3% and gained more strength at 28 days when compared to 56 days.

A. Saadun *et al.*, (2016), the flexural strength increased 14.62 % and 2.34 % for 1 Kg/m³ and SC3, respectively (Dr.T.Ch.Madhavi *et*

al., (2014), studied the with M15, M20 and M25 grade concrete with 0%, 0.5 % and 1% fibers for flexure and shear behavior of deep beams and it is reported that there is marginal increase in flexural strength at first crack as fiber content increased from 0% to 1.0%.

Divya S *et al.*, (2016) strength enhancement in split tensile strength is 22%, flexural strength is 24% and modulus of elasticity is 11% compared to that of Conventional concrete. The experimental studies proved to be the best method or way in providing strong and durable concrete. It is observed 1.5% fiber in concrete yields max strength. The enhancement in flexural strength is achieved due to improvement in mechanical bond between the cement paste and fiber. As amount of fiber increases in mix, it greatly helps to reduce widening of cracks more effectively.

There is about 80% increase in flexure strength by adding 0.20% fibers in concrete after which strength starts reducing with further increment in fiber ratios (Saeed *et al.*, 2006; Hamed *et al.*, 2016)

The comparison between flexural strength values of concrete for (7 and 28 days) shows a gradual decrease with the addition of polypropylene fiber. There is a decrease in flexural strength as compared to normal plain concrete (without fibers). Thus the percentages of flexural strength decreases are: (63.5%, 59.8%, 42.56%, and 40.54%), for fiber content percentages of (0.00%, 0.50%, 1.00%, and 1.50%) respectively. There is a reduction in slump with increase in fiber content, especially beyond 1.5% dosage. However, the flexural strength for controlled mix at 28 days was observed as (4.84) MPa (Hamed and Abdulkader, 2016).

Mahendra Prasad, Chandak Rajeev *et al.*, (2013) conducted investigations on Polypropylene fiber reinforced silica fume concrete of M30 grade. The cement replacement by silica fume was 0%, 5%, 10%, 15% and fibers were added in the 0%, 0.2%, 0.4%, and 0.6% by volume

fraction of concrete. It is reported that the increase in flexural strength was around 40% with use of Polypropylene fibers and silica fume in concrete.

For 2.0 percent by volume fibrillated polypropylene FRC, the compressive strength was low due to the higher air content and, hence, the flexural strength was also low. Similarly, for 1.0 and 1.5 percent fibrillated polypropylene fiber volumes, the compressive strengths were low, and hence, the flexural strengths were also low. As a result, the direct flexural strength comparisons may be misleading (Shende. A.M and Pande. A.M, 2011).

There is no consensus in the published literature about the effect of adding polypropylene fibers on the first-crack strength and modulus of rupture. It has been reported that at a fibrillated polypropylene fiber content of 0.1 percent by volume, there was a slight increase in flexural strength (0.7 to 2.6 percent) and at 0.2 to 0.3 percent by volume there was a slight decrease. Others (Ramakrishnan *et al.*, 1987) Performance Characteristics and Fatigue of Polypropylene Fiber Reinforced Concrete, SP-105, American Concrete Institute, (Detroit, 1987) have reported that the modulus of rupture determined at 7 and 28 days was slightly greater for fibrillated polypropylene FRC at fiber contents of 0.1 to 0.3 percent by volume in comparison to plain concrete. When the same basic mix proportions were used, the modulus of rupture decreased as the fiber content was increased from 0.1 to 2.0 percent by volume (Ramakrishnan *et al.*, 1989) "Flexural Behavior and Toughness of Fiber Reinforced Concretes," *Transportation Research Record* 1226, National Research Council, Washington D. C., 1989. For 2.0 percent by volume fibrillated polypropylene FRC, the compressive strength was low due to the higher air content and, hence, the flexural strength was also low. Similarly, for 1.0 and 1.5 percent fibrillated polypropylene fiber volumes.

- **Tensile Strength**

The problem of low tensile strength of concrete can be overcome by addition of polypropylene fibers to concrete (T.Ch.Madhavi *et al.*, 2014).

Direct and indirect tensile testing of concrete has indicated little improvement in tensile strength when fibers are added (Malisch, W. R, 1986).

Murahari, Rama Mohan Rao, (2013) from their experimental investigations observed that there is not much significant interference of fibers on the split tensile strength. The split tensile strength gained more strength at early age of 28 days compared to 56 days.

So on an average to gain maximum compressive and tensile strength with mono-filament macro fiber the optimum dosage be limited 1% to 1.5%, after further increase these strength properties decreases (Saman *et al.*, 2015). The M25 and M30 grades of concrete mixes and polypropylene mono-filament macro-fibers of length 35mm at volume fractions of 0.0%, 0.5%, 1.0%, 1.5%, 2.0%, 2.5% and 3.0% were used.

A. Saadun *et al.*, (2016), the addition of 2 kg/m³ PP increased the splitting tensile strength to 18.32 % from 0 Kg/m³. The increment of PP volume enhances the tensile strength of concrete since PP fiber has high tensile strength. Maximum effect (39% increases) on tensile strength was noted with 0.1% fiber inclusion and with the increase in fiber content the strength was gradually decreased. However, the result was higher than that obtained for control concrete up to fiber content 0.25% (G.M. Sadiqul and Sristi, 2016).

Mustapha Abdulhadi, (2014) was observed that the incorporation of fibers in the concrete matrix greatly increases splitting tensile strength. Addition of 0.3% and 0.6% volume, the optimum dosage for the splitting tensile strength of polypropylene fiber is in the vicinity of 0.3%

Failure patterns of splitting tensile test indicate that specimens after first cracking do not separate unlike the concrete failure. Large damage zone is produced due to closely spaced micro cracks surrounding a splitting plane. Fiber bridging mechanism is responsible for such enhanced ductile failure pattern. Polypropylene fiber reinforced concrete has found to be 17% increase in strength, when compared to that of Conventional concrete. Strength enhancement in split tensile strength is 22%, flexural strength is 24% and modulus of elasticity is 11% compared to that of Conventional concrete. The experimental studies proved to be the best method or way in providing strong and durable concrete. It is observed 1.5% fiber in concrete yields max. strength (Divya *et al.*, 2016).

Hamed *et al.*, (2016). The comparison between tensile strength values of concrete for (7 and 28 days) shows a gradual decrease due to the addition of polypropylene fiber from 0.00% to 1.5%. There is a decrease in tensile strength as compared with normal plain concrete (without fibers). Thus the percentage tensile strength decreases are: (73.99%, 31.1%, 38.3%, and 48.5%), for fiber content percent of (0.00%, 0.50%, 1.00%, and 1.50%)

There is a reduction in slump with the increase in fiber content, especially beyond 1.5% dosage. However, the split strength for controlled mix at 28 days was observed as 3.88 MPa (Ramakrishnan *et al.*, 1987).

A P Sathe, (2014) when it observed Fiber volume fraction – 0%, 0.5%, 1%, 1.5% and 2 %. With superplasticizer Strength enhancement in splitting tensile strength due to polypropylene fiber addition varies from 5% to 23%. Split tensile strength at 28 days is approximately 50% higher than 7 day's strength.

The optimum dosage for the splitting tensile strength of polypropylene fiber is in the vicinity of 0.3% (Mustapha Abdulhadi, 2014)

The Compressive strength and splitting tensile strength increases proportionately with the increase in volume ratios of Polypropylene Fibers (Kolli, 2013).

- **Shear Strength**

Dr.T.Ch.Madhavi *et al.*, (2014) reported that the ultimate shear strength of the deep beams increased up to 5% for all the M15, M20 and M25 grades of concrete.

The shear capacity of concrete increases when fibers are added. There is a remarkable increase in load carrying capacity up to first crack appears (Saeed *et al.*, 2008).

The percentage increase in shear strength of the polypropylene fiber mix varies from 23% to 47% (Dr.T.Ch.Madhavi *et al.*, 2014) when it observed Fiber volume fraction – 0%, 0.5%, 1%, 1.5% and 2 % with super plasticizer. This is because of fibers enhances the load carrying capacity of mix.

- **Impact Strength**

Some recent research indicated that using fibers in concrete has limited effect on the impact resistance of the materials. This finding is very important since traditionally, people think that the ductility increases when concrete is reinforced with fibers. The results also indicated out that the use of micro fibers offers better impact resistance compared with the longer fibers (Amit, 2013) the impact strength increases as fiber content is increased (Mindess, S., Vondran, G., *et al.*, 1987).

Presence of fibers reduces the settlement and bleeding in concrete. The resistance to abrasion, freeze and thaw, Impact is improved (Dr.T.Ch.Madhavi *et al.*, 2014).

- **Dynamic Strength**

Inclusion of three-quarters of an inch long, fibrillated polypropylene fibers significantly improves the impact resistance of concrete slabs without affecting the natural frequency. However, the static compression and flexural strength decrease with increasing fiber content. With this information known, some of the possible applications of the composite are in machine pads, in warehouse and loading dock slabs, in sidewalks, and in roads. Several areas of interest remain to be explored. These include: utilizing a different material, such as crushed stone or sand, as the sub-base; varying the fiber length; trying different mix designs to maximize the fibers' contribution to strength; comparing the impact resistance of concrete slabs reinforced with polypropylene fibers to concrete reinforced with welded wire fabric; and determining how weathering affects the impact resistance (G. D. Manolis *et al.*, 1997).

The observations in (A. Saadun , 2016) study showed that The values of the dynamic increase factor (DIF) for polypropylene fiber reinforced concrete samples with 1.0 kg / m³ and 2.0 kg / m³ fibers are 2.14 and 4.15 respectively. This shows that the ultimate dynamic compressive strength in polypropylene fiber reinforced concrete increased significantly two- to fourfold compared with static compressive strength. Thus, it can be concluded that PP fiber increases the ultimate dynamic compressive strength of polypropylene fiber reinforced concrete.

- **Fatigue Strength**

The addition of polypropylene fibers, even in small amounts, has increased the flexural fatigue strength. Using the same basic mixture proportions, the flexural fatigue strength was determined for three fiber contents (0.1, 0.2, and 0.3 percent by volume) and it was shown that the endurance limit for two million cycles had increased by 15 to 18 percent

(Ramakrishnan *et al.*, 1987).It has good resistance to fatigue (Dr.T.Ch.Madhavi *et al.*,2014).

The endurance limits for two million cycles (the ratio of the maximum flexural fatigue strength to the modulus of rupture)increased by 16, 18, and 38 percent for 0.1, 0.5, and 1.0percent fiber content by volume, respectively, in comparison to plain concrete (Mindess, S. and Vondran, G., 1988)“Fatigue Strength of Polypropylene Fiber Reinforced Concretes,” *Fiber Reinforced Cements and Concretes: Recent Developments*, (R. N. Swamy and B. Barr, 1990).

Polypropylene FRC also shows increased static flexural strengths after being subjected to fatigue loading (Ramakrishnan *et al.*, 1989) value, there is an increase in the potential modulus of rupture value.

- **Toughness**

Some researchers also reported evidence of small but favorable effect of fiber addition on toughness (A. Mustapha, 2014).

The use of polypropylene fibers has successfully increased the toughness of concrete. Although polypropylene fibers are characterized by low elastic modulus and poor physiochemical bonding with cement paste, it is quite apparent that the load carrying ability of a structure under flexural loading is considerably increased (Hannant, D.J., 1978).

- **Permeability**

The presence of polypropylene fibers had caused delay in starting the degradation process by reducing permeability, reducing the amount of shrinkage and expansion of concrete that can significantly affect the lifespan of the structure (Saeid *et al.*, 2012).

Polypropylene fibers reduce the water permeability, plastic, shrinkage and settlement and carbonation depth (T.Ch.Madhavi *et al.*, 2014).

Permeability refers to the amount of water migration through concrete, Therefore, higher the permeability lesser will be the durability. Decreased permeability improves concrete's resistance to re-saturation, sulfate and other chemical attack, and chloride ion penetration (G.M. Sadiqul and Sristi, 2016).

With the addition of polypropylene fiber both water and gas permeability coefficients were increased. This might suggest restricting the use of polypropylene fiber content in the case of structural elements exposed to water (such as water tanks, dams, spillways, swimming pools) and harmful gases. Further work can be carried out with 0.1% and 0.15% polypropylene fiber to examine the optimum fiber content with respect to permeability characteristics of concrete.

In general, inclusion of 0.1% polypropylene fiber was found to be beneficial for concrete considering compressive (2% reduction) and tensile (39% increase) strengths and shrinkage (50% crack reduction and 32% crack with reduction) properties of concert (G.M. Sadiqul and Sristi, 2016).

The presence of polypropylene fibers had caused delay in starting the degradation process by reducing permeability, reducing the amount of shrinkage and expansion of concrete that can significantly affect the lifespan of the structure(Saeid *et al.*, 2012) of polypropylene fibers reduces the water permeability, increases the flexural strength due to its high modulus of elasticity (T.Ch.Madhavi *et al.*, 2014).

- **Durability**

Addition Polypropylene play an important role in durability because it controls the rate of entry of moisture that may contain aggressive chemicals and the movement of water during heating or freezing (G.M. Sadiqul and Sristi, 2016).

The durability of concrete improves and addition of polypropylene fibers greatly improves the fracture parameters of concrete (T.Ch.Madhavi *et al.*, 2014). It is well known that cracking control is essential for the development of more durable and long-lasting structures (Marijana *et al.*, 2015).

The durability of concrete improves and addition of polypropylene fibers greatly improves the fracture parameters of concrete (T.Ch.Madhavi *et al.*, 2014).

- **Failure**

However, the addition of polypropylene fibers has a significant effect on the mode and mechanism of failure of concrete cylinders in a compression test, The fiber concrete fails in a more ductile mode. This is particularly true for higher strength fiber concretes (T.Ch.Madhavi *et al.*, 2014).

The failure is gradual and ductile in polypropylene fiber reinforced concrete (T.Ch.Madhavi *et al.*, 2014) reported that Fiber addition has significant control on the failure modes of concrete and random orientation of fibers improve the fracture properties of concrete.

The presence of fibers in concrete alerts the failure mode of material. It is found that the failure mode of plain concrete is mainly due

to spalling, while the failure mode of fiber concrete is bulging in transverse directions (T.Ch.Madhavi *et al.*, 2014).

The failure is gradual and ductile in polypropylene fiber reinforced concrete (T.Ch.Madhavi *et al.*, 2014).

2.2.4 Applications of Polypropylene Fiber Reinforced Concrete (PpFRC)

Polypropylene fiber is a synthetic fiber with low density, fine diameter and low modulus of elasticity. It has some special characteristics such as high strength, ductility and durability, abundant resources, low cost, and easily physical and chemical reformations according to certain demands. Thus it can be widely utilized in the field of concrete products (Salahaldein and Muhsen, 2016).

Nowadays, the application of fiber in concrete increase gradually as an engineering material demand. The Knowledge is not only necessary to provide Safe (Shahiron Shahidan, 2009).

Many forms of commercial polypropylene are available. One form of Pp is a semi-crystalline solid with good physical and mechanical and thermal properties. Another form of PP, produced in much lower volumes as a byproduct of semi-crystalline PP production and having very poor mechanical and thermal properties. The crystallizable form of PP is termed as "isotactic" PP and the non-crystallizable form is termed as "atactic" PP (D. Jothi, 2008).

Generally, polypropylene fibers are new generation chemical fibers. They are manufactured in large scale and have fourth largest volume in production after polyesters, polyamides and acrylics. About 4 million tones of polypropylene fibers are produced in the world in a year (Dr.T.Ch.Madhavi *et al.*, 2014).

Several manufacturers currently produce polypropylene fiber specifically for use in concrete as a form of reinforcement as they possess many properties that make them particularly adaptable for use in concrete (D. Jothi, 2008).

Other suggested applications for concrete containing polypropylene fibers include structures such as median barriers that are subjected to impact loads, placements where all materials must be nonmetallic and areas requiring materials that are resistant to alkalis and other chemicals Polypropylene fibers in concrete (W.R Malisch,1986)

➤ Areas of Application Ground Supported Slabs

- Heavy parking areas.
- Drive through areas.
- Roadways.
- Pavements and Roadways.
- Warehouse Slabs.
- Bottling Hall.
- Storage Bins.



Figure (29): Application of PpFRC (www.bosfa.com).



Figure (30): Application of PpFRC for blast resistance, Military College of Engineering, Risalpur, Pakistan (Shehnil Fatima , 2013).



Figure (31): Applications of PPFRC for Sewage Channel, Khayaban-e- Jami, DHA, Karachi, Pakistan. (Shehnil Fatima, 2013).



Figure (32): Application of PpFRC for Man holes in industrial zone, Landhi, North Karachi, Pakistan. (Shehnail Fatima, 2013).



Figure (33): Application of PPFRC to reduce shrinkage cracking in column footing, Karachi, Pakistan. (Shehnail Fatima, 2013).