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Statistical Analysis of Polypropylene Fibre Reinforced Concrete

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***Abstract:** The capability of durable structure to resist weathering action and other degradation processes during its service life with the minimal maintenance is equally important as the capacity of a structure to resist the loads applied on it. Although concrete offers many advantages regarding mechanical characteristics, the brittle behaviour of the material remains a larger handicap for the seismic and other applications where flexible behaviour is essentially required. Reinforcement with randomly distributed short fibres presents an effective approach to the stabilisation of the crack and improving the ductility and tensile strength of concrete. Polypropylene (PP) fibre reinforcement is considered to be an effective method for improving the shrinkage cracking characteristics, toughness, and impact resistance of concrete materials. In the present study, we are carrying out the statistical analysis of Polypropylene fiber reinforced concrete by comparing various properties such as compressive strength, tensile strength, workability properties with various content of fiber (0%, 0.5%, 1% and 1.5%).*

***Keywords:** Polypropylene fiber Reinforced Concrete.*

CHAPTER - (1)

1.1 INTRODUCTION

Concrete is the most commonly used construction material worldwide. Reinforced concrete (RC) is extensively used in the construction of a variety of civil infrastructure applications including small and large buildings, houses, bridges, storage tanks, dams and numerous other types of structures.

Concrete is a brittle, composite material that is strong in compression and weak in tension. The tensile strength of plain concrete is about 10% of its compressive strength. Cracking occurs when the concrete tensile stress produced from the externally applied loads, temperature changes, or shrinkage in a member reaches the tensile strength of the material. Formation of tensile cracks in reinforced concrete flexural members containing conventional, non-prestress reinforcement is usually unavoidable since concrete has a low tensile straining capacity. While cracks barely wide enough to be visible may be objectionable only because of appearance, cracks of greater width can be dangerous because of the possibility of corrosive agents attacking the steel reinforcing bars. Excessively wide cracks can also result in leakage in such structures as dams, tanks, and pools. In many of the cases, this cracking is so significant that it may lead to failure of the structure. The deterioration of such structures is of great concern since the repairing and rehabilitation of these structures are time-consuming and costly. Hence there is an intense need to take measures that can control the cracking of concrete and thus cause overall safety of a structure and increase its useful life. Use of short discrete fibers in cementitious composites (concrete) is one approach to mitigate the cracking and increasing the tensile straining capacity.

The fibre reinforced concrete (FRC) contains randomly distributed short discrete fibres which act as internal reinforcement so as to enhance the properties of the cementitious composite (concrete). The principal reason for incorporating short discrete fibres into a cement matrix is to increase the toughness and tensile strength and to improve the cracking deformation characteristics of the resultant composite. These properties of FRC primarily depend upon the type of the fibres used in the concrete.

Several different types of short discrete fibres have been used to reinforce concrete. The choice of fibres varies from synthetic organic materials such as polypropylene or carbon, synthetic inorganic such as steel or glass, natural organic such as cellulose to natural inorganic asbestos. Short discrete steel, glass, polyester and polypropylene fibres are most commonly being used as reinforcement to the FRC. The selection of the type of fibres is guided by the properties of the fibres such as diameter, specific gravity, young's modulus, tensile strength etc. and the extent these fibres affect the properties of the cement matrix.

Polypropylene fibres are chemically inert, and so will not rust, corrode or rot, and will not absorb water. Little or no flame spread on the surface of polypropylene fibre reinforced panels was reported in laboratory tests. The introduction of polypropylene fibres in concrete affects its properties both in the fresh and hardened state. In fresh state, it may reduce the workability and the also slows down the rate of bleeding. It may also increase the setting times for the concrete. However, in the hardened state, polypropylene fibres act as crack arrestors. Like any secondary reinforcement, the short discrete fibres tend to mitigate the crack propagation by bridging the cracks and providing increased resistance to crack propagation. The structure of the fibrillated polypropylene fibres is such that it provides three-dimensional reinforcement to the Cementitious matrix thus; enhancing tensile strength, tensile strain capacity and the improved resistance to impact and fatigue.

The polypropylene fibre reinforced concrete (PPFRC) has seen limited applications in several structures including parking areas, driveways, industrial floorings, water and other chemical storage tanks, walkways, pavements, roof screeds, mosaic flooring, structural concrete and also in pre-cast slabs. The applications are primarily to inhibit the cracking. However, due to the lack of awareness, design guidelines and construction specifications, its uses are limited by the local construction industry.

Therefore there is a need to develop information on the properties of Polypropylene Fibre Reinforced Concrete (PPFRC) in which indigenous polypropylene fibres are used.

1.2. OBJECTIVE

The objectives of this research are:

Conducting experimental investigation for measurement of workability, compressive strength and split tensile strength of Polypropylene Fibre Reinforced Concrete (PPFRC).

For the measurement of workability of the PPFRC, the standard method is used for characterizing workability in terms of consolidation, however; four standard test methods are used to characterise the flow property of PPFRC.

For the properties, the following tests are conducted to study the effect of a number of fibres and the length of fibres on the compressive, tensile strength and the associated straining capacity.

1. Compressive Strength of concrete cylinders (ASTM C39)
2. Split Tensile Strength of concrete cylinders (ASTM C496)

1.3. RESEARCH SIGNIFICANCE

The use of PPFRC in the local construction industry is limited. The purpose of this work is to develop evidence of the engineering properties of PPFRC in which polypropylene fibres are used. This includes the properties of PPFRC such as workability in the fresh state, free shrinkage and other properties in the hardened state.

The results of this work will be useful for the local construction industry and could be used for developing specification guidelines for the use of PPPFC in the local construction.

1.4 METHODOLOGY

The research methodology was to conduct a literature review of the studies on FRC and PPFRC that have been conducted in the past two decades. On the basis of the literature review, knowledge gaps were identified. It was realised that mechanical properties of Polypropylene fibre reinforced concrete have been studied by many researchers in different areas of the world; however there still a need to provide experimental and knowledge ground for the use of PPFRC in the local construction industry. An experimental program was developed to study the properties of PPFRC. The experimental program included a number of variables such as the length of the PPF, amount of PPF, test age etc. Concrete mixture proportions for plain and PPRC concrete were developed to maintain a target slump. Using these PPFRC concrete mixes, test specimens were cast, cured and tested as per the experimental matrix. The results of the plain and PPFRC concrete test specimens were compared to quantify the beneficial effects of PPF on concrete. The results are discussed and presented along with an analytical equation for characterising the stress-strain curve of PPFRC in compression.

CHAPTER - (2)
LITERATURE REVIEW
2.1. INTRODUCTION

This chapter presents the review of studies conducted on the history, performance, and behaviour of FRC and the properties of different fibres that affect the performance of the composite. The studies conducted in the past two decades are mainly focused.

2.1.1. Historical Evolution of FRCC

The use of randomly distributed fibres in concrete is not new. Since ancient times, fibres like straws, horse hair and other vegetable fibres have been used to reinforce brittle materials [ACI 544.1R (1996)]. However, after 1960's, a great evolution took place in this regard and a number of different fibres and other materials were introduced to enhance the most significant mechanical properties of concrete. The use of those materials was supported by an extensive number of research results showing the ability of fibres to improve the mechanical properties and durability of concrete. Modern developments and worldwide interest on the subject took off during the early 1960's following studies by Romualdi on the use of steel fibres in concrete [Romualdi et al (1964), Romualdi et al (1969)]. Use of glass fibres in concrete was first attempted in the late 1950s by Biryukovich [Biryukovich et al (1965)]. After this initial work, a substantial amount of research, development, experimentation, and industrial application of fibre reinforced concrete has occurred.

2.1.2. Classification of fibres

A wide variety of fibres has been used in concrete. For each application, it needs to be determined which type of fibre is optimal in satisfying the concrete application. The different types of fibres used as concrete reinforcement are synthetic fibres and steel fibres.

For architectural and decorative concrete products and for prevention of early age cracking, synthetic fibres may be used. Steel fibres are used for applications where properties of concrete in the hardened stage have to be modified, namely, post cracks flexural strength, abrasion resistance, impact resistance and shatter resistance of concrete.

STEEL FIBRE REINFORCED CONCRETE

Steel fibre reinforces concrete is a composite material which is made up from cement concrete mix and steel fibres as a reinforcing. The steel fibres, which are uniformly distributed in the cementations mix.This mix, have various volume fractions, geometries, orientations and material properties. It has been shown in the research that fibres with low volume fractions. Generally, SFRC is very ductile and particularly well suited for structures which are required to exhibit:

• High fatigue strength resistance to impact, blast and shock loads
• Shrinkage control of concrete
• Tensile strength, very high flexural, shear
• Erosion and abrasion resistance to splitting
• Temperature resistance, high thermal

GLASS FIBRE REINFORCED CONCRETE

Glass fibre–reinforced concrete is (GFRC) basically a concrete composition which is composed of a material of cement, sand, water, and admixtures, in which short length discrete glass fibres are dispersed. The inclusion of these fibres in these composite results in improved tensile strength and impact strength of the material. GFRC has been used for a period of 30 years in several construction elements but at that time it was not so popular, mainly in non-structural ones, like facing panels (about 80% of the GRC production), use din piping for sanitation network systems, decorative on-recoverable formwork, and other products.

At the beginning age of the GFRC development, one of the most considerable problems was the durability of the glass fibre, which becomes more brittle with time, due to the alkalinity of the cement mortar. After some research, significant improvement has been made, and presently, the problem is practically solved with the new types of alkali-resistant (AR resistance) glass fibres and with mortar additives that prevent the processes that lead to the embrittlement of GFRC.

POLYMER FIBRE REINFORCED CONCRETE

Civil structures made of steel reinforced concrete normally suffer from corrosion of the steel by the salt, which results in the failure of those structures. Constant maintenance and repairing are needed to enhance the life cycle of those civil structures. There are many ways to minimise the failure of the concrete structures made of steel reinforced concrete. The custom approach is to adhesively bond polymer fibre composites onto the structure. This also helps to increase the toughness and tensile strength and improve the cracking and deformation characteristics of the resultant composite. But this method adds another layer, which is prone to degradation. These fibre polymer composites have been shown to suffer from degradation when exposed to marine environment due to surface blistering. As a result, the adhesive bond strength is reduced, which results in the delamination of the composite.

NATURAL FIBRE REINFORCED CONCRETE

The first use of fibres in reinforced concrete has been dated to 1870‟s. Since then, researchers around the world have been interested in improving the tensile properties of concrete by adding, iron and other wastes. Local interest has been demonstrated through research work performed. In addition to industrial fibres, natural organic and mineral fibres have been also investigated in reinforced concrete. Wood, sisal, jute, bamboo, coconut, asbestos and rock wool, are examples that have been used and investigated.

The fibres are categorised into four, namely the geometrical properties, mechanical properties, physical/chemical properties and material type. For practical utilisation of fibres in FRC applications, properties which are given significant considerations in the selection of fibres are the material type, tensile strength, elastic modulus and the aspect ratio (the ratio of fibre length to the diameter or equivalent diameter).

2.1.3. Fibre Reinforced Cementitious Composites

Fibre Reinforced Concrete, (FRC) as a composite material made of hydraulic cement, water, fine and coarse aggregate, and a dispersion of discontinuous fibres.

Naaman classified fibre reinforced Cementitious composites into two broad categories according to their tensile response, namely, either Strain-Softening or Strain- Hardening. Strain-softening FRC composite exhibit strain softening and crack localization immediately following first cracking whereas Strain-hardening FRC composites are characterised by a stress-strain response in tension that exhibits strain hardening behaviour after first cracking, accompanied by multiple cracking.

Another classification of fibre reinforced Cementitious materials on the basis of structural applications is given by Stang [(2004)]. According to that, the general mechanical response of these materials under a uniaxial state of stress can be either of the three:

1. Tension softening response is so significant that it can be allowed to be taken into account in structural design,
2. The strain hardening portion is significant enough that it can be taking into account in structural contexts, or
3. Both the hardening and the softening regimes are significant enough to be taken into account in the structural design.

Polypropylene Fibres

Polypropylene is available in two forms, monofilament fibres and film fibres. Monofilament fibres are produced by an extrusion process through the orifices in a spinneret and then cut to the desired length. The newer film process is similar except that the polypropylene is extruded through a die that produces a tubular or flat film. This film is then slitten into tapes and uniaxial stretched. These tapes are then stretched over carefully designed roller pin systems which generate longitudinal splits and these can be cut or twisted to form various types of fibrillated fibres. The fibrillated fibres have a net-like physical structure. The tensile strength of the fibres is developed by the molecular orientation obtained during the extrusion process. The draw ratio (final length/initial length), a measure of the extension applied to the fibre during fabrication, of polypropylene fibres is generally about eight.

Polypropylene fibres are new generation chemical fibres. They are manufactured in large scale and have fourth largest volume in production after polyesters, polyamides, and acrylics. About 4 million tonnes of polypropylene fibres are produced in the world in a year. Polypropylene fibres 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.

Subsequently, the polypropylene fibre has been improved further and is now used as short discontinuous fibrillated material for the production of fibre reinforced concrete or as a continuous mat for the production of thin sheet components. Further, the application of these fibres in construction increased largely because the addition of fibres in concrete improves the tensile strength, flexural strength, toughness, impact strength and also failure mode of concrete these fibres are manufactured using conventional melt spinning. Polypropylene fibres are thermoplastics produced from Propylene gas. Propylene gas is obtained from the petroleum by-products or cracking of natural gas feedstocks. Propylene polymerises to form long polymer chain under high temperature and pressure. However, polypropylene fibres with controlled configurations of molecules can be made only using special catalysts. Polypropylene fibres were formerly known as Stealth, These are micro reinforcement fibres and are 100% virgin homopolymer polypropylene graded monofilament fibres. They contain no reprocessed Olifin materials. The raw material of polypropylene is derived from monomeric C3H6 which is purely a hydrocarbon. For effective performance, the recommended dosage rate of polypropylene fibres is 0.9 kg/m3, approximately 0.1% by volume.

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

2.2. FRESH (PLASTIC) PPFRC

2.2.1. Workability

American Concrete Institute (ACI) Standard defines workability as *"that property of freshly mixed concrete which determines the ease and homogeneity with which it can be mixed, placed, consolidated, and finished.* "Workability is the measure of the ability of concrete to be mixed, handled, transported, placed, and consolidated. Workability plays a key role in the performance of the hardened product. The strength and serviceability properties of FRC are greatly affected by the mixing, dispersion, consolidation and hydration of fresh FRC. Hence it is mandatory to ensure good flowability, place ability, segregation resistance and uniform dispersion of fibres in the fibre reinforced concrete. Fresh concrete properties and workability (flowability, passing ability and segregation resistance) determined by different methods were reported for polypropylene fibre reinforced concrete having different fibre content that is percentage by volume.

Most of the studies conducted to evaluate the workability of the fibre reinforced concrete deal with the flow property of Self-Consolidating Concrete (SCC), which is one kind of high-performance concrete. The main character of self-compacting concrete is that there is no need of vibrating during the construction process, reducing manpower demand in the construction stages of concrete structures. It is, therefore, important to study the flow characteristics of self-consolidating concrete mixtures that incorporate this type of synthetic fibre reinforcement in order to identify and characterise the main factors affecting its flow.

2.2.1.1. Uniform Dispersion of Fibres

Mixing of FRC can be accomplished by several methods, with the choice of method depending on the job requirements and the facilities available. It is important to have a uniform dispersion of the fibres and to prevent the segregation of the fibres during mixing. Segregation of the fibres during mixing is related to a number of factors. The most important factors appear to be the Aspect Ratio of the fibres, the volume percentage of fibres, the maximum size and gradation of the aggregates, and the method of adding the fibres to the mixture. As the first three of these factors increase, the tendency for balling increases. Therefore, before mixing the concrete, the fibre length, amount and design mix variables are adjusted to prevent the fibres from balling. The aspect ratio for the fibres is usually restricted between 100 and 200 since fibres which are too long tend to "ball" in the mix and create workability problems. There should be sufficient compaction so that the fresh concrete flows satisfactorily and the PP fibres are uniformly dispersed in the mixture.

2.2.1.2. Setting time

The addition of fibres in concrete reduces the amount of bleed water from concrete and so the rate of bleeding decreases. The use of polypropylene fibres may increase the time to initial and final set of the concrete as this led to a slower rate of drying in the concrete.

Alhozaimy (1995) investigated the effect of polypropylene fibres on the initial and final setting time of concrete and found that the initial and final setting times were decreased by 9 and 27 percent, respectively, with the addition of polypropylene fibres. This reduction is expected to reduce the period of exposure prior to setting of fresh concrete to the dry environment, which is responsible for plastic shrinkage cracking. The amount of bleed water for plain and fibrous concretes was also reduced. Due to the addition of polypropylene fibres, there was an 18 percent decrease in the amount of bleed water of concrete; the fibres possibly reduce the settlement of heavier mix constituents (e.g., aggregates), thereby reducing the upward movement of water (bleeding) in concrete.

2.2.1.3. Volume Stability

The serviceability of Portland cement concrete (PCC) and of reinforced concrete structures is closely associated with their ability to resist and control cracking. There are many causes of cracking on brittle cement concrete mixes; volume change is one of them. Volume change causes cracking in concrete both in plastic (early age) concrete and Hardened Concrete. The use of fibre reinforcement in concrete reduces cracking and shrinkage and thus ensures volume stability of the cementitious composite to a great extent.

2.2.2. Early Age and Plastic Shrinkage

Plastic shrinkage cracking of concrete occurs when it is exposed to drying environment while it is still in plastic form. Normally it occurs within the first few hours after the concrete is placed and before it attains any significant strength. The adverse effects of drying shrinkage at a very initial phase include an unsightly and non-uniform appearance on the concrete surface. Later, the plastic shrinkage cracks become critical weak points for aggressive substances to penetrate into the internal portion of concrete leading to the acceleration of other detrimental forms of concrete deterioration. Consequently, the performance, serviceability, durability and aesthetic qualities of concrete structures are reduced. Controlling plastic shrinkage cracking in concrete is essential for developing more durable and longer-lasting structures at a minimum life-cycle cost.

One of the primary causes of plastic shrinkage cracking is the loss of water from evaporation that leads to a build-up tensile shrinkage stress when concrete is subjected to sufficient restraint. When the rate of water loss due to evaporation exceeds the rate at which the bleed water is supplied to the surface, negative capillary pressures form that result in volume changes in the concrete. Tensile stresses in the paste form due to the negative capillary pressure and the development of strength in the concrete. Cracking occurs if the tensile stresses are greater than the tensile strength of the concrete.

The most effective method to prevent the plastic shrinkage of concrete that has become more and more popular in the last two decades is to add fibres to the matrix of the concrete. Such fibres are supposed to be randomly distributed and can be of different materials and geometries. Dependent on the volume, the added fibres improve the shrinkage cracking behaviour of the concrete by either simply bridging cracks after their occurrence (lower volumes) or increasing the actual tensile strength of the matrix and thereby delaying or preventing the cracking (higher volumes).

Effect of Aspect Ratio of fibres

The proportion between length and diameter or equivalent diameter is an important fibre parameter defined as the fibre aspect ratio. In the case of Polypropylene fibres, the fibre aspect ratio does not influence plastic shrinkage cracking however for Polyvinyl Alcohol Fibres; fibre aspect ratio seems to be a significant factor for controlling plastic shrinkage cracking. The total crack area decreases drastically from 32.183 to 1.913 mm² when the fibre aspect ratio increases from 120 to 300.

2.3. HARDENED PPFRC

Concrete gains strength as it gets hardened. The process of gaining strength is accompanied by the evolution of heat of hydration upon curing. The strength of concrete is a function of time. It gains strength as it gets old up to a certain specified age. The strength of the fibre reinforced concrete can be measured in terms of its maximum resistance when subjected to compressive, tensile, and flexural and shear stresses either individually or combined. With the increasing use of fibre reinforced concrete as a structural material, more information on its mechanical properties was needed. Researchers have done significant work for establishing the impact of different fibres on the mechanical properties of fibre reinforced cementitious composites. Conclusions of some reports and researches on compressive strength, splitting tensile strength and flexural strength are presented under:

2.3.1Compressive Strength of PPFRC

The effect of polypropylene fibre on the compressive strength of concrete has been discussed in many studies and resulted that polypropylene fibres either decrease or increase the compressive strength of concrete, but the overall effect is negligible in many cases. Many researchers have reported no or a very small influence of small volume fraction (from 0.05% to 0.5%) of polypropylene fibres on compressive strength of Fibre Reinforced Concrete, while some of the researchers have shown a significant increase in the compressive strength of fibre reinforced concrete. Found increase in the compressive strength of concrete because of the presence of fibres in the concrete mix. The investigation resulted that the Polypropylene fibre inclusions in the amount of 0.4% and 1.5% increased the compressive strength up to 11% and 56% respectively. Ahmed et al noted that polypropylene fibres, when used in higher dosage (0.55% and 0.6%), decreased the 28 days compressive strength of concrete by 35% of that of plain concrete [Saeed Ahmed et al (2006)].

2.3.2Tensile Strength of PPFRC

Brittle matrices, such as plain mortar and concrete, lose their tensile load-carrying capacity almost immediately after formation of the first matrix crack. The addition of fibres in conventional fibre reinforced concrete (FRC) can increase the toughness of cementitious matrices significantly; however, their tensile strength and especially strain capacity beyond first cracking are not enhanced [Gregor Fischer (2004)].

The tensile strength of concrete is only about 10 % of its compressive strength. It is clear that addition of fibres to a concrete mixture is beneficial to the tensile properties of concrete. The fibres act as crack arresters in the concrete matrix prohibiting the propagation of cracks in plastic state and propagation of cracks in the hardened state. Once the splitting occurred and continued, the fibres bridging across the split portions of the matrix acted through the stress transfer from the matrix to the fibres and, thus, gradually supported the entire load. The stress transfer improved the tensile strain capacity of the fibre-reinforced concrete and, therefore, increased the splitting tensile strength of the reinforced concretes over the unreinforced control counterpart.

Ahmed et al studied that the tensile strength of concrete increases linearly with the addition of fibres up to about 0.40% after which the tensile strength decreases with the addition of more fibres. The tensile strength increases about 65%~70% up to 0.40% after which it decreases. Tensile strength is increased due to the bridging mechanism of polypropylene fibres and after a certain time it reduced the bond strength between concrete ingredients so results in quick failure as compared to fewer volumes of fibres. Song et al noted an increase of 10% in the split tensile strength of fibre reinforced concrete at the fibre dosage of 0.6kg/m³.

Table 2.1 A compilation of mechanical properties of commonly used fibres in concrete materials [ACI 544.5R (2010)]

Type of Fibre	Equivalent Diameter (mm)*	Specific Gravity (Kg/m³)**	Tensile Strength (MPa)***	Young's Modulus (GPa)	Ultimate Elongation (%)
Acrylic	0.02 to 0.35	1100	200 to 400	2	1.1
Asbestos	0.0015 to 0.02	3200	600 to 1000	83 to 138	1.0 to 2.0
Cotton	0.2 to 0.6	1500	400 to 700	4.8	3.0 to 10.0
Glass	0.005 to 0.15	2500	1000 to 2600	70 to 80	1.5 to 3.5
Graphite	0.008 to 0.009	1900	1000 to 2600	230 to 415	0.5 to 1.0
Aramid	0.01	1450	3500 to 3600	65 to 133	2.1 to 4.0
Nylon	0.02 to 0.40	1100	760 to 820	4.1	16 to 20
Polyester	0.02 to 0.40	1400	720 to 860	8.3	11 to 13
Polypropylene	0.02 to 1.00	900 to 950	200 to 760	3.5 to 15	5.0 to 25.0
Polyvinyl alcohol	0.027 to 0.66	1300	900 to 1600	23 to 40	7 to 8
Carbon	-	1400	4000	230 to 240	1.4 to 1.8
Rayon	0.02 to 0.38	1500	400 to 600	6.9	10 to 25
Basalt	0.0106	2593	990	7.6	2.56
Polyethylene	0.025 to 1.0	960	200 to 300	5	3
Sisal	0.08 to 0.3	760 to 1100	228 to 800	11 to 27	2.1 to 4.2
Coconut	0.11 to 0.53	680 to 1020	108 to 250	2.5 to 4.5	14 to 41
Jute	0.1 to 0.2	1030	250 to 350	26 to 32	1.5 to 1.9
Steel	0.15 to 1.00	7840	345 to 3000	200	4 to 10

* 1 mm = 0.0393 in, ** 1 Kg/m³ = 0.0624 lb./ft³, ***1 MPa = 145 psi
*

Table 2.2 Properties of different types of polypropylene fibres [S.K. Singh (2010)]

Fibre Type	Length (mm)*	aimeter (mm)*	Tensile Strength (Mpa)**	Modulus of Elasticity (Gpa)	Density (kg/m³)***
Monofilament	30-50	0.30-0.35	547-658	3.50-7.50	0.9
Microfilament	12-20	0.05-0.20	330-414	3.70-5.50	0.91
Fibrillated	19-40	0.20-0.30	500-750	5.00-10.00	0.95

* 1 mm = 0.0393 in, **1 MPa = 145 psi, *** 1 kg/m³ = 0.0624 lb./ft³

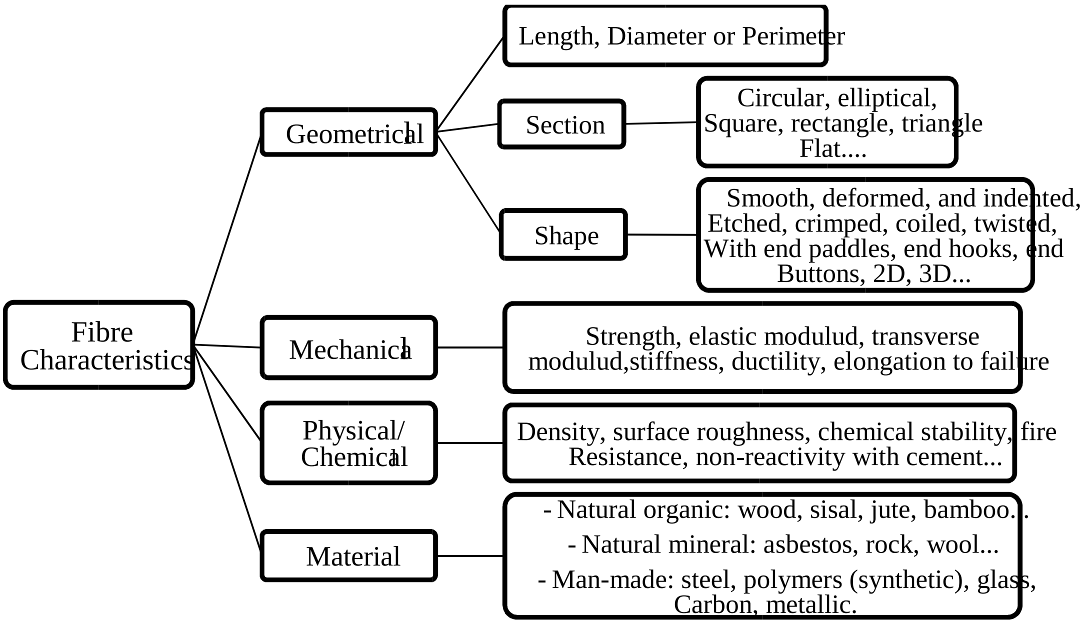

Figure 2.1 Main characteristics of fibres [Naaman et al (2006)]

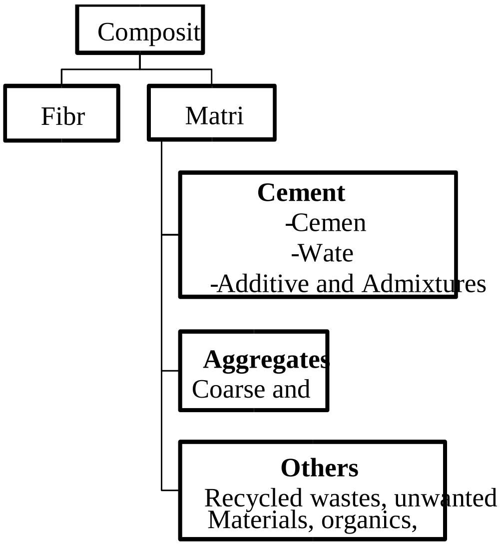

Figure 2.2 Composite model of FRC with two main components, namely fibre and matrix [Naaman et al (2006)]

CHAPTER – (3)
EXPERIMENTAL PROGRAM

3.1GENERAL

This chapter provides a detailed description of the materials used in the experimental program and experimental methods used in this study. The experimental program consisted of laboratory tests on plain concrete and polypropylene fibre reinforced concrete (PPFRC) to characterise the properties such as flowability in the fresh state, early-age plastic shrinkage and mechanical properties in the hardened state. For this purpose total of seven (7) concrete mixtures were cast with one control mix (plain concrete) and six PPFRC mixes.

The materials, mix design (mixture proportions), casting, curing, test methods and procedures for the workability of PPFRC, tests for plastic shrinkage of PPFRC and tests for selected mechanical properties of hardened concrete are described in detail in the respective sections.

3.2MATERIALS

3.2.1. Cement

The cement used was 53 grade Ordinary Portland cement (OPC).It has a specific gravity of 3.13 with initial and final setting times of cement were 45 and 185 mins respectively. The physical properties are confirming to IS 12269-1987.

S.N O	**Characteristic**	**ISSpecifications (IS:12269- 1987)**	**Test results**	**Remarks**
1	Standard consistency		32%	
2	Setting time in minutes i. Initial setting time ii.Final setting time	 >30 <600	 112 240	 Satisfactory Satisfactory
3	Specific gravity	3.15	3.12	

3.2.2. Aggregates

The material whose particles are of a size as are retained on I.S Sieve No.480 (4.75mm) is termed as coarse aggregate. The size of coarse aggregate depends upon the nature of work. The coarse aggregate used in this experimental investigation are of 12.5mm size crushed angular in shape. The aggregates are free from dust before used in the concrete. Good quality sand is used as fine aggregate.

3.2.3. Water

The water causes the hardening of concrete through a process called hydration. It is a chemical reaction in which the major compounds in cement form chemical bonds with water molecules and become hydrates or hydration products. According to IS: 456-2000, water for concrete should be of portable quality (PH- 6.8 to 8.0). Ordinary tap water, which is fit for drinking has been used in preparing all concrete mixes and curing in this investigation

3.2.4. Fibre

Fibrillated polypropylene fibres (PPF) with two different lengths were used in different volume percentage. The fibre and the material specifications were provided by the Reliance Company. The polypropylene fibres are composed of film sheets which are cross-linked by fine fibre along their length. These fibres are manufactured in a chicken mesh form and then cut into the desired length. It was manufactured by the name Recron 3s by Reliance Industry Limited (RIL). The fibres are available in 3 different sizes i.e. 6mm, 12mm, and 24mm. In this project, 12mm fibre is used.

CHAPTER – (4)
TEST PROCEDURE

4.1 MIX DESIGN

A suitable concrete mix design was established on the basis of preliminary testing of mortar cubes having cement to the sand ratio of 1:2.75 and w/c ratio of 0.48. Twelve number of 2”x2” cubes were cast and cured in the water tank and then tested under compression using Universal Testing Machine at a loading rate of 60 psi/min. The strength- time curve was developed for 28 days of curing. (See Figure 3.3) Each point on the strength time curve is an average of three replicate cube specimens. Note that the 28-day strength is in excess of 3000 psi.

The mixing of concrete was done in rotary drum mixer at a mixing rate of 40 rpm. Pictorial view of the mixer is shown in Figure 3.4. The drum was previously moistened by spraying just enough water to moist the inner surface of the drum. The mixing sequence used for all mixtures was as follows:

- Add the fine aggregate (sand) to the mixer and mix for 30 seconds
- Add the coarse aggregate to the mixer and mix for 30 seconds
- Add the fibres and mix for 3 minutes (not done the plain concrete)
- Add 50% of the adjusted water and mix for 30 seconds
- Add all the cement to the mixer and mix for 30 seconds
- Add admixture into the balance of the water, introduce into the mixer and mix for 4 minutes
- Let the mixed PPFRC be idle for 2 minutes and then mix for 4 additional minutes

After mixing, the concrete was placed into lubricated moulds and vibrated externally. A smooth steel trowel was used to finish the fresh concrete. The mix proportions of concrete mixtures are shown in Table 3.2.

4.2 TESTS FOR WORKABILITY OF FRESH PPFRC

Standard test methods were used to study the workability of PPFRC in terms of flowability. Slump test was performed on the batch of concrete for the purpose of homogeneity and the results obtained thus were compared and calibrated. The complete experimental matrix for workability tests is given.

4.2.1 Standard Slump Test

The slump test is the most well-known and widely used test method to characterise the workability of fresh concrete. The inexpensive test, which measures consistency, is used on job sites to determine rapidly whether a concrete batch should be accepted or rejected.

The apparatus consists of a mould in the shape of a frustum of a cone with a base diameter of 200 mm, a top diameter of 100 mm, and a height of 300 mm. During this test, the mould is filled with concrete in three layers of equal volume. Each layer is compacted with 25 strokes of a tamping rod. The slump cone mould is lifted vertically upward and the change in height of the concrete is measured.

4.2.2 Compacting Factor Test

The compaction factor test measures the degree of compaction resulting from the application of a standard amount of work. The test was developed in Britain in the late 1940s and has been standardized as British Standard 1881-103 [Eric et al (2003), BS 1881-103 (1993)].

The apparatus, which is commercially available, consist of a rigid frame that supports two conical hoppers vertically aligned above each other and mounted above a cylinder, as shown in Figure 3.8. The top hopper is slightly larger than the bottom hopper, while the cylinder is smaller in volume than both hoppers. To perform the test, the top hopper is filled with concrete but not compacted. The door on the bottom of the top hopper is opened and the concrete is allowed to drop into the lower hopper. Once all of the concrete has fallen from the top hopper, the door on the lower hopper is opened to allow the concrete to fall to the bottom cylinder. A tamping rod can be used to force especially cohesive concretes through the hoppers. The excess concrete is carefully struck off the top of the cylinder and the mass of the concrete in the cylinder is recorded. This mass is compared to the mass of fully compacted concrete in the same cylinder achieved with hand rodding or vibration. The compaction factor is defined as the ratio of the mass of the concrete compacted in the compaction factor apparatus to the mass of the fully compacted concrete.

4.3 TESTS FOR MECHANICAL PROPERTIES OF HARDENED PPFRC

Some of the mechanical properties of PPFRC are considered in this study. These include Compressive strength, splitting tensile strength. Standard methods of test for each of the property are described in the following sections.

4.3.1 Compressive Stress-Strain Curve

This test method covers the determination of cylindrical compressive strength of concrete specimen. The specimens are prepared by pouring freshly mixed concrete into lubricated cylinders. The mixing procedure is the same as described in this report. Consolidation is done externally over the vibrating table for 3-5 minutes. After vibration and finishing, the moulds are kept at normal atmospheric conditions for 23 ½ ± ½ hours after which de-moulding is done. The specimens are then cured in the water tank.

The test is conducted at the surface dry condition. The specimens are capped, placed and seated in the testing machine as described in section 7 of ASTM C39. The specimens are tested at the age of 7, 14 and 28 days of curing under the Universal Testing Machine. This machine applies compressive stress on the cylinder due to the downward movement of the platen at a constant displacement rate of 0.1 mm/sec. The load and stroke measurements are noted from which stress and longitudinal strain values are computed and plotted for each set. The strength-time curves for plain concrete and PPFRC were also obtained for an average of three values and then compared to each other.

4.3.2 Split Tensile Strength of Concrete Cylinders

This test method covers the determination of splitting tensile strength of concrete cylinders. The procedure for preparation of specimens for split cylinder testing is similar to the procedure described in the Section 3.6.1 of this report.

This test method consists of applying a diametric compressive force along the length of a cylindrical concrete specimen at a rate that is within a prescribed range until failure occurs. This loading induces tensile stresses on the plane containing the applied load and relatively high compressive stresses in the area immediately around the applied load. Tensile failure occurs rather than a compressive failure because the areas of load application are in a state of multiaxial compression, thereby having a much higher resistance as compared to uniaxial compressive strength test result.

The test was performed in the Universal Testing Machine (see Figure 3.17). The load and stroke values are recorded by the test machine and the split tensile stresses were calculated

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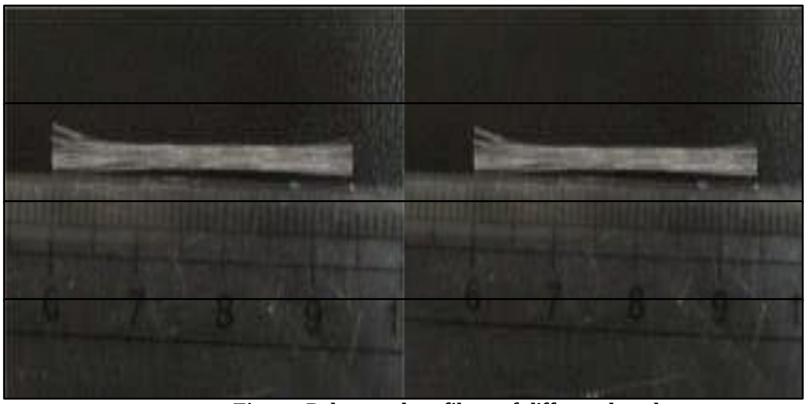


Figure -Polypropylene fibres of different length

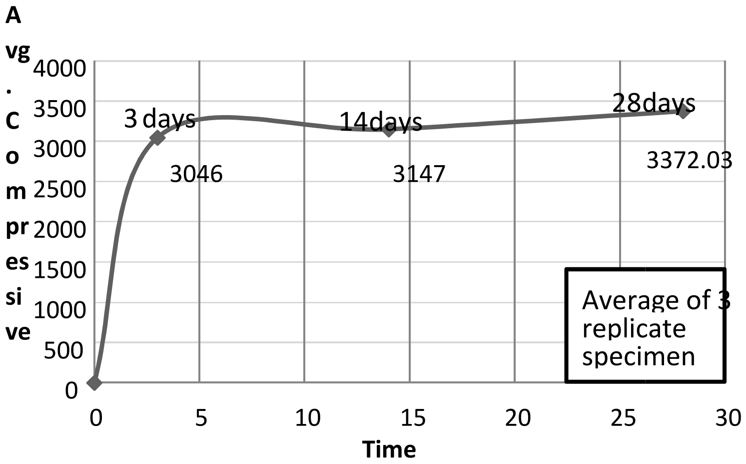


Figure - The average compressive strength-time curve of 2"x2" mortar cubes

Figure - Pictorial view of rotary drum mixer

Figure - Pictorial view of freshly prepared FFRRC

Figure - Pictorial view of standard slump test apparatus

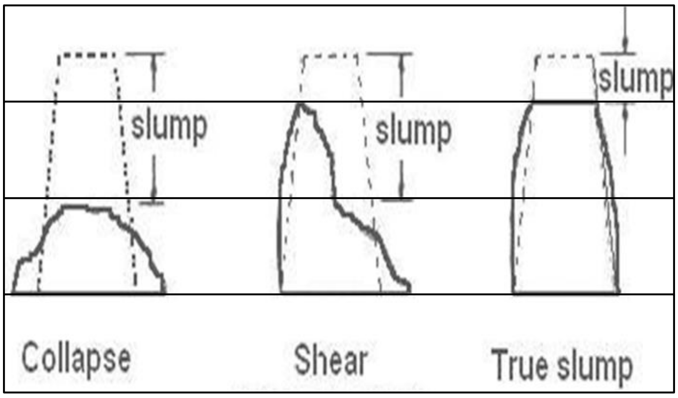


Figure -Types of concrete slump [Eric et al (2003)]

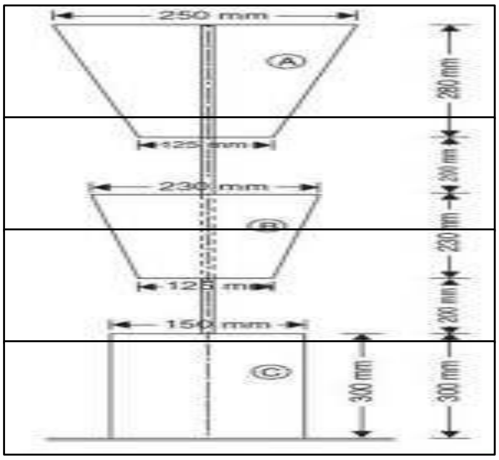


Figure - Compacting factor test apparatus [Eric et al (2003)]

Figure: The universal testing machine

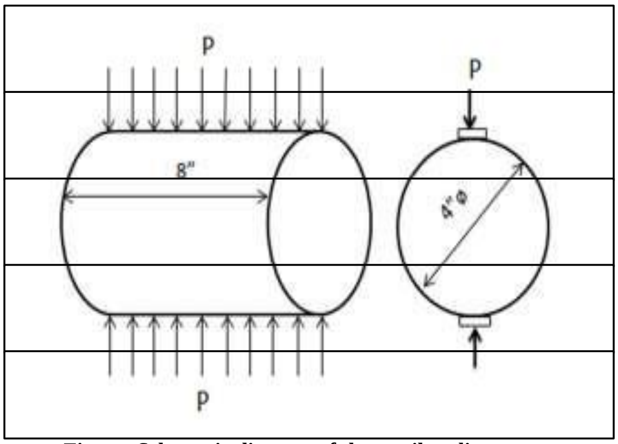


Figure: Schematic diagram of the tensile split test setup

CHAPTER – (5)
RESULTS

4.1 MIX DESIGN

4.2. WORKABILITY OF FRESH PPFRC

For the workability of fresh concrete, tests used were traditional Slump Cone Test, Compacting Factor, Compressive Test and Tensile Strength. These tests were performed on concrete without polypropylene fibres (PPF) termed as "control" specimens and on polypropylene fibre reinforced concrete (PPFRC) specimens.

The tests results of various fresh properties tests of Plain Concrete (PC) and polypropylene fibre reinforced concrete (PPFRC) with different volume fraction (V_f) and length of fibre (L_f) are presented.

The PPFRC mixtures were proportioned to give slump values which are needed to ascertain adequate workability of the fresh concrete to be placed and finished. For all the concrete mixes having different fibre contents and with different lengths of fibres, the measured slump is greater than 3 in. (76 mm), which is an acceptable slump value for the ease of construction and finish ability. For the PPFRC mixtures, in order to maintain reasonable slump, and approximately similar w/c, the quantity of cement was increased with increase in the amount of chemical admixture as segregation was observed to occur when only water content was increased in order to increase the workability of the PPFRC mixtures.

4.3. PLASTIC SHRINKAGE OF FRESH PPFRC

The test procedure for shrinkage test is described in Chapter 3. The results of the shrinkage tests performed on the control specimen PC and four different PPFRC mixtures are shown. The length measurement was done using a digital calliper and then the results were computed. The results were then plotted against time and then compared. The graphical representation of the results is given. In general, it can be noted that the shrinkage of both PC and PPFRC mixtures varies greatly in the initial 24 hours and then gradually reduces with the passage of time. It is evident that the shrinkage of PC specimens is larger than shrinkage of PPFRC specimens and that addition of PPF reduces the early-age plastic shrinkage of concrete. Among the four PPFRC mixtures, the PPFRC 0.4-25 is found to be the most efficient in controlling early age shrinkage as it showed the maximum average shrinkage of 0.106% at 72 hours.

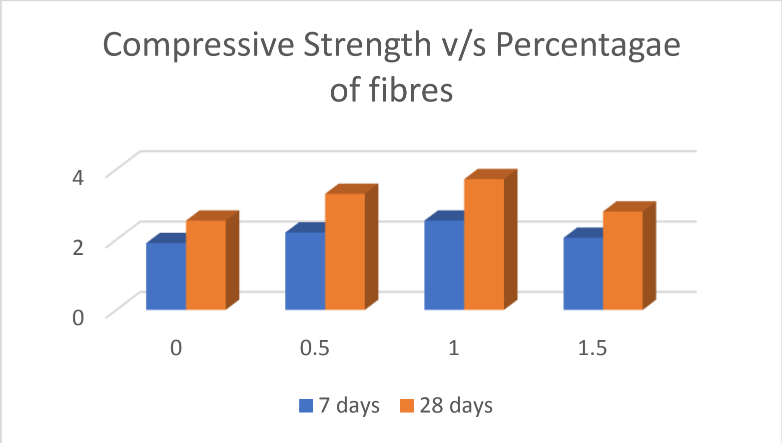
PFRC

The addition of the PPF to the concrete mixtures has beneficial effects on the mechanical properties of hardened concrete. The effect of volume of fibres (V_f) and the length of fibres (L_f) on the mechanical properties such as compressive strength, split cylinder tensile strength, flexural tensile strength at different test ages are reported.

4.4.1. Compression Test Results

The compressive strength tests were performed on one plain concrete mixture "Control" concrete polypropylene fibre reinforced concrete (PPFRC) mixtures These were tested at the ages of 7, 14 and 28 days. Three replicate specimens were tested at each test age for each type of mixture.

At each of the test age, three (3) specimen were taken out from curing, dried and then capped with sulphur and were tested to get the load-stroke data. From the load-stroke data, stress-strain data was computed. From the stress-strain data of each of the 3 specimens, an average stress-strain data was obtained, which was plotted.



4.4.2. Splitting Cylinder Tensile Test Results

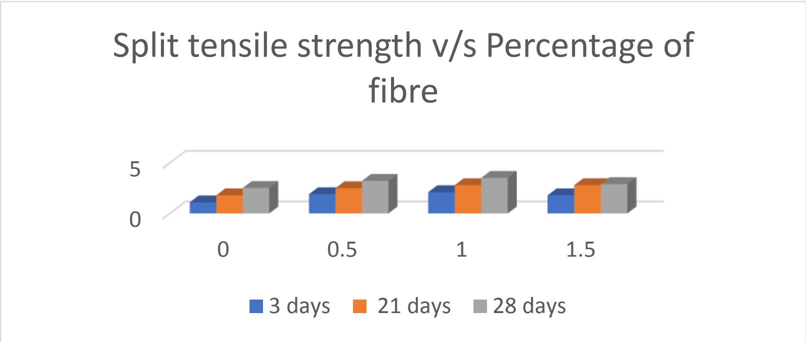
The splitting cylinder tensile tests were performed on one plain concrete mixture "Control" concrete and polypropylene fibre reinforced concrete (PPFRC). The seven different mixtures. These were tested at the ages of 7, 14 and 28 days. Three replicate specimens were tested at each test age for each type of mixture.

At each of the test age, the specimens were tested and the load-stroke data was obtained from which stress-displacement data was computed. From the stress-displacement data of each of the 3 specimens, an average stress-displacement data was obtained, which was plotted.

The average stress-displacement behaviour of PC shows a linear trend up to the cracking. After the first crack occurs, the strength of the PC reduces immediately and the crack widening leads to the splitting of the cylinder.

The average stress-displacement behaviour of PC and PPFRC with different $V_f$and L_f at different test ages. From these, it can be seen that the stress-displacement behaviour up to the first crack is almost the similar for both PC and PPFRC; however, the post-peak behaviour is different and the addition of PP fibres to concrete helps in increasing the post peak deformation capacity and enhancing the post-cracking strength of PPFRC in tension.

In the case of PPFRC, the PP fibres come into action after the first crack. The PP fibres bridge these cracks and restrain them from further opening and hence improve the load-carrying capacity of structural member beyond cracking. After the first crack, a drop in the stress is noted which shows the stress transfer from concrete to the randomly distributed fibres, which further take the applied load by elongating. The failure or the splitting on the cylinder occurred when the fibres elongation exceeds the allowable i.e. the breaking of the fibres under axial tension.



CHAPTER – (6)
APPLICATIONS OF FIBRE

Hydraulic structures
Residential roads and driveways
Tennis courts
Foundations/floors for greenhouses
concrete pavements
Well linings
Sidewalks
pathways

The lists of some projects where PPFRC is used for different applications are attached in Appendix-II.

Table - Typical dosages of PPFRC for various applications

Type of Work	Fibre Length (mm)	Minimum Dosage (gms/50 Kg cement bag)
Plaster Works (Including Colour Crete)	6	100
External Plaster Works, Precast Concrete, and Repair of Plaster Works	13	100
Residential and Commercial Roof Screed and Roof Slab, Industrial Flooring and Pavement, RCC Structure for Water Tank, Basement Walls, Manhole and Canal Lining	25+13	300
Water Reservoir, Sewerage Drain, Storm Water Drain and Residential Roof Screed (Over Flexible Insulation Base)	25+13	450
Heavy Duty Industrial Floor, Hanger Floor, Runway, Quay Wall, Sea Block, Bridge Deck Screed, Expansion Joint and	25	600

CHAPTER – (7)
CONCLUSIONS

1. Polypropylene fibres reduce the water permeability, plastic, shrinkage, and settlement and carbonation depth.
2. Workability of concrete decreases with increase in polypropylene fibre volume fraction. However, higher workability can be achieved with the addition of HRWR admixtures even with w/c ratio of 0.3.
3. Polypropylene fibres enhance the strength of concrete, without causing the well-known problems, normally associated with steel fibres.
4. The problem of low tensile strength of concrete can be overcome by addition of polypropylene fibres to concrete.
5. A notable increase in compressive strength is reported with the addition of polypropylene fibres.
6. The durability of concrete improves and the addition of polypropylene fibres greatly improves the fracture parameters of concrete.
7. The compressive strength, split tensile strength, flexural strength, and modulus of elasticity increase with the addition of fibre content as compared with conventional concrete.

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