PROPERTIES

OF

HUMAN HAIR MICRO FIBRE REINFORCED CONCRETE

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Submitted by

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CERTIFICATE

I Gopal Krishan hereby declare that this dissertation entitled, **"Properties of Human Hair Micro Fibre Reinforced Concrete"** is an authentic record of my own review carried out as requirements for the award of degree **Master of Engineering Civil Structures** in the **Civil Engineering Department, Thapar University, Patiala**, under the supervision and guidance of **Dr. Prem Pal Bansal, Associate Professor, Department of Civil Engineering, Thapar University, Patiala**. The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

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ABSTRACT

Micro Fibre reinforced concrete can offer a convenient, practical and economical method for overcoming micro-cracks and similar type of deficiencies. Since concrete is weak in tension hence some measures must be adopted to overcome this deficiency. Human hair is strong in tension; hence it can be used as a Fibre reinforcement material. Hair Fibre (HF) an alternate non-degradable matter is available in abundance and at a very cheap cost. It also creates environmental problem for its decompositions. Present studies has been undertaken to study the effect of human hair on plain cement concrete on the basis of its compressive, split tensile, flexural strength and Permeability to economize concrete and to reduce environmental problems. Experiments were conducted on concrete cubes, cylinders & beams with various percentages of human hair Fibre i.e. 0%, 1%, 2%, and 3% by weight of cement using different Micro Fibre lengths i.e. 12, 24 and 36mm. During the studies it was observed that at 2% content the performance of MFRC was better thus an experiment was also conducted by using hybrid human hair Micro Fibre @ 2% by weight of cement using Micro Fibre lengths 12, 24 and 36mm in equal fractions. For each combination of proportions of concrete 3 cubes, 3 cylinders and 3 beams are tested for their mechanical properties at 7 days curing and at 28 days curing. By testing these samples it has observed that there is an increment in the various properties and strength of concrete by the addition of human hair as Micro Fibre reinforcement.

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Micro fibre Reinforced Concrete (MFRC) is concrete containing fibrous material which increases its structural integrity and is gaining importance. It contains short discrete micro fibre that are uniformly distributed and randomly oriented. The concept of using micro fibre as reinforcement is not new. Micro fibres have been used as reinforcement since ancient times. Historically, horsehair was used in mortar and straw in mud bricks. In the early 1900s, asbestos micro fibre were used in concrete, and in the 1950s the concept of composite materials came into being and micro fibre reinforced concrete was one of the topics of interest. Later, the use of asbestos for concrete reinforcement was discouraged due to the associated health risks. New materials like steel, glass, and synthetic micro fibre replaced asbestos for reinforcement. Active research is still in progress on this important technology, and research into new micro fibre reinforced concretes continues today.

Basically, it can be defined as a composite material consisting of mixtures of cement, mortar or concrete and discontinuous, discrete, uniformly dispersed suitable micro fibre. Continuous meshes, woven fabrics and long wires or rods are not considered to be discrete micro fibre. Micro fibre includes steel micro fibre, glass micro fibre, synthetic micro fibre and natural micro fibre.

1.2 BACKGROUND

Micro fibre Reinforced Concrete (MFRC) was invented by French gardener Joseph Monier in 1849 and patented in 1867. The concept of using micro fibre as reinforcement is not new. This can be proved by the following: Micro fibre have been used as reinforcement since ancient times. Historically, horsehair was used in mortar and straw in mud bricks. In the early 1900s, asbestos micro fibre were used in concrete, and in the 1950s the concept of composite materials came into being and micro fibre reinforced concrete was one of the topics of interest. There was a need to find a replacement for the asbestos used in concrete and other building materials once the health risks associated with the substance were discovered. By the 1960s, steel, glass (GFRC), and synthetic micro fibre such as polypropylene micro fibre were used in concrete, and research into new micro fibre reinforced concretes continues today.

1.3 DEFINITION OF MICRO FIBRE

A Micro fibre is a small piece of reinforcing material possessing certain characteristics properties. Addition of micro fibre to concrete influences its mechanical properties which significantly depend on the type and percentage of micro fibre. The properties of micro fibre reinforced concrete are influenced mainly by the physical and mechanical properties of the micro fibre. A good micro fibre should have good adhesion within the matrix and adaptable elasticity modulus. It must be compatible with the binder, which shouldn't be attacked or destroyed in the long term. It should be short, fine and flexible to permit mixing, transporting and placing and also strong enough to withstand the mixing process.

1.4 NECESSITY OF MICRO FIBRE IN CONCRETE

Generally, Concrete is weak in tension and has a brittle character. Hence micro fibres are added to increase its tensile strength and improve the characteristics of construction materials. Addition of micro fibre to concrete makes it a homogeneous and isotropic material. When concrete cracks, the randomly oriented micro fibre start functioning, arrest crack formation and propagation, and thus improve strength and ductility. Micro fibres are usually used in concrete for the following reasons:

1. To control cracking due to both plastic shrinkage and drying shrinkage.
2. They also reduce the permeability of concrete and thus reduce bleeding of water.
3. Some types of micro fibre also produce greater impact, abrasion and shatter resistance in concrete.
4. The fineness of the micro fibre allows them to reinforce the mortar fraction of the concrete, delaying crack formation and propagation. This fineness also inhibits bleeding in the concrete, thereby reducing permeability and improving the surface characteristics of the hardened surface.

1.5 FACTORS EFFECTING PROPERTIES OF MFRC

Properties of Concrete are affected by many factors like Properties of Cement, Fine aggregate and Coarse aggregate. Other than this micro fibre reinforced concrete is affected by following factors:

- **Types of Micro Fibre:** A good micro fibre should have good adhesion within the matrix and adaptable elasticity modulus. It must be compatible with the binder, which shouldn't be attacked or destroyed in the long term. It should be short, fine and flexible to permit mixing, transporting and placing and also strong enough to withstand the mixing process.
- **Aspect Ratio:** The micro fibre is often described by a convenient parameter called aspect ratio. The aspect ratio of the micro fibre is the ratio of its length to its diameter. Its value varies for different micro fibre.
- **Quantity of Micro Fibre:** The amount of micro fibre added to a concrete mix is measured as a percentage of the total volume of the composite (concrete and micro fibre) termed as volume fraction (Vf). Vf typically ranges from 0.1 to 3%. Also it can be taken as percentage by weight of cement that is used in preparing concrete. The increase in the volume of micro fibre, increase approximately linearly, the tensile strength and toughness of the composite. But use of higher percentage of micro fibre is likely to cause segregation and harshness of concrete and mortar.
- **Orientation of Micro Fibre:** One of the differences between conventional reinforcement and micro fibre reinforcement is that in conventional reinforcement, bars are oriented in the direction desired while micro fibres are randomly oriented. It was observed that the micro fibre aligned parallel to the applied load offered more tensile strength and toughness than randomly distributed or perpendicular micro fibre.
- **Relative Micro Fibre Matrix Stiffness:** The modulus of elasticity of matrix must be much lower than that of micro fibre for efficient stress transfer. The Interfacial bond between the matrix and the micro fibre also determine the

effectiveness of stress transfer, from the matrix to the micro fibre. A good bond is essential for improving tensile strength of the composite.

1.6 MAIN INGREDIENTS OF MFRC

1.6.1 Portland Cement

The raw materials required for manufacture of Portland cement are calcareous materials, such as limestone or chalk and argillaceous material such as shale or clay. Cement factories are established where these raw materials are available in plenty. Cement factories have come up in many regions in India, eliminating the inconvenience of long distance transportation of raw and finished materials.

The process of manufacture of cement of grinding the raw materials, mixing them intimately in certain properties depending upon their purity and composition and burning them in a kiln at a temperature of about 1300 of 1500^0 C, at which temperature, the material sinters and partially fuses to form nodular shaped clinker. The clinker is cooled and ground to fine power with addition of about 3 to 5% of gypsum. The product formed by using this procedure is Portland cement.

There are two processes known as “wet” and “dry” processes depending upon whether the mixing and grinding of raw materials.

For many years the wet process remained popular because of the possibility of more accurate control in the mixing of raw materials. The technique of intimate mixing of raw materials in powder form was not available then. Later, the dry process gained momentum with the modern development of the technique of dry mixing of powdered materials using compressed air. The dry process requires much less fuel as the materials are already in a dry state.

1.6.2 Aggregates

Generally 85% of the volume of concrete is occupied by the aggregates. Aggregates are those inert materials, which when bound together by cement, form mortar or concrete. Aggregates are known as inert materials because they remain chemically inactive during setting and hardening of cement. Aggregates mostly used for the manufacture of concrete are sand, blast furnace slag, saw dust, crushed rock etc.

The aggregates are cheaper than cement and a concrete mix which makes use of maximum quantity of aggregates is economical. Aggregates provide greater volume stability and better durability to concrete.

According to size the aggregates are classified into the following **three types**:

a) **Fine Aggregates.** The aggregates which pass through 4.75mm sieve and retained on 75 micron (0.075mm) sieve are known as fine aggregates. The lower size limit of sand is about 0.077 mm. The material having particle size from 0.06mm to 0.002 mm is classified as silt and those with particle size less than 0.002 mm is known as clay. The soft deposit consisting of sand, silt and clay in about equal proportions is called loan. Fine aggregates fill up the voids in coarse aggregates and thus strong concrete with less quantity of cement is obtained by using fine aggregates. It reduces the cost of concrete. It also increases workability of concrete.

b) **Coarse Aggregates.** The aggregates which pass through 75 mm sieve and retained on 4.75 mm sieve are known as coarse aggregates. The maximum particle size of coarse aggregate is 75 mm and its minimum particle size is 4.75 mm the aggregate of particle size greater than 75 mm is known as c**yclopean aggregate.** The size of coarse aggregates depends on the type of work and arrangement of reinforcement provided in the concrete.

c) **All-In-Aggregates.** The aggregate which is the combination of coarse aggregate and fine aggregate is called all-in-aggregate. These aggregates are not generally used for making high quality concrete.

1.6.3 Water

Water is the most important and least expensive ingredient of concrete. A part of mixing water is utilized in the hydration of cement to from the binding matrix in which the inert aggregates are held in suspension until the matrix has hardened. The remaining water serves as lubricant between the fine and coarse aggregates and makes concrete workable, i.e. readily place able in forms.

The strength and durability of concrete is reduced due to the presence of impurities in the mixing water. The effects are expressed mainly in terms of differences in the setting times of concrete mixes containing proposed mixing water as compared in distilled water and concrete strengths compared with those of control specimens prepared with distilled water. The differences in 28 days compressive strength up to 10 percent of control test in generally considered to be a satisfactory measure of the quality of mixing water.

The water for the mixing and curing of concrete should be free form injurious amounts of deleterious materials. The unwanted situations, leading to the distress of concrete, have been found to be a result of, among others, the mixing and curing water being inappropriate quality. Potable water is generally considered satisfactory for mixing concrete. In the case of doubt about the suitability of water, particularly in remote areas or where water is derived from sources not normally utilized for domestic purposes, water should be tested.

1.6.4 Micro Fibres

The desired result of adding fibres to any concrete mix is to enhance its mechanical and shrinkage properties. The improvements gained by using fibres depend on the properties of the fibre which include the fibre material as well as fibre length and geometry to name a few.

Various materials are used to produce fibres for use in concrete. Currently the main distinctly different categories are steel fibres, synthetic fibres, glass Fibres and organic or natural fibres. **Table** 1.1 shows some of the fibres from every category along with the basic material properties. Manufacturers produce Fibres in different geometrical forms to improve the bond characteristics between fibre and the concrete matrix while trying to prevent fibre bundling from occurring during the mixing process.

All fibres are either categorized as macro or micro fibres. These fibres are expected to bridge cracks and provide structural support of the hardened state of concrete. Micro fibres on the other hand are included in a mix to help improve the fresh and early-age tensile- and flexural strength of concrete. These fibres provide the necessary resistance to tensile forces developed by drying shrinkage as well as plastic shrinkage.

Table 1.1: Properties of Various Fibre Types.

Micro Fibre	Specific Gravity	Tensile Strength (MPa)	Elastic Modules (GPa)
Acrylic	1.16-1.18	296-1000	14-19
Aramid I	1.44	2930	62
Aramid II	1.44	2344	117
Carbon I	1.9	1724	380
Carbon II	1.9	2620	230
Nylon	1.14	965	5
Polyester	1.34-1.39	228-1103	17
Polyethylene	0.92-0.96	76-586	5- 117
Polypropylene	0.9-0.91	138-690	3.0-5.0
Alkali-resistant	2.7-2.74	2448-2482	79-80
Non Alkali-resistant	2.46-2.54	3103-3447	655-72
Coconut	1.12-1.15	120-200	19-26
Sisal	-	276-568	13-26
Bagasse	1.2-1.3	184-290	15-19
Steel	7.8	1000-3000	200
Glass	2.6	2000-4000	80

The shapes of synthetic fibres are similar to that of steel fibres with the straight and crimped forms being the most common for macro fibres. Micro fibres for both steel and synthetic fibres are usually only available in short straight forms.

1.7 PERFORMANCE CRITERIA FOR STRUCTURES

For today's structures, we look for materials with four distinctive properties: strength, workability, durability and affordability.

When we say high performance, we refer to the improvement in some or all of these properties. Sometimes, we have to give up a little in one to gain a little in the other. But, in general, with time, all these properties improve. We will discuss these four properties one by one as follows:

1.7.1 Strength

Higher strength offers savings in material. Weight, or the structural dead load, is a major loading in the design of structures. Consequently, higher strength usually gives us two advantages: less material and less weight. The reduction in weight in turn reduces the demand on material because it reduces the load the structure has to carry this is many folds higher than the regular concrete.

1.7.2 Workability

A structure is not only designed, but it also must be constructed. Workability affects the cost and the time required to build the structure. Obviously time and cost are often the two fundamental determinants on whether a bridge or a certain type of structure will be built. Workability also implies that a material is reliable and consistent. We need better equipment to achieve that in an industrial scale.

1.7.3 Durability

When we look at some of the ancient structures of Roman and Byzantine eras that are still standing, we wonder how long our structures will last. Our ancient fellow engineers just built major structures based on their best knowledge and usually expected the structures to last forever. Today, we know that nothing will last forever and we become more humble and design our buildings and bridges to a defined design life. With the design life of major bridges usually being 100 to 150 years, we are in need of durable materials that will last a long time and are easy to maintain. MFRC does offer us good potential in this respect. However, in an engineering world that values performance records, a certain amount of time will be needed to assure people that the long term performance of the material is what the laboratory tests have shown us.

1.7.4 Affordability

Cost is often a determining factor on whether a structure will be built. There are probably other good construction materials that can be used for construction except that their high cost may have prevented them from being used.

A potentially good but expensive material may become affordable when its application is more widespread due to mass production, while its application can only get widespread if its cost is sufficiently low.

For example, Stainless steel is good for many applications in construction. However, the higher price of stainless steel is a hindrance to its widespread use.

1.8 TERMINOLOGY

Various terms are used to refer to cementitious-based composite materials with high compressive strength and enhanced durability. These include the following:

- Micro Fibre Reinforced Concrete (MFRC)
- Compact reinforced composite (CRC).
- Densified small-particle (DSP) concrete.
- Fibre-reinforced high-performance concrete (FRHPC).
- High-performance micro fibre reinforced cement composite (HPMFRCC).
- Macro defect free (MDF) concrete.
- Multi-scale micro fibre-reinforced concrete (MSMFRC).
- Reactive powder concrete (RPC).
- Steel fibrous cement-based composite (SFCBC).

In addition, various patterns of hyphens are used to form compound adjectives. For this report, the product is generally called micro fibre reinforced concrete or MFRC unless it is necessary to differentiate the different types.

1.9 ADVANTAGES OF MICRO FIBRE REINFORCED CONCRETE

- MFRC is used in civil structures where corrosion is to be avoided at the maximum.
- MFRC is better suited to minimize cavitations /erosion damage in structures where high velocity flows are encountered.
- A substantial weight saving can be realized using relatively thin MFRC sections having the equivalent strength of thicker plain concrete sections.
- When used in ridges it helps to avoid catastrophic failures. In quake prone areas the use of micro fibre reinforced concrete would certainly minimize the human casualties.
- Micro fibre reduces internal forces by locking microscopic cracks from forming within the concrete.

- Studies have been proven that micro fibre reinforced concrete is found to improve the mechanical properties of ordinary concrete such as Compressive Strength, Modulus of Elasticity and flexural strength, Toughness, Splitting Tensile Strength, Fatigue Strength, and Impact Resistance.

1.10 DISADVANTAGES OF MICRO FIBRE REINFORCED CONCRETE

- The micro fibres have to be uniformly mixed and spread throughout the concrete mix. At times, this is found to be a difficult process and time consuming. If this limitation has been overcome by new and effective methods of fabrication, micro fibre reinforced concrete is found to be more adaptable for common concreting works.

1.11 HUMAN HAIRS AS MICRO FIBRE

As an Innovation to the field of micro fibre Reinforced Concrete, usage of Human Hair as a micro fibre gained its importance. Chemically, about 80% of human hair is formed by a protein known as keratin, with a high grade of sulfur coming from the amino acid cysteine – which is the characteristic to distinguish it from other proteins. Keratin is a laminated complex formed by different structures, which gives the hair strength, flexibility, durability, and functionality. Basically, the hair thread has a cylindrical structure, highly organized, formed by inert cells, most of them keratinized and distributed following a very precise and pre-defined design. Hair forms a very rigid structure in the molecular level, which is able to offer the thread both flexibility and mechanical resistance. Human hair has about 65-95% of its weight in proteins, 32% of water, lipid pigments and other components.

Human Hair micro fibre is composed by three main structures: cuticle, cortex and medulla. Proteins with α-helix structure which are winded in the hair have long filaments of unknown micro fibre which link to each other to form bigger structures, in order to produce cortex cells. This enchained structure offers the capillary micro fibre more strength and elasticity. The main factor to be considered in the human hair is the high amount of the amino acid cysteine, which may be degraded and afterwards may be re-oxidated under a disulphidic bounding form. Hair is surprisingly strong. Cortex keratin is responsible for this propriety and its long chains are compressed to form a regular structure which, besides being strong, is flexible. The physical proprieties of hair involve: resistance to stretching, elasticity and hydrophilic power.

Benefits of Human Hair as a Micro Fibre

Hair is used as a micro fibre reinforcing material in concrete for the following reasons:

- It has a high tensile strength which is equal to that of a copper wire with similar diameter.
- Hair, a non-biodegradable matter is creating an environmental problem so its use as a fibro reinforcing material can minimize the problem.
- It is also available in abundance and at a very low cost.
- It reinforces the mortar and prevents it from spalling. As a consequence of increased strength with lower w/c ratio, it also permits a reduction of cement content.

1.12 STRUCTURE OF THE DISSERTATION

The dissertation has hitherto provided a general background on micro fibre reinforced cement concrete, its ingredients and performance criteria.

Chapter 2 reports a state of the art and critical review on the properties of micro fibre reinforced concrete using various micro fibre contents and different aspect ratio.

Chapter 3 outline the research methodology by targeting the introduction of raw materials and experimental techniques in preparation, characterization and evaluation for MFRC samples

Chapter 4 presents the results for compressive strengths, split tensile strength, flexural strength and rapid chloride penetration tests and their discussions. Also this chapter presents SEM images of various specimens and their discussions.

Chapter 5 presents the conclusions expected from the results and discussion from chapter 4 for the performance of MFRC.

References for all chapters are listed at the end of the dissertation in chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Micro fibre-reinforced concrete (MFRC) is concrete containing fibrous material which increases its structural integrity. It contains short discrete micro fibre that are uniformly distributed and randomly oriented. Micro fibre includes steel micro fibre, glass micro fibre, synthetic micro fibre and natural micro fibre – each of which lends varying properties to the concrete. In addition, the character of micro fibre-reinforced concrete changes with varying concretes, micro fibre materials, geometries, distribution, orientation, and densities. Micro fibres are usually used in concrete to control cracking due to plastic shrinkage and to drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Some types of micro fibre produce greater impact, abrasion, and shatter resistance in concrete.

According to Bentur and Mindess (2007) micro fibre are known and accepted for their effects on shrinkage cracking resistance than long-term shrinkage reduction. Several types of micro fibre have been introduced to industry thus far. They listed them as: steel micro fibre, glass micro fibre, asbestos micro fibre, natural micro fibre and synthetic micro fibre which contains polypropylene (PP), polyethylene (PE), acrylic, polyester, nylon, carbon, aramid, and polyvinyl alcohol (PVA). In general, there is not many research studies carried out on the effects of micro fibre and micro fibre in drying shrinkage reduction of mortar and concrete. Therefore, micro fibres are mostly used for prevention of plastic shrinkage cracking.

2.2 CONSTITUENT MATERIALS AND MIX PROPORTIONS

Pedram Hamedanimojarrad (2012) all cement mortar mixes are simply named after their concentration of PE micro fibre. Therefore, the term Co stands for the control mix without micro fibre. Terms such as PE0.01 to PE0.7 stand for mixes with PE micro fibre concentration of 0.01% to 0.7% to cement weight, respectively. In addition, PE1.0+SP2 and PE2.0+SP2 stand for mixes with 1.0 and 2.0% of PE micro fibre and with 2 mL of HWR, while other mixes contain only 1 mL of HWR. **(Table 2.1)**

Table 2.1 Mix Proportion of Fibre Reinforced Cement Mortars (Pedram Hamedanimojarrad, 2012)

Mixes / Raw materials	Co	PE0.01	PE0.025	PE0.05	PE0.1	PE0.3	PE0.7	PE1.0	PE1.0+SP2	PE2.0+SP2
Cement (g)	450	450	450	450	450	450	450	450	450	450
Sand (g)	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350
Water (g)	224.35	224.35	224.35	224.35	224.35	224.35	224.35	224.35	224.35	224.35
HWR (ml)	1	1	1	1	1	1	1	1	2	2
Micro Fibre (g)	0	0.045	0.1125	0.225	0.45	1.35	3.15	4.50	4.50	9.00

According to Shashi Kant Sharma et al. (2013) by optimizing the cementations matrix for fresh state tests like normal consistency, initial and final setting time tests (IST and FST) were performed on four blended pastes and one normal cement (OPC 43 grade) paste. The blends were made by replacing cement with silica fume (0, 7.5% by weight) and wollastonite micro Fibre (10, 20, and 30% by weight) respectively in all mixes. In all five mixes were tested: pure cement mix, cement plus wollastonite micro Fibre and three mixes of ternary combination of cement with wollastonite micro Fibre and silica fume. Mortar mixes were then prepared on the basis of water demand obtained from the normal consistency test, having 1:3 proportion of cementitious material: sand. IS 4031 (Part 6):1988 and IS 516:1959 were followed to perform compression and flexural strength test respectively. For mortar cubes of 7.06×7.06×7.06 cm^3 were cast and tested after 7, 28 and 56 days at a uniform and steady load of 35N/mm^2/min. Beams of size 10×10×50 cm^3 were cast and tested after 28 and 56 days of curing, at a steady and uniform loading rate of 180 kg/min as shown in **Table 2.2.**

Table 2.2 Mix Proportion (Shashi Kant Sharma et al., 2013)

Mix	Composition (%age) (C+WMF+SF)	Consistency	IST min.	FST Min.
C0	100	29	150	220
W0	90+10	30.5	170	255
X1	82.5+10+7.5	32	140	249
X2	72.5+20+7.5	32	140	249
X3	62.5+30+7.5	35.5	152.	275

According to Mustafa Sahmaran and Victor C. Li (2007) the components of ECC material are similar to typical fiber reinforced cement composites, consisting of ordinary portland cement (C), Class-F fly ash (FA) with a lime content of 10.44%, silica sand with an average and maximum grain size of 110 lm and 200 lm, respectively, water, polyvinyl alcohol (PVA) fibers, and a high range water reducing admixture (HRWR). The PVA fibers are purposely manufactured with a tensile strength, elastic modulus, and maximum elongation matching those needed for strain hardening performance. Additionally, the surface of the PVA fibers is coated with a proprietary hydrophobic oiling agent 1.2% by weight to tailor the interfacial properties between fiber and matrix for strain-hardening performance. Standard ECC mixture (M45) was used in this investigation, details of which are given in **Table 2.3**. ECC mixture was prepared in a standard mortar mixer at water to cementitious material (W/CM) ratio of 0.27 and had a fly ash-cement ratio (FA/C) of 1.2 by mass. The compressive strength was computed as an average of three standard 75mm x150mm cylinder specimens.

Nila V. M et al. (2015) considered human hair as a waste material in most parts of the world and is a common constituent found in municipal waste streams which cause enormous environmental problems. This particular topic has been first chosen as a method of finding the possibilities of hair rather than considering it as a non-bio degradable waste material. It is also available in abundance and at a very low cost. It reinforces the mortar and prevents the spalling of concrete. The properties like high tensile strength, unique chemical composition, thermal insulation etc. makes it suitable to be used as a reinforcing material. **(Table 2.4)**

Table 2.3

Mixture Properties of ECC and Mortar(Mustafa Sahmaran and Victor C. Li, 2007)

	ECC (M45)
FA/*C*	1.2
W/CM[a]	0.27
Water (W), kg/m^3	331
Cement (C), kg/m^3	570
Fly ash(FA) kg/m^3	684
Sand (S) , kg/m^3	455
Fibre (PVA) , kg/m^3	26
HRWR, kg/m^3	4.9
7-day compressive strength, MPa	38.1
28-day compressive strength, MPa	50.2

[a] CM: Cementitious materials. (cement+fly ash).

Table 2.4 Details of Necessary Materials Required (Nila V. M et al., 2015)

MIX PROPORTION	**M15**	**M20**	**M25**
Quantity of cement (kg)	3.82	4.86	6.68
Quantity of sand (kg)	7.64	7.29	6.68
Quantity of coarse aggregate (kg)	15.27	14.58	13.36
Water cement ratio	0.48	0.5	0.55
Quantity of water (1)	1.834	2.43	3.67
Quantity of hair (kg) (1.5%)	0.0573	0.073	0.1

2.3 MECHANICAL PROPERTIES OF MICRO FIBRE REINFORCED CONCRETE

The performance of MFRC can often be compared to that of steel bar or steel mesh reinforcement. This is because of the level of confidence that designers and contractors use the conventional method to improve the concrete's tensile and flexural resistance. In literature there have been many experimental investigations into finding an alternative to this type of reinforcement. In the following paragraphs some of the most relevant findings from literature are documented to compare the performance of various types of MFRC for their structural use.

Micro fibre begins to function in a structural supportive manner when the concrete matrix starts to crack. The micro fibre then provide ductility and support by bridging cracks and thus providing post crack strength to the concrete. When performing a load deflection test of any kind, it can be noticed that by adding micro fibre to a mix there exists a strain softening behavior of MFRC where some loads can be supported after the concrete first begins to crack. Strain hardening is encountered, when a higher load is reached after the concrete cracks for the first time, by the micro fibre bridging the cracks. This only occurs if the reinforcing provide by the micro fibre is sufficient. **Figure 2.1** demonstrates this strain softening and hardening behavior. Typically only high performance fibre reinforced concretes (HPFRCC) show strain hardening. The toughness and thus the energy which could be absorbed by the addition of micro fibre could be computed by determining the area under a stress-strain curve (from flexural strength tests). It is essential to understand that the first crack strength of a micro fibre reinforced specimen will not necessarily give higher values than plain concrete. The effect of pull-out forces which is generated as the micro fibre gradually slip out of the matrix causes the improved toughness. It is thus preferred that pull-out of the micro fibre do occur instead of micro fibre breaking which is the result of too large bond strength between micro fibre and the surrounding matrix. In order to achieve optimum efficiency of the micro fibre, the bond strength between micro fibre and the matrix needs to be as close as possible to the same value as the tensile strength of the micro fibre, but still less **(Banthia, 2012)**. Steel micro fibres are currently one of the most used micro fibre in concrete to improve structural performance. This is the only type of micro fibre for which there exists design guidelines and frameworks on an international level. The Concrete Society of the United Kingdom documented guidelines for the use of Steel micro fibre reinforced concrete (SMFRC) in their technical report in 2007. In this report they provide a framework for the design of structures like slabs on various support structures, linings for tunnel construction and the design of in situ concrete members. **Table 2.5** shows the performance enhancing capabilities that steel Fibres can provide compared to unreinforced concrete according to the mentioned reference.

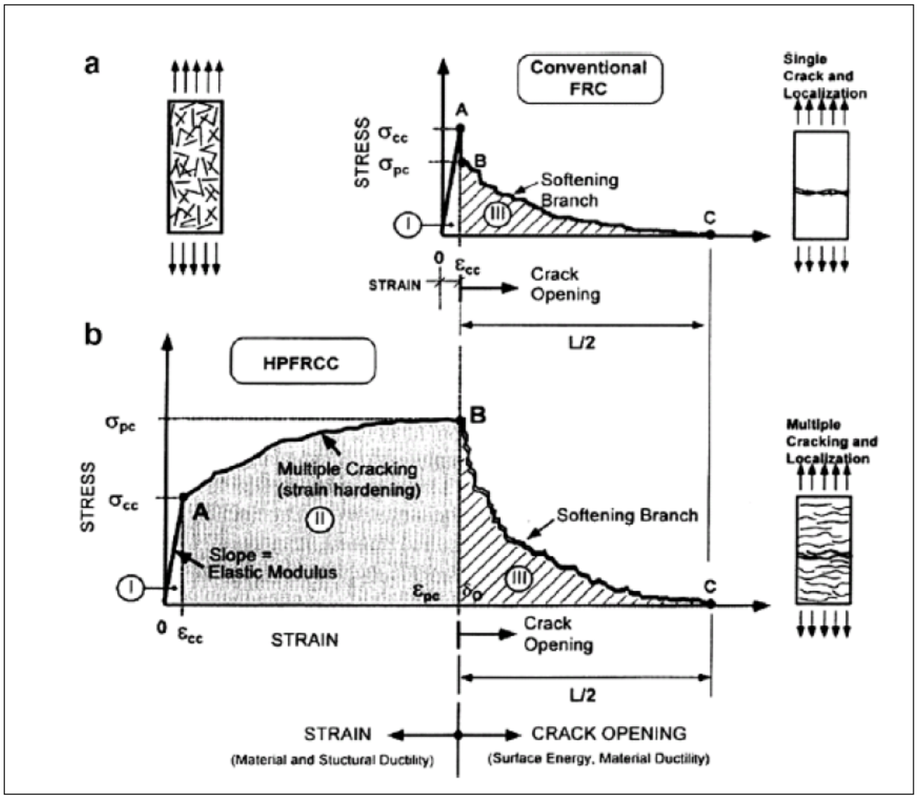


Figure 2.1: Strain Hardening and Strain Softening Behavior of Different MFRC's (Brandt, 2008).

Doo-Yeol Yoo et al. (2014) investigates the bond performance of steel and glass fiber-reinforced polymer (GFRP) rebars embedded in ultra-high-performance fiber-reinforced concrete (UHPFRC). The steel rebar showed 2.8–3.6 times higher bond strengths than the GFRP rebar and rebar yielding at embedment length of 2 times the rebar diameter. The bond failure of GFRP rebar occurred by delaminating resin and fiber in GFRP rebar, different to that of steel rebar (shearing off and crushing of concrete). For GFRP rebar, higher bond strength was obtained when a larger rebar diameter and a shorter embedment length were used, and re-increase of pull-out stress in softening branch was observed owing to wedging effect.

Table 2.5: The Performance of SMFRC Compared to Unreinforced Concrete (Concrete Society UK, 2007).

Property	**Comment**
Abrasion resistance	Improvement may be achieved as a result of reduced bleeding.
Compressive strength	Little change.
Electrical resistance	No significant change at fibre dosage generally used.
Fatigue resistance	Improvements even at low dosages.
Flexural strength	Little change in first crack strength at dosage rates commonly used.
Freeze-thaw resistance	Can reduce the deterioration caused by freeze-thaw cycling.
Impact resistance	Major improvements.
Modulus of elasticity	No significant change at fibre dosages generally used.
Restrained shrinkage	Even at low dosage, better distribution of stresses can reduce crack widths.
Shear strength	Improvements even at low dosage can be achieved in combination with reinforcing bars.
Spalling resistance	Being dispersed throughout the matrix, steel fibre reinforcement gives superior protection to exposed areas such as the joint arris.
Thermal shock resistance	As with impact resistance, there are improvements even at low dosage rates, a typical application being foundry floors.
Toughness	Major improvements, even at low dosages.

Feng J. et al. (2014) studied, a practical model to simulate the pullout performance of hooked steel Fibre in ultra-high-performance concrete is proposed. Straight and hooked Fibre pullout tests were performed to evaluate the pullout mechanism, based on which slip-hardening; matrix spelling and tunnel damage assumptions are made.

With energy conservation, static and fracture mechanical analyses, this model investigates the pullout load due to mechanical deformation as well as additional friction caused by bending. Model predictions are compared with the experimental results of hooked Fibre pullout data and reasonably good correlation is observed.

Mahmud G.H et al. (2013) Ultra High Performance Steel Micro Fibre Reinforced Concrete (UHPMFRC) is a relatively new construction material with high strength, fracture toughness and ductility. Although many aspects of UHPMFRC have been investigated extensively, the size effects on structural strength of UHPMFRC members remain largely unknown. This is mainly due to the lack of sufficient and reliable experimental data. This study investigates the size effects on flexural strength of similar notched UHPMFRC beams under three-point bending tests. It was found that the size effect on the beam nominal strength is little due to high ductility of UHPMFRC.

Park S.H. et al. (2012) reported the interfacial bond strength of long high-strength steel Fibres embedded in ultra-high-performance concrete (UHPC) reinforced with short steel micro Fibres was investigated by conducting single-Fibre pullout tests. In particular, the influence of the addition of a shrinkage-reducing to a UHPC matrix on the pullout resistance of high-strength steel Fibres was investigated. The addition of a shrinkage-reducing agent produced a noticeable reduction in the Fibre pullout resistance owing to the lower matrix shrinkage, although the reduction of pullout resistance differed according to the type of Fibre. Long smooth and twisted steel Fibres were highly sensitive to the addition of the shrinkage-reducing agent whereas hooked Fibres were not. Among the various high-strength steel Fibres tested, twisted steel micro Fibres showed the highest interfacial bond resistance, although twisted Fibres embedded in UHPC showed slip softening pullout behavior rather than the typical slip hardening behavior observed in mortar.

2.3.1 Compressive Strength

Since the compressive strength of concrete is one of its main attributes and the reason for adding any reinforcing material is in most cases to improve other characteristics, little focus has been put on the compressive strength of MFRC. Because compressive strength tests measure the load until failure (first cracks) and since micro fibre only contributes to the structural integrity of concrete by bridging cracks after cracks begins to form, the effect on compression strength is not its main attribute. By bridging cracks, micro fibre stops or limits the propagation of cracks and also limits crack widths. These attributes not only contributes to structural integrity, but also improves the durability of structures made from such materials.

Different and often contradicting results on compression strength tests were found in literature. **Alhozaimy et al. (1995)** found in their research that the addition of low volumes (0.1%) of polypropylene micro fibre to a concrete mix has no significant effect on the compressive strength of conventional concrete. Previous research suggests that the compressive strength of concrete containing synthetic micro fibre (0 – 0.3%) is less than that of plain concrete **(Zollo, 1984)**. Other studies found that by using 0.5% micro fibre by volume, the compressive strength could be increased by as much as 25% **(Mindess, S. and Vondran, 1988).** The addition of supplementary materials such as silica fume or slag in combination with the use of micro fibre could yield some improvement in compressive resistance of the composite as **Figure 2.2** shows for specimens of conventional concrete and that of mixed binder type with and without 0.1% micro fibre by volume.

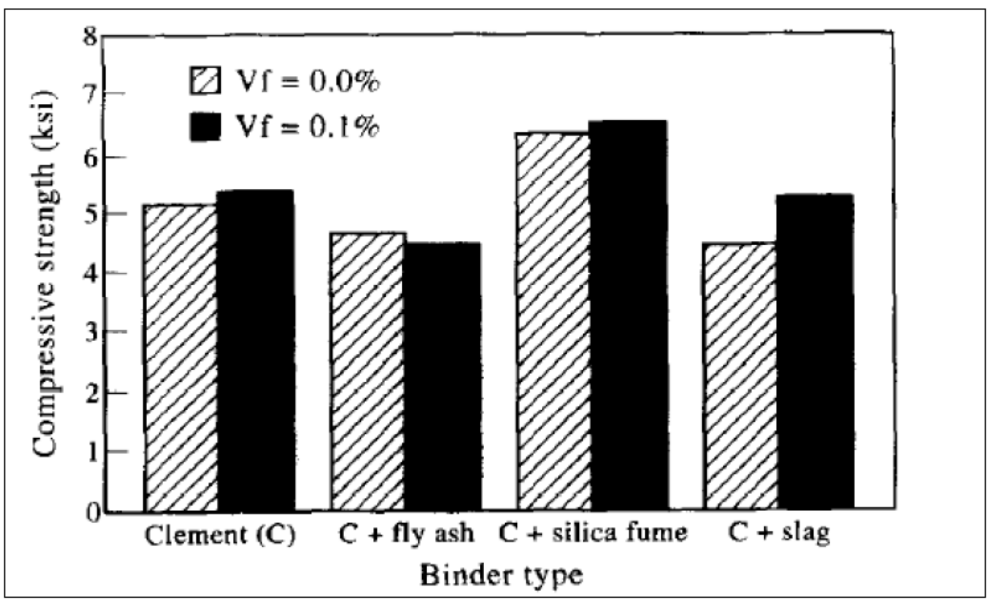


Figure 2.2: Compressive Strength of Different Concrete Mixes Comprising of Plain and Fibre Reinforced Concrete (Alhozaimy et. al, 1995)

2.3.2 Tensile Strength

The splitting tensile strength of concrete can be increased by adding micro fibre to a concrete mix. **Choi et al (2004)** found that glass fibre reinforced concrete (GFRC) and polypropylene fibre reinforced concrete (PFRC) have a splitting tensile strength of 20-50% more than that of unreinforced concrete **(Figure 2.3)**. They also concluded that the splitting tensile strength of these composites ranged between 9-13% of their compressive strengths.

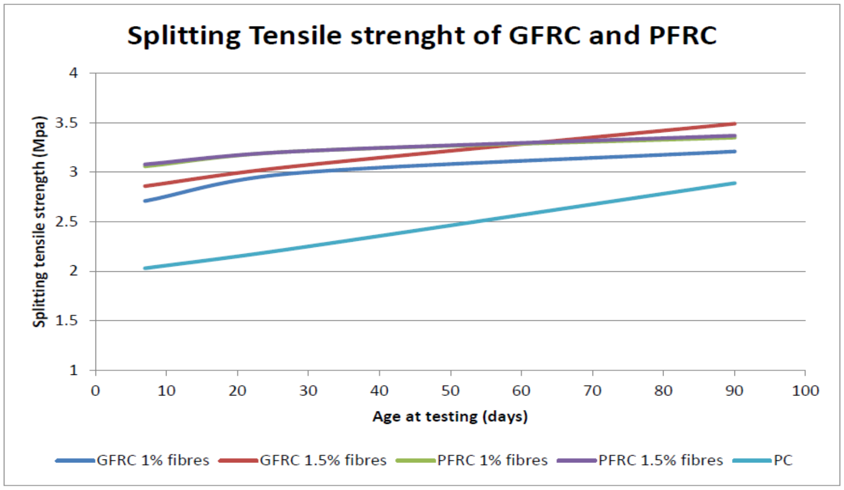


Figure 2.3 Comparison of Splitting Tensile Strength of GFRC and PFRC with Unreinforced Concrete after Choi and Yuan (2004).

Leutbecher, et al. (2004) has proposed the idealized tensile stress-strain response shown in **figure 2.4.** This response is based on direct tension tests of two UHPCs with multiple Fibre contents. It is proposed as a conceptual illustration of the pre cracking and post cracking tensile stress-strain response of strain-hardening Fibre reinforced concretes, such as UHPC. The behavior is divided into four phases. Phase I is elastic behavior. Phase II is the phase wherein multiple tightly spaced cracks form in the UHPC matrix. The cracks occur individually as the stress in the matrix exceeds the matrix cracking strength. Phase III begins at the strain level where additional cracking between existing cracks is unlikely. Individual cracks widen in this phase. Lastly, Phase IV begins when an individual crack has reached its strain limit and the Fibres bridging that crack begin to pull out of the matrix. In a strain-hardening Fibre-reinforced concrete, the Fibre bridging strength where localization occurs is greater than the cracking strength where multi cracking occurs.

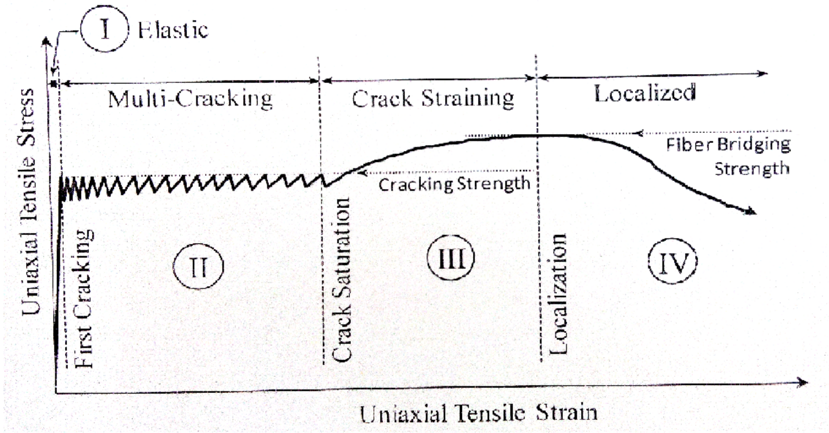


Fig. 2.4 Graph Idealized Uniaxial Tensile Mechanical Response of a UHPC (Leutbecher, et al., 2004)

Qian, S.et al (2008) Standard tensile test methods designed to assess the cracking strength of conventional concrete may be appropriate for assessing the first cracking strength of MFRC, but are unlikely to be appropriate for quantitatively assessing the post-cracking tensile response of MFRC. The ASTM C78—Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading) and ASTM C496—Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens fall into this category. Both test methods include assumptions of mechanical behaviors that are not consistent with strain-hardening Fibre reinforced concretes and thus are likely to overestimate the tensile strength of the MFRC.

Wille, K.et al (2012) has proposed a modified version of ASTM C496. The modified test method includes a requirement to monitor the first cracking of the MFRC during the test and calculate the splitting tensile strength based on the observed first cracking load.

Flexure-based test methods have been proposed, and in some cases, standardized. ASTM C1018, ASTM C1609, and RILEM TC 162-TDF all present test methods for use in determining the tensile response of Fibre-reinforced concretes. Methods have been proposed for analyzing the test results so as to develop uniaxial tensile response curves. However, these types of flexure tests have been demonstrated to be susceptible to over indications of strength as a result of the use of inappropriate support conditions.

A variety of direct tension test methods have been developed. In a direct tension test, the MFRC specimen is loaded in uniaxial tension and thus the tensile response can be directly captured by measuring the load on and the strain experienced by the specimen. Direct tension tests can be divided into two groups, namely, tests that allow rotation of the ends of the test specimen and tests that do not. The tests with rotation might provide an indication of first cracking strength, but are not appropriate for assessment of post-cracking behaviors. This is because local inconsistencies in stiffness at the plane of the first crack result in rotation and Fibre pullout at this Localized Uniaxial Tensile Stress Uniaxial Tensile Strain Localization Crack prior to the generation of a full set of additional cracks. Fixed-end tests that do not allow rotation at cracks are appropriate for capturing the full tensile stress-strain response. However, these tests are difficult to complete because of the bending stresses that can be imparted to the specimen during initial setup.

2.3.3 Flexural Strength

The calculated flexural resistance of concrete components is generally based on the conditions of equilibrium of forces and strain compatibility. The usable compressive strain in unconfined concrete is limited to a maximum value of 0.003. The shape of the stress-strain curve may be any shape that results in a prediction of strength in substantial agreement with test results. For simplification, a rectangular stress block for the compression zone is usually assumed. The tensile strength of the concrete is neglected. The applicability of this approach for use with MFRC has been addressed in several articles.

Meade and Graybeal (2010) reported the results of sixteen 6-inch (152mm)wide, 15-inch (381mm) deep rectangular MFRC beams tested in four-point bending over a span length of 16 ft (4.88m).The test variables were Fibre content (0, 1, and 2 percent by volume) and quantity of conventional non pre stressed reinforcement (0.00 to 1.00 percent by area).

Beams containing 1 and 2 percent Fibre reinforcement had higher first cracking strengths, better post-cracking flexural response, and higher peak loads than beams without Fibres. Increasing the Fibre content from 1 to 2 percent resulted in stiffer post-cracking response and higher peak loads. The beams containing no Fibres failed when flexure-shear cracks extended into the compression region under the load points, leading to a shear failure of the flexural compression block in the shear span. The beams containing the Fibres failed when the Fibres pulled out across a critical crack and the reinforcing bars ruptured. No concrete crushing was noted.

Visage et al. (2012) reported the results of ten 6-inch (152mm) square beams tested in flexure. Test variables included compressive strength, amount of flexural reinforcement, volume of steel Fibres, and beam length. Test results were compared with traditional methods of estimating moment-curvature relationships.

Adeline and Behloul (1996) reported flexural tests of two 49.2-ft (15m) long MFRC beams containing only flexural reinforcement. The beams contained eight or four 0.6-inch (15.2mm) diameter strands. The beam with eight strands failed by crushing of the UHPC, whereas the beam with two strands failed by strand rupture. Both beams exhibited large deflections before failure. The authors used a nonlinear multilayer program to predict the moment-deflection curves. They obtained very good agreement between the measured and calculated curves in both the elastic and plastic parts of the curves.

The stress–strain curves of UHPHMFRC during the flexural test at 7 and 28 days are shown in **Fig. 2.5(a) and (b).** Similarly to the results shown in the literature, the addition of steel micro fibre (2 vol. %) can not only enhance the ultimate flexural strength, but also improve the energy absorption capacity of the designed UHPHMFRC.

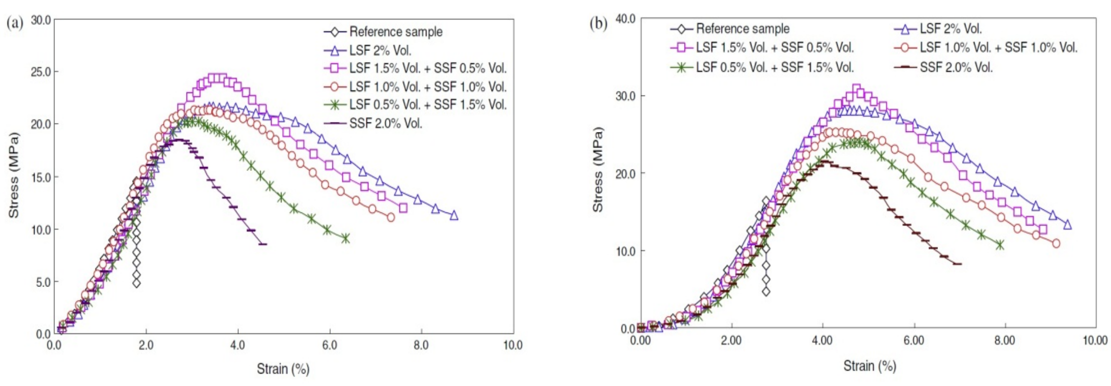


Fig. 2.5 Stress–Strain Curve of UHPHMFRC under Flexural Test: (a) after curing for 7 days; and (b) after curing for 28 days (Adeline and Behloul, 1996)

This should be attributed to the fact that the additional steel micro fibre can bridge cracks and retard their propagation, which could change the fracture behavior of concrete from brittle to plastic and significantly increase the ultimate flexural strength of concrete .Moreover, it is important to notice that the flexural properties of the specimen strongly depend on the fractions of the long and short steel micro fibre in the total fibre amount. As can be seen in **(Fig. 2.5 a and b),** the ultimate flexural strengths of the concrete with long steel micro fibre (1.5 vol. %) and short steel micro fibre (0.5 vol.%) at 7 and 28 days are always the largest, which are 24.3 MPa and 30.9 MPa, respectively. When only short steel micro fibre are utilized (2 vol. %), the ultimate flexural strengths at 7 and 28 days reduce to around 18.4 MPa and 21.5 MPa, respectively. This can be explained by the following two reasons:

(1) Short micro fibre can bridge micro-cracks more efficiently, because they are very thin and their number in concrete is much higher than that of the long steel micro fibre, for the same fibre volume. Hence, when the micro-cracks are just generated in the concrete specimen, the short steel micro fibre can effectively bridge the micro-cracks. As the micro-cracks grow and merge into larger macro-cracks, the long steel micro fibre become more and more active in crack bridging. In this way, primarily the ductility can be improved, and partly also the flexural strength. Long micro fibre can therefore provide a stable post-peak response. Short micro fibre will then become less and less active, because they are being more and more pulled out, as the crack width increases.

(2) Long micro fibres are always well oriented between the two imaginary borders. If casting of concrete in layers is applied (these borders may also be the walls of the moulds). With such positions, the long micro fibres form a kind of a barrier for short micro fibre, and limit their space for rotation. The short micro fibre will therefore be somewhat better oriented when combined together with long micro fibre, than on their own **(Fig. 2.6).** Hence, more micro fibres distribute in the direction parallel to the force direction in the flexural test, and the mechanical properties can be significantly improved. Additionally, for the Sample with the largest ultimate flexural strength.

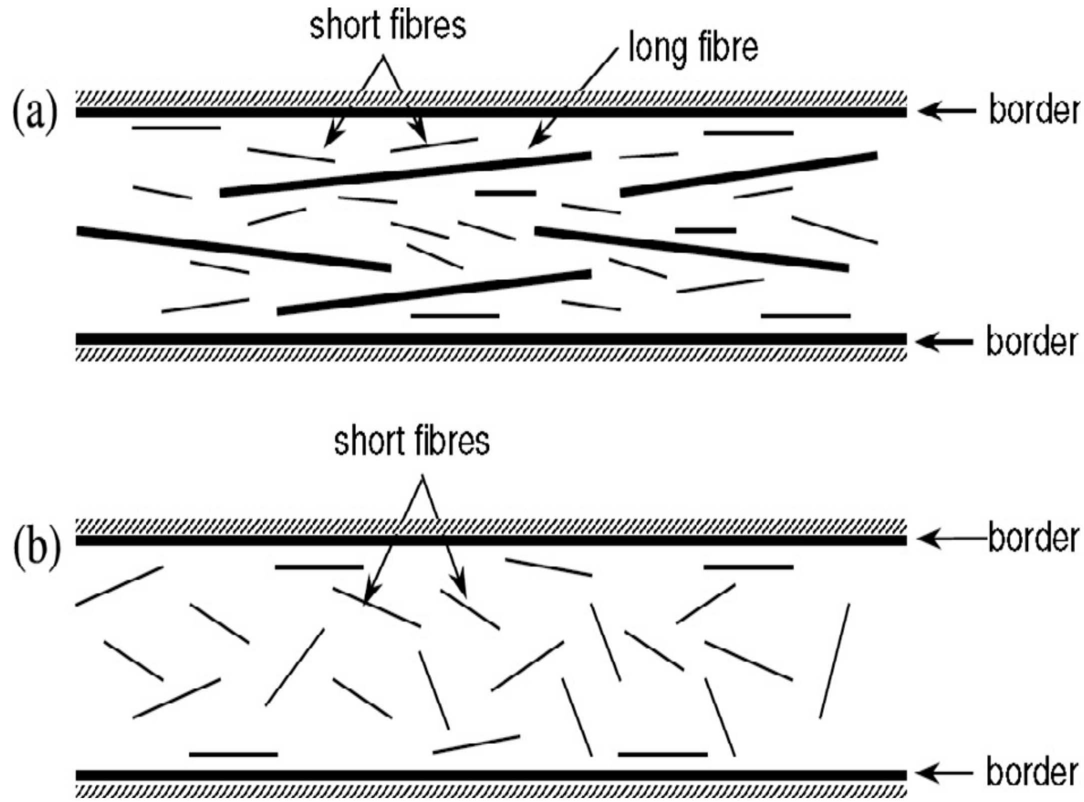


Fig.2.6 (a) Orientation of Short Micro Fibre between the walls of the Mould (or any other borders in general) in Combination with Long Micro Fibre and (b) when they are alone on their own (Adeline and Behloul, 1996)

It is important to notice that the stress quickly drops after reaching the stress peak. This should be attributed to the fact that the short steel micro fibre are less effective in bridging the macro-cracks and cannot provide a stable post-peak response. After calculating the area under the curves shown in **(Fig. 2.7)**, it is demonstrated that the energy absorption capacity of the batch with largest flexural strength may not be the largest, compared to the other mixtures in this research (161.4 units for reference sample and 139.8 units for LSF 1.5% Vol. + SSF 0.5% Vol. at 28 days).

In summary, the flexural properties of UHPHMFRC largely depend on the proportions between the long and short steel micro fibre. In this study, although the sample with long steel micro fibre (1.5 vol. %) and short steel micro fibre (0.5 vol. %) shows the largest ultimate flexural strength, its post-peak response is not the highest observed.

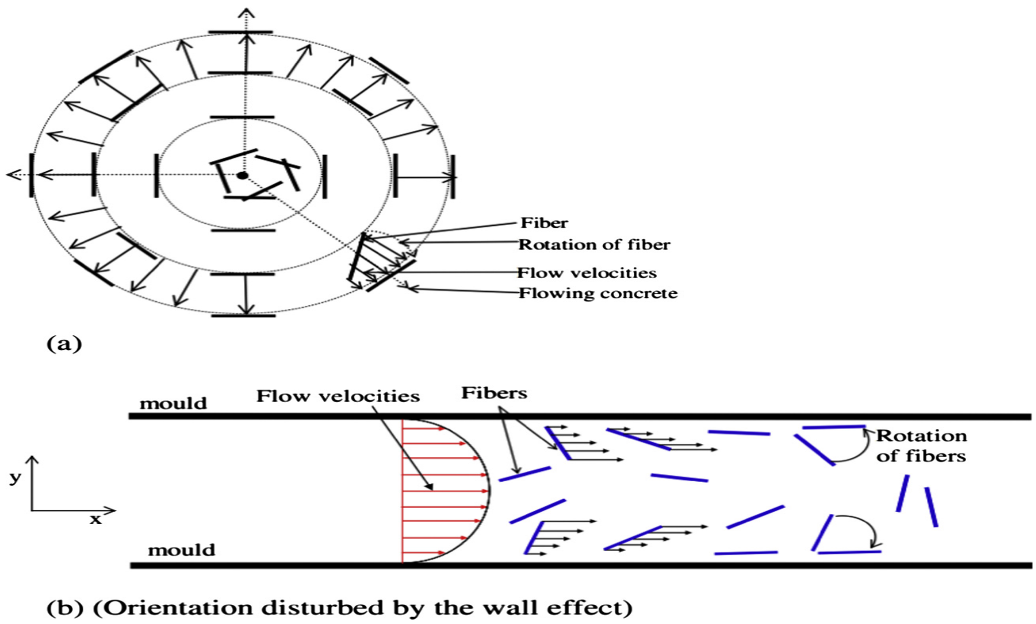


Fig. 2.7 Single type Steel Fibre Orientations in (a) Fountain Flowing and (b) Canal Channel Flowing (by Boulekbache B et al., 2010)

Based on the investigation by **Boulekbache B et al. (2010)** the mutual effects between hybrid micro fibres are utilized to produce the concrete, should be considered. It is known that different flow velocities affect the micro fibres and may cause them to rotate in such a way that the micro fibres reorient perpendicularly to the flow direction as shown in **(Fig. 2.7).** In the presence of relative velocities in translation and rotation, the fluid exerts forces and momentums on the micro fibres. Hence, for the fresh concrete with single type micro fibres, the entire micro fibre orientation tends to be perpendicular to the flow direction in the fountain flowing mode, which can generate the largest resistant force and reduce the slump flow of the fresh concrete. Nevertheless, when hybrid micro fibres are added into the fresh concrete, the fountain flowing mode may be relatively disturbed. When casting concrete in moulds, the micro fibres close to the walls of the moulds tend to be parallel to the borders, which is named the **''wall-effect''**.

Markovic I et al. (2006) shows in his study, when hybrid micro fibres are added into the fresh concrete, the long steel micro fibres can be treated as ''imaginary borders'' to the short steel micro fibres, and can relatively resist the rotation of the short micro fibres and reduce the resistance force in the fountain flow. Furthermore, the short steel micro fibres can also conversely restrict the rotation of the long steel micro fibres and further improve the ''wall-effect'' of long steel fibres. Therefore, the flowability of the hybrid micro fibres reinforced concrete is larger than that with only one type of steel fibres.

Ding and Kurstele (1999) found that the early age flexural and shear strength of SMFRC greatly out performs that of unreinforced concrete of the same age and is can replace steel mesh reinforcement. The flexural panel tests were conducted in accordance to the European standard for panel tests for sprayed concrete **(EFNARC, Figure 2.8).**

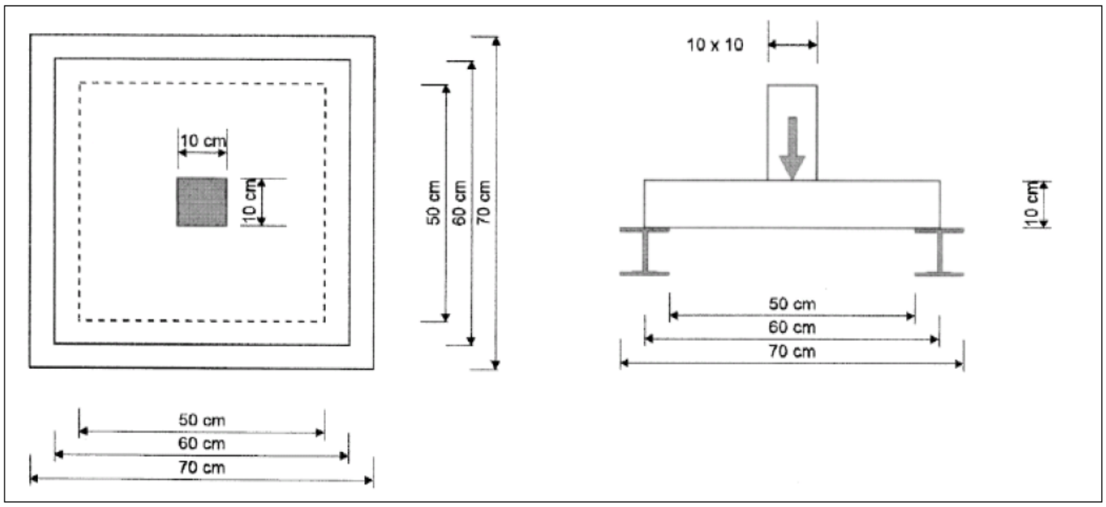


Figure 2.8 Test Set Setup For Panel Tests According To EFNARC (Ding and Kurnele, 1999)

The tests were conducted from an age of 10h and up to 48h and found that the optimal dosage of micro fibre is 40kg/m^3 to improve flexural and shear capacity. It was also found that from a dosage of 20kg/m^3 micro fibre the failure mode for a panel test changed from punching shear as for steel mesh reinforcement (SRC) to flexural failure for SMFRC. The research concluded from their test results that the influence of SMFRC is most contributing in the early ages, green state, than it is for hardened concrete. This was found by comparing the load deflection curves for 20, 40 and 60kg/m^3 of steel micro fibre in a mix to that of minimum steel reinforcement needed (mesh) for ages 10h, 18h, 30h and 48 hours. They found that the 20kg/m^3 dosage outperformed SRC at the age of 10 hours for its energy absorption capacity. But from an age of 18 hours the SRC exceed the capacity provided by the micro fibre. **Fig 2.9** shows the load to deflection curves obtained in their study for an age of 48 hours of the concrete panels.

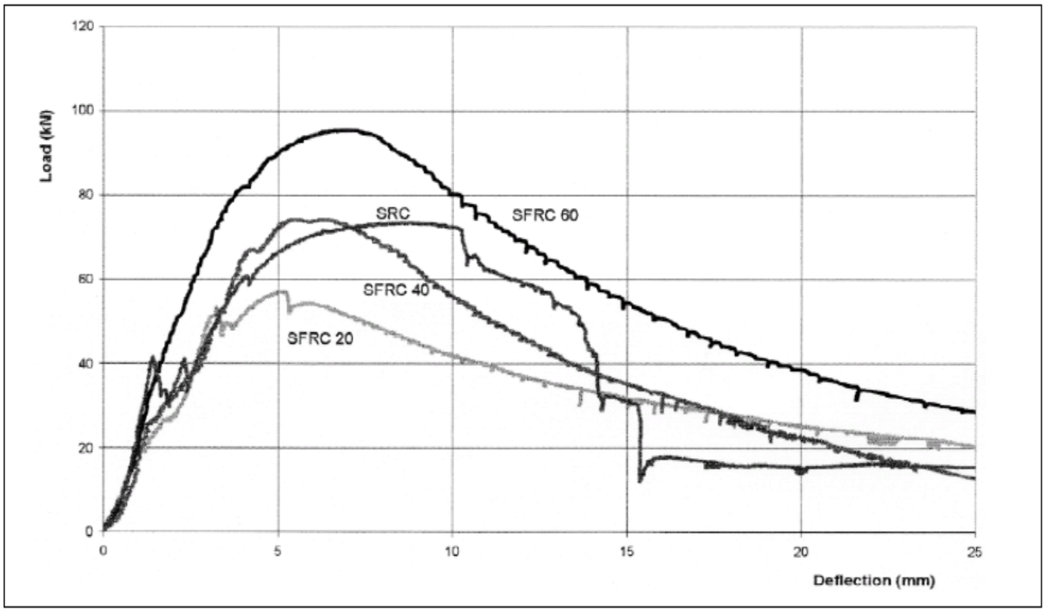


Figure 2.9 Comparison of SRC to SMFRC for Different Fibre Dosages at an Age of 48h (Ding and Kurnele, 1999).

Cengiz and Turanli (2004) performed similar panel tests to compare the performance of steel mesh reinforcement to that of steel fibre reinforcement, high performance polypropylene fibre reinforcement and a hybrid mix of both steel and polypropylene micro fibre. Their most important conclusions obtained were that PP micro fibre greatly enhanced the flexural ductility, toughness and load carrying capacity of the concrete matrix. They further discovered that a hybrid polypropylene- and steel fibre mix can be used alternatively to steel mesh and steel bars in shotcrete applications to gain improvements in mechanical properties efficiently. **Figure 2.10** shows the comparison of a hybrid fibre reinforced mix to that of high performance polypropylene micro fibre (HPPFR) of different dosages for a panel load-deflection shotcrete test. 30kg/m³ of steel micro fibre and 5 kg/m³ of polypropylene micro fibre were used in the hybrid fibre mix and 10 kg/m³ and 7 kg/m³ were used for the polypropylene mix.

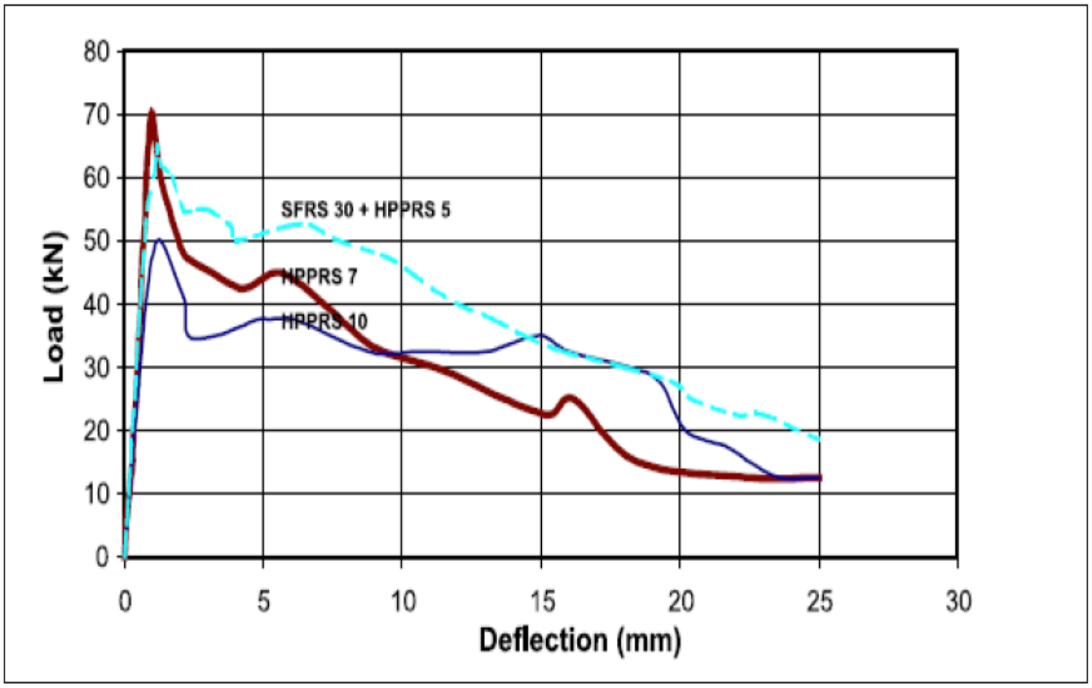


Figure 2.10: Comparison of Hybrid Fibre Reinforcement to HPPFR (Cengiz and Turanli, 2004).

The flexural strength of SMFRC increases as the temperature decreases as were found in a study which tested the flexural strength on to different dosages of micro fibre under temperature below freeze point.

Pigeon and Cantin (1998) conducted a four point flexural test on beam specimens with water:cement (w/c) ratios of 0.45 and 0.3 respectively. The research found that for both normal strength concrete (w/c of 0.45) and a more high performance one (w/c of 0.3) flexural strength of the concrete increased for temperatures under 0°C. Two different micro fibre dosages were used: 40 and 60kg/m^3 respectively. This increase in flexural strength was noticed first at a temperature of -10°C but was quit significant at -30°C.

An increase in flexural toughness was witnessed by **Alhozaimy et al. (1995)** in their research by performing flexural strength tests on concrete specimens reinforced with polypropylene micro fibre. They found that for volume fractions of 0.1%, 0.2% and 0.3% of micro fibre the flexural toughness increased by 44%, 271% and 386% respectively over that of plain unreinforced concrete for the same mix compositions.

2.3.4 Fire Resistance

J Bothma (2015) found that polypropylene fibres perform well as a measure to improve fire resistance of concrete since it has a low melting point (107 - 141 °C), which is a desirable attribute during a fire in a building. During fires, high temperatures cause the trapped water particles, still present in the concrete, to turn into vapour and this result in pressures within the concrete, which tends to cause brittle failure. When polypropylene fibres are present, they melt and provide channels through which the vapour could escape.

2.3.5 Impact Resistance

Impact resistance refers to the strength provided by the concrete when exposed to an increase in strain rate. Fibre reinforced concrete is known to have an increased resistance to impact loading over that of unreinforced concrete. In literature there is no unique standard or specific test that can be performed to determine impact resistance. The method that is mostly used for testing is to subject a concrete sample to a dynamic load from a drop weight system. Other methods include the use of a pendulum to subject an impact load or to use high velocity projectiles. The testing method that is chosen depends on the conditions under which the concrete will be used in the field. For concrete structures like warehouse floors, the drop weight system should be sufficiently accurate in simulating loading conditions. For more extreme loading like impacts through high velocity projectiles like bullets or explosive fragments, other methods should be used to simulate the actual conditions.

Mindess and Vondran (1988) found in their research that polypropylene fibres with a length of 19.1mm which were added in volume fractions from 0.1% to 0.5% increased impact resistance and fracture energy of the concrete. The experimental method used was a 345kg drop hammer released from 0.5m above the concrete specimen. Beam specimens of 1200mm in length, 100mm wide and 125mm deep were used. From the tests they found that an increase in fracture energy and impact resistance occurred as the volume fraction of fibres in the mix increased. At a dosage of 0.5% fibres a maximum bending load, as a measure of impact strength, was obtained which was 40% higher that of plain concrete. They also noticed that the fracture energy doubled at this volume of fibres. The primary mode of failure was fibre rupture rather than fibre pull-out.

In another similar study conducted by **Wang and Mindess and Ko, (1996)** the effect of adding polypropylene fibres as well as steel fibres were tested to determine whether an increase in impact resistance can be achieved. For this study beam specimens was tested under a dynamic load from a drop hammer (60.3kg). **Figure 2.11** shows the schematic test setup. This study found that polypropylene fibres improved impact loading resistance marginally (21% increase at 0.5% volume). When steel fibres were used at the same volume fraction an increase of 41% in impact resistance was noticed. This study also concluded that the mechanism of failure changed from fibre rupture to fibre pull-out as the volume fraction approached the region of 0.5% to 0.75%. Below this region rupture of the fibre is the dominating mode of failure for greater volumes of fibres a pull-out mechanism occurs

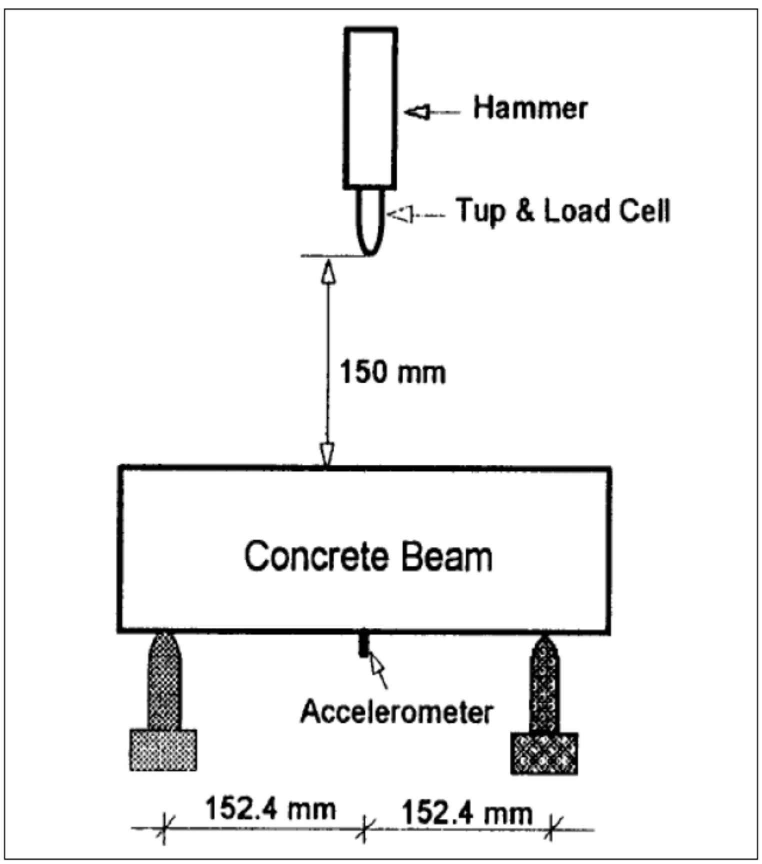


Figure 2.11: Impact Load Test Setup (Wang and Mindess and Ko, 1996).

2.4 CURING

Curing of MFRC considers two distinct components, specifically temperature and moisture. As with any cementitious composite material, maintaining an appropriate temperature is critical to achieving the desired rate for the cementitious reactions. In addition, given the low water content in MFRC, eliminating loss of internal water by sealing the system or maintaining a high humidity environment is also critical.

Graybeal (2011) reported the curing of MFRC occurs in two phases. Given that UHPC tends to exhibit a dormant period prior to initial setting, the initial curing phase consists of maintaining an appropriate temperature while precluding moisture loss until setting has occurred and rapid mechanical property growth is occurring. The second curing phase may or may not include elevated temperature conditions and a high moisture environment, depending on whether accelerated attainment of particular material characteristics is desired.

Graybeal (2006) also reported on an extensive program to determine material properties of MFRC using four different post-set curing procedures. These involved steam curing at 194 °F (90 °C) or 140 °F (60 °C) for 48 hours, starting about 24 hours after casting; steam curing at 194 °F (90 °C), starting after 15 days of standard curing and curing at standard laboratory temperatures until test age.

These three steam-curing methods increased the measured compressive strengths and modulus of elastic, decreased creep, virtually eliminated drying shrinkage, decreased chloride ion penetrability, and increased abrasion resistance. The enhancements achieved by the lower steam temperature and delayed steam curing were slightly less than achieved by steam curing at the higher temperature. The specimens steam cured at 194 °F (90 °C) after 24 hours reached their full compressive strengths within 4 days after casting.

More recent work by **Graybeal (2012)** has focused on characterizing the performance of ambient-cured MFRC. This research stems from the recognition that accelerated curing in a steam environment is frequently not practical and also that the ambient-cured properties of MFRC are appropriate for many applications.

Ay et al (2004) compared the compressive strength of 4-inch (100mm) cubes cured by the following three methods:

- Curing in water until 1 hour before testing.
- Curing in water for 5 days followed by air curing.
- Sealing the cubes in plastic sheeting and then storing them at 68 °F (20 °C) until tested.

The MFRC cubes stored in water followed by air curing had slightly higher compressive strengths than cubes cured by the other two methods.

Massidda et al. (2001) showed that autoclaving at a temperature of 356 °F (180 °C) and 145 psi (1 MPa) with saturated steam produced higher compressive strengths and flexural strengths compared with specimens cured at 68 °F (20 °C).

CHAPTER 3

EXPERIMENTAL PROGRAMME AND METHODOLOGY

3.1 GENERAL

This chapter deals with the experimental programme and methodology for conducting various tests on Micro Fibre (human hair) reinforced concrete. In order to achieve the objectives of present study, an experimental program was planned to investigate the effect of Micro Fibre (human hair) and plain cement concrete on compressive strength, tensile strength, flexural strength, and permeability.

3.2 MATERIALS

The properties of material used for making micro Fibre (human hair) reinforced concrete mix are determined in laboratory as per relevant codes of practice. Different materials used in present study were Ordinary Portland cement (43 grade as per IS code 8112-1989(re-affirmed in 2000)), micro Fibre (human hair), fine aggregates and coarse aggregate. The aim of studying of various properties of material is to check the compliance with codal requirements and to enable an engineer to design a cement concrete mix for a high strength. The description of various materials which were used in this study is given below:

3.2.1 Ordinary Portland Cement

Ordinary Portland Cement (OPC) of J.K. make from a single lot was used throughout the course of the investigation. It was fresh and without any lumps. The physical properties of the cement as determined from various tests conforming to Indian Standard IS: 8112-1989 (Re-affirmed in 2000) are listed in **Table 3.1**. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture.

3.2.2 Fine Aggregates

According to size, the fine aggregate may be described as coarse, medium, and fine sands. The sand used for the experimental works is procured from Pathankot and conformed to grading zone II. Depending upon the particle size distribution IS: 383-1970 has divided the fine aggregate into four grading zones (Grade I to IV). The grading zones become progressively finer from grading zone I to IV. It was coarse sand light grey in colour. Sieve analysis and physical properties of fine aggregate are tested as per IS: 383-1970 and results are shown in **Table 3.2** and **Table 3.3** respectively.

Table 3.1: Properties of Ordinary Portland Cement (OPC)

Sr. No.	Characteristics	Values Obtained Experimentally	Value Specified By IS : 8112-1989 (re-affirmed in 2000)
1.	Standard Consistency, (percent)	27.5	-
2.	Fineness residue of Cement as retained on 90 Micron Sieve (percent)	2%	Not more than 10%
3.	Specific Gravity	3.12	-
4.	Soundness of cement (mm) by Le-Chatelier apparatus	2	Not more than 10mm
5.	Initial Setting Time (minutes)	120	Not less than 30
6.	Final Setting Time (minutes)	410	Not more than 600
7.	Compressive Strength (N/mm^2) 3 days	24.3	23 (minimum)
	7 days	35.9	33 (minimum)
	28 days	48.1	43 (minimum)

NOTE: It can be observed from above Table that all the results satisfy the physical requirements of cement which is used in throughout the course of the investigation.

3.2.3 Coarse Aggregates

Crushed stone aggregate of 20mm and 10mm nominal size is used in this study. The aggregates are arranged from Pathankot quarry. The sieve analysis of 20mm aggregate and 10mm aggregate is shown as per **Table 3.4 and Table 3.5**.The physical properties of aggregate are shown in **Table 3.6.**

Table 3.2: Sieve Analysis of Fine Aggregates

Weight of sample taken =2287 gm.

Sr. No.	IS-Sieve size (mm)	Weight of aggregate retained (gm)	%age Retained	Cumulative % Retained	% Passing	Limits of zone II as per IS-383
1	4.75	106	4.63	4.63	95.37	90-100
2	2.36	185	8.09	12.72	87.28	75-100
3	1.18	481	21.03	33.75	66.25	55-90
4	600 μ	446	19.50	53.25	46.75	35-59
5	300 μ	668	29.21	82.46	17.54	8-30
6	150 μ	333	14.56	97.02	2.98	0-10
7	Pan	68	2.98	2.98	-	-
	Total	2287.00		ΣF =283.83		
			FM = 283.83 / 100 =2.84			

Table 3.3: Physical Properties of Fine Aggregates

Sr. No.	Characteristics	Value
1	Type	Natural Sand
2	Specific Gravity	2.603
3	Water Absorption	1.02 %
4	Moisture Content	0 %
5	Fineness Modulus	2.84
6	Grading Zone	II

Table 3.4: Gradation of 20mm Nominal Size Aggregate.

Weight of sample 11030 gm.

Sr. No.	IS-Sieve size (mm)	Weight of aggregate retained (gm)	%age Retained	Cumulative % Retained	% Passing	Limits of zone II as per IS-383
1	40	--	--	--	100%	100
2	20	--	--	--	100%	85-100
3	10	10780	97.73	97.73	2.27	0-20
4	475	185	1.68	99.41	0.59	0-5
5	pan	65	0.59	100.00	--	

Table 3.5: Gradation of 10mm Nominal Size Aggregate.

Weight of sample 12305 gm.

Sr. No.	IS-Sieve size (mm)	Weight of aggregate retained (gm)	%age Retained	Cumulative % Retained	% Passing	Limits of zone II as per IS-383
1	20	--	--	--	100%	100
2	10	5187	42.15	42.15	57.85	85-100
3	4.75	6108	49.64	91.79	8.21	0-20
4	2.36	746	6.06	97.85	2.15	0-5
5	1.18	104	0.85	98.70	1.30	
6	600 µ	26	21	98.91	1.09	
7	300 µ	0	0	98.91	1.09	
8	150 µ	35	0.28	99.19	0.81	
9	Pan	99	0.81	100	--	

Table 3.6: Physical Properties of Coarse Aggregates

Sr. No.	Characteristics	Value
1	Type	Crushed
2	Specific Gravity	2.647
3	Water Absorption	0.54 %
4	Moisture Content	0 %

For this experimental study both 20mm coarse aggregates and 10mm coarse aggregates are blended in the ratio of 67:33.

3.2.4 Water

Water is an important and least expensive ingredient of concrete. A part of mixing water is utilized in the hydration of cement to form the binding matrix in which the inert aggregates are held in suspension until the matrix has hardened. If water is fit for drinking it is fit for making concrete. This does not appear to be a true statement for all conditions. Some waters containing a small amount of sugar would be suitable for drinking but not for mixing concrete and conversely water suitable for making concrete and not necessarily be fit for drinking. If water is not obtained from source that have proved satisfactory, the strength of concrete made with questionable water would be compared with similar concrete made with pure water. If the pH value of water is lies between 6 and 8 and water is free from organic matter is acceptable for mixing the concrete. In the present investigation, tap water is used for both mixing and curing purposes.

3.2.5 Micro Fibre (Human Hair)

A hair can be defined as a slender, thread-like outgrowth from a follicle in the skin of mammals. Composed mainly of keratin, it has three morphological regions namely cuticle, medulla, and cortex. These regions are illustrated **in Figure 3.1** with some of the basic structures found in them. A hair grows from the papilla and with the exception of that point of generation is made up of dead, cornified cells. Good quality of hair purchased from Remi and Virgin Human Hair Exports, Ludhiana (Punjab) was used throughout the course of the investigation. The hair was arranged in 35cm to 40 cm long which were cut accurately to required length of 12mm, 24mm, 36mm. the human hair diameter is 100 to 120μm having tensile strength 380MPa and ultimate tensile strain 50.16% **(T.Naveen Kumar et al., 2015)**

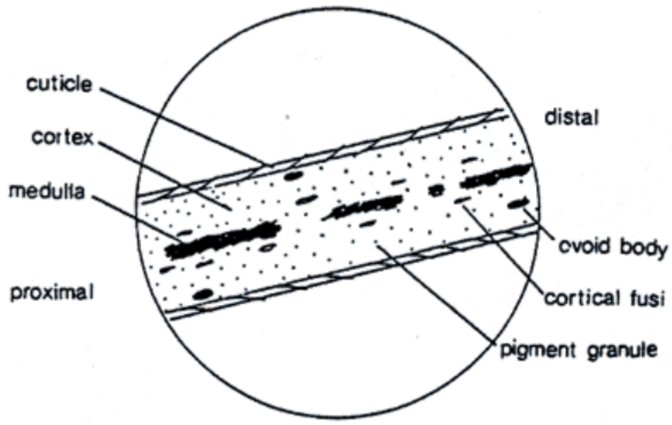


Fig. 3.1: Hair Diagram

3.3 PREPARATION OF SAMPLE

The quantities of cement, micro Fibre (human hair), coarse aggregate, fine aggregate and water for each batch was weighed separately. Firstly, cement and aggregates were mixed separately to form uniform colour and then added the micro Fibre (human hair) in dry state and mix in mixture for minimum 5 minutes to make a uniform colour. Firstly, 50% to 70% of water was added to the dry mix and then mixed thoroughly for 1 to 2 minutes. Then the remaining water added in mixture and again mixes thoroughly for 1-2 minutes. After properly mixing the micro Fibre (human hair) reinforced concrete was filled into the required moulds of cube size 150 mm X 150mm X 150mm (for compressive strength), moulds of beam Size 150mm x 150mm x 700mm (for flexural strength), cylindrical moulds of 150mm (diameter) X 300mm (long) (for split tensile strength) and cylindrical moulds of 100mm (diameter) X 200mm (long) (for Rapid Chloride ion Permeability Test). Vibration is provided for compaction of concrete. The surface of the concrete was finished and leveled with the trowel to the top of the moulds. The finished specimens were left to harden in air for 24 hours. The specimens were removed from the moulds after 24 hours of casting and were placed in potable water at room temperature in the laboratory. The age of sample is calculated from the time of addition of water to the dry ingredients. Three specimens are casted for testing at each selected age.

3.4 TEST METHODS

To obtain the different parameters like compressive strength, split tensile strength flexural strength and permeability, first of all select the material volume for micro Fibre (human hair) reinforced concrete. Mix Proportion of different ingredients of MFRC used in the present study is as per **Table 3.7**.

Table 3.7: Mix Proportion of Different Ingredients of MFRC

S. No.	Description	Cement (in Kg)	Fine Aggregate (in Kg)	Micro Fibre (Human Hair)		Coarse Aggregate (in Kg)	Water (in Kg)
				Length (in mm)	Weight (in gm)		
1	H_oC	30	60.34	0	0	103.58	13.8
2	H_1L_{12}	30	60.34	12	300	103.58	13.8
3	H_2L_{12}	30	60.34	12	600	103.58	13.8
4	H_3L_{12}	30	60.34	12	900	103.58	13.8
5	H_1L_{24}	30	60.34	24	300	103.58	13.8
6	H_2L_{24}	30	60.34	24	600	103.58	13.8
7	H_3L_{24}	30	60.34	24	900	103.58	13.8
8	H_1L_{36}	30	60.34	36	300	103.58	13.8
9	H_2L_{36}	30	60.34	36	600	103.58	13.8
10	H_3L_{36}	30	60.34	36	900	103.58	13.8
11	H_2L_m	30	60.34	12,24,36	600	103.58	13.8

3.4.1 Compressive Strength

Determination of compressive strength of the micro Fibre (human hair) reinforced concrete with cubes of size 150 mm X 150 mm X 150 mm as shown in **Fig. 3.2** were casted for determination of compressive strength under different percentage and length of human hair .Total 66 no. specimens are casted for testing at each selected age.

At the test age of the specimens stored in tap water are tested immediately on removal from the water and while they are still in the wet condition. Surface water and grit is wiped off from the specimen and any projecting fins removed which are to be in contact with the compression platens. In the case of cubes the specimens are placed in the machine in such a manner that the load is applied to the opposite sides of the cubes as cast that is not to the top and bottom. The axis of the specimen shall be carefully aligned with the centre of thrust of the spherically seated platen. No packing shall be used between the faces of the test specimen and the steel platen of the testing machine (**Fig.3.3)**. The load is applied without shock and increased continuously at a rate of approximately 70kN/min specified IS: 516 - 1959. Until the resistance of specimen increasing load break down and no greater load can be sustained. The maximum load applied to the specimen than recorded and the appearance of the concrete and any unusual feature to the type of failure is noted.

Fig. 3.2: Cube Specimens of Size 150mm x 150mm x 150mm

Fig. 3.3: Compressive Strength Testing of Cube under UTM

3.4.2 Split Tensile Strength

Determination of split tensile strength of the micro Fibre (human hair) reinforced concrete with cylinders of size 150mm X 300mm **(Fig.3.4)** was casted for determination of split tensile strength under different percentage and length of human hair. Total 66 no. specimens are casted for testing at each selected age.

Fig. 3.4: Cylinder Specimens of Size 150mm (diameter) x 300mm for split tensile strength testing.

Fig. 3.5: Split Tensile Strength Testing of Cylinder under UTM

The split tensile test are well known indirect test used for determining the tensile strength of concrete **(Fig. 3.5)**. This test performed on cylinders by splitting in the following ways:

3.4.3 Flexural Strength

Flexural Strength of material is resistance to deformation when it is subjected to lateral loading. The flexural test is more easily carried out than crushing test for use in field, since in this test much smaller loads are required. It is also known as Modulus of rupture, bend strength, fracture strength. Flexural test intended to give flexural strength of concrete in tension. To determine the flexural strength of micro Fibre (human hair) reinforced concrete, the specimens of size 150mm X 150mm X 700mm (**Fig.3.6)** were casted under different percentage and length of human hair. Total 66 no. specimens are casted for testing at each selected age.

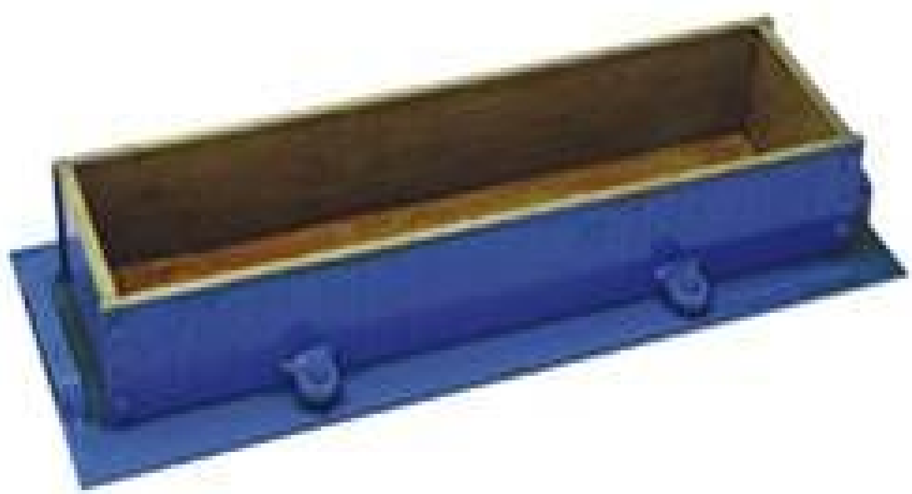


Fig. 3.6: Mould Specimen of Size 150mm x 150mm x 700mm

The specimens of size 150mm x 150mm x 700mm were tested at the ages of 7 days and 28 days. The position of specimen during flexural testing by two point loading method was shown in **Fig. 3.7** and in schematic diagram shown in **Fig. 3.8.** The tests were performed on Universal Testing Machine (UTM). During testing loading is applied gradually at the rate of 2.65kN/min. and the effective length of beam is taken as 600mm without shock till the failure of the specimen occurs.

Fig. 3.7: Flexural Strength Testing of Specimen under UTM

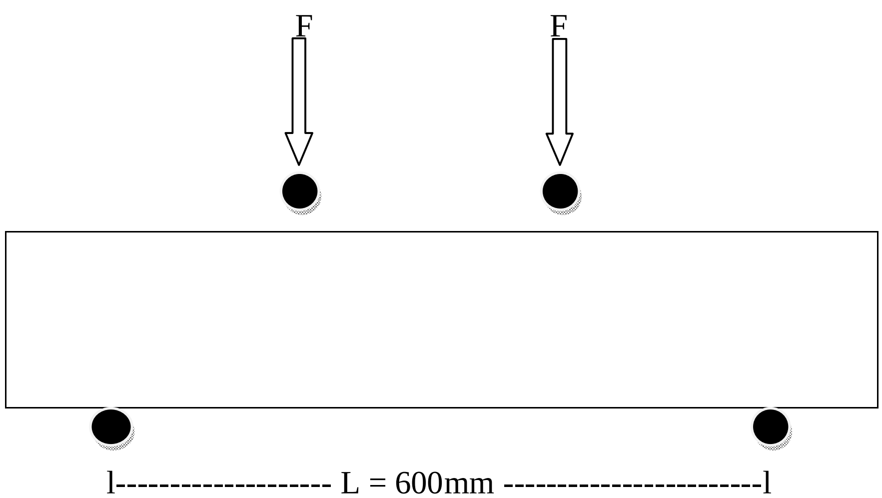


Fig.3.8: Schematic Diagram for Two Point Loading Method

3.4.4 Rapid Chloride Permeability Test

This test method consists of monitoring the amount of electrical current passed through 2-in. (51mm) thick slices of 4-in. (102mm) nominal diameter cores or cylinders during a 6 hour period. A potential difference of 60V dc is maintained across the ends of the specimen, one of which is immersed in a sodium chloride solution, the other in a sodium hydroxide solution. The total charge passed, in coulombs, has been found to be related to the resistance of the specimen to chloride ion penetration. Sample age has significant effects on the test results, depending on the type of concrete and the curing procedure. Most concretes, if properly cured, become progressively and significantly less permeable with time. Numerical results of this test (total charge passed, in coulombs) can be used as a basis for determining the acceptability of a concrete mixture as shown in **Table 3.8**. Factors such as the ingredient materials used and method and duration of curing of test specimens affect results of this test.

The test is not valid for specimens containing reinforcing steel positioned longitudinally that is, providing a continuous electrical path between the two ends of the specimen.

Table no. 3.8: Provide a Qualitative Relationship between the Results of this Test and the Chloride Ion Penetrability of Concrete

Sr. No.	Charge Passed (in coulombs)	Chloride Ion Penetrability
1	>4000	High
2	2000-4000	Moderate
3	1000-2000	Low
4	100-1000	Very Low
5	<100	Negligible

To determine the permeability of micro Fibre (human hair) reinforced concrete with cylindrical specimens of 100mm (diameter) X 200mm (long) **(Fig.3.9 a and b)**were casted under different percentage and length of human hair at 28 days curing. Total 33 samples were casted and cut with the cutter machine **(Fig. 3.10)** to the size of 51mm (long) X 100mm (diameter) as shown in **Fig 3.11**.

Fig. 3.9 (a): Cylindrical Mould of size 100mm x 200mm

Fig. 3.9 (b): Casted Cylindrical Specimens of Size of 100mm x 200mm

Fig. 3.10: Cylindrical Specimens Cutter Machine

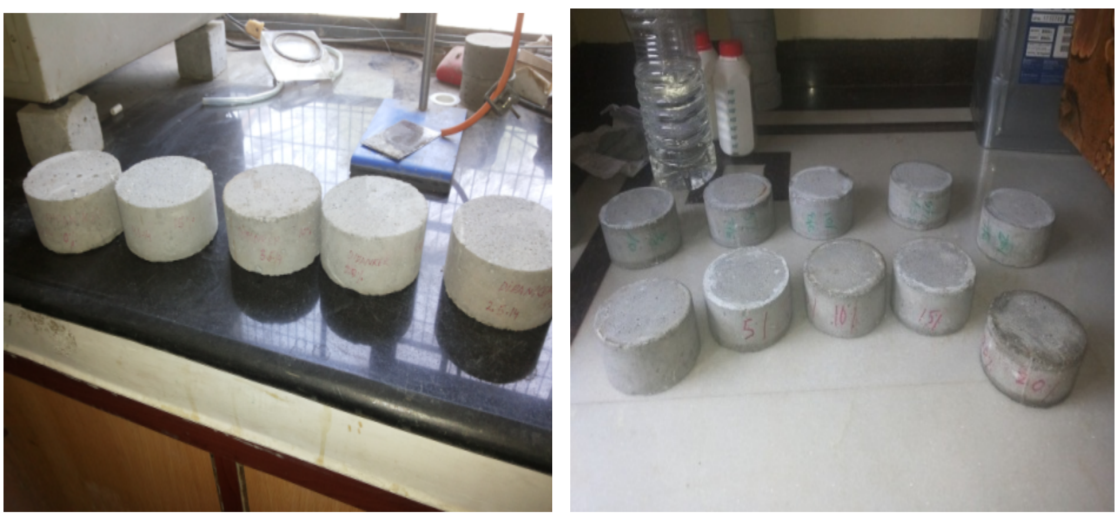


Fig. 3.11: Cylindrical Specimens of Size 51mm x 100mm

The specimens at the age of testing i.e. 28 days were placed in curing tank for at least 24 hours before the RCPT. Then specimens were placed in the vacuum desiccators' bowl as shown in **Fig 3.12** which illustrates the setup of the vacuum pump, desiccators with stopcock, vacuum gauge and valve and the de-aerated water container after the water has filled the desiccators. The vacuum was maintained in the desiccators bowl for 3 hours.

Fig 3.12: Vacuum Desiccators' Bowl

The specimens were removed from the desecrator, dried and placed in gasket. The specimen is then placed in the testing apparatus as shown in **Fig. 3.13** where one end of the specimen is exposed to a solution containing sodium chloride (NaCl) and the other end is exposed to a solution containing sodium hydroxide (NaOH) as shown in schematic **Fig.3.14**. To increase the rate of chloride penetration into the polymer modified cement mortar specimens, thus speeding up the test, a constant 60V potential were applied across the specimens. The current across the specimens were measured after the 6 hour test and then permeability was evaluated.

Fig.3.13: Rapid Chloride Permeability Test Setup

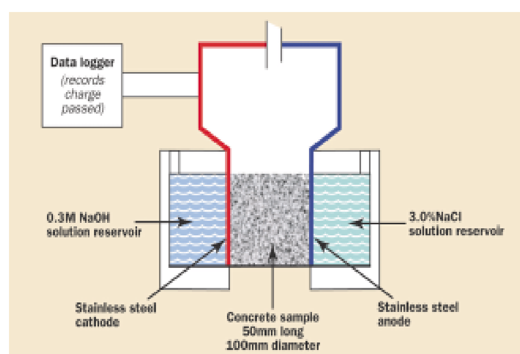


Fig.3.14: Schematic of Rapid Chloride Permeability Test Setup

CHAPTER - 4

RESULTS AND DISCUSSION

4.1 GENERAL

In this chapter results obtained from various tests conducted on various specimens casted and tested as detailed in chapter 3 are presented and discussed. In order to discuss the results of different parameters like compressive strength, split tensile strength, flexure strength and permeability with specimen designation are briefed.

4.2 COMPRESSIVE STRENGTH

To study the effect on compressive strength, 66 cubes (size 150mm x 150mm x 150mm) each for calculated material weight for different percentage and length of human hair and tested at 7 days and 28 days. The average compressive strength results at 7 days and 28 days curing are shown in **Table 4.1**, **Fig.4.1 (a)** and **Fig.4.1 (b)** respectively. Variation of compressive strength using different fibre length and at different percentage fractions at 28 days is shown graphically in **Fig.4.2**

Table 4.1: Compressive Strength Results at 7 Days and 28 Days

Sr. No.	Specimen Description	Average Compressive Strength(N/mm^2) 7 Days	Average Compressive Strength (N/mm^2) 28 Days
1	H_0 C	21.29	26.26
2	H_1 L_{12}	22.62	27.60
3	H_1 L_{24}	21.64	27.07
4	H_1 L_{36}	23.15	27.24
5	H_2 L_{12}	24.89	28.93
6	H_2 L_{24}	24.31	29.29
7	H_2 L_{36}	24.49	28.80
8	H_3 L_{12}	22.62	28.27
9	H_3 L_{24}	23.24	28.00
10	H_3 L_{36}	22.84	28.18
11	H_2L_m	26.80	31.15

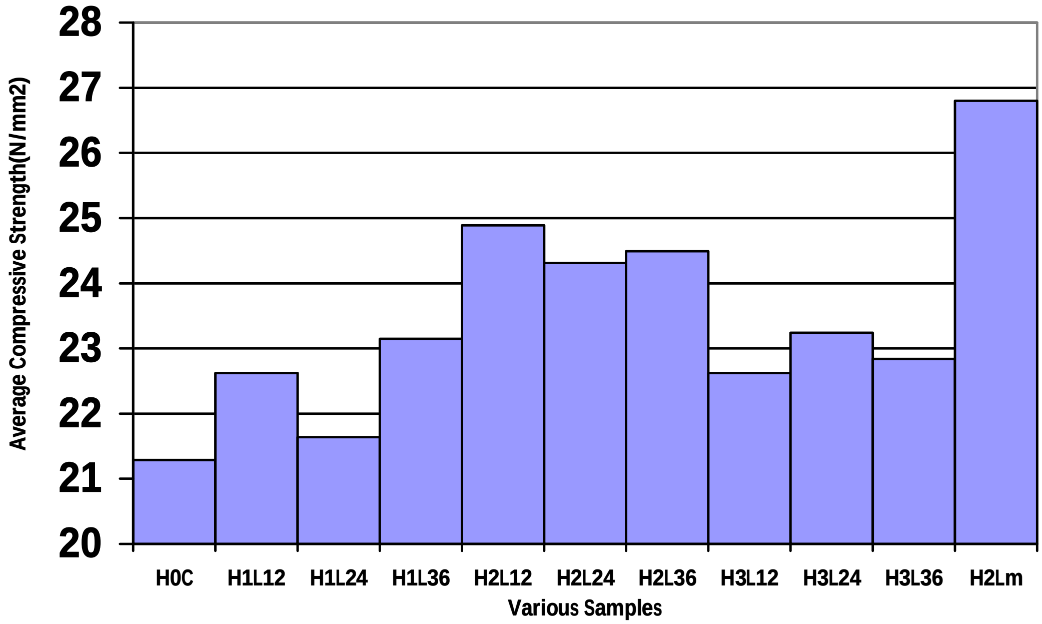


Fig. 4.1(a): Graph Showing Comparison between Compressive Strength with Different Percentage and Length of Human Hair MFRC at 7 days.

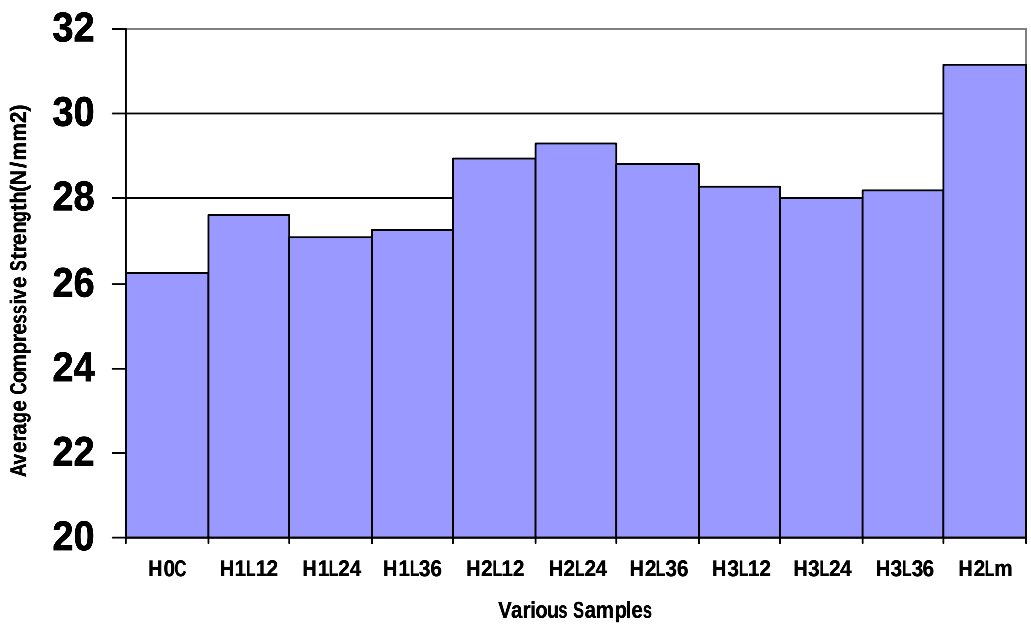


Fig. 4.1(b): Graph Showing Comparison between Compressive Strength with Different Percentage and Length of Human Hair MFRC at 28 days.

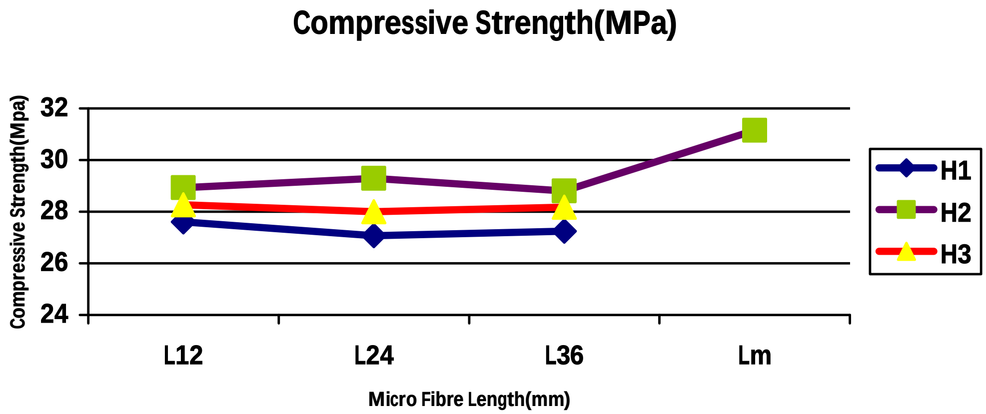


Fig. 4.2 Variation of Compressive Strength using Different Aspect Ratio and at Different Percentage Fractions (28 days).

The variation of 7 days and 28 days compressive strength for mixes under examination are evaluated. It is observed that:-

- The addition of 12 mm long human hair micro fibre @ 1%, 2% and 3% by weight of cement increased the compressive strength at 7 days by 6.24%, 16.91% and 6.24% respectively and at 28 days by 5.10%, 10.17% and 7.65% respectively as compared controlled sample.
- The addition of 24 mm long human hair micro fibre @ 1%, 2% and 3% by weight of cement increased the compressive strength at 7 days by 1.64%, 14.18% and 9.16% respectively and at 28 days by 3.08%, 11.54% and 6.63% respectively as compared with controlled sample.
- The addition of 36 mm long human hair micro fibre @ 1%, 2% and 3% by weight of cement increased the compressive strength at 7 days by 8.74%, 15.03% and 7.28% respectively and at 28 days by 3.73%, 9.67% and 7.31% respectively as compared with controlled sample.
- During the experiment, it was observed that at 2% addition of human hair micro fibre by weight of cement the increase in compressive strength was maximum, Thus an experiment was conducted with the addition of 2% human hair micro fibre of length 12, 24 and 36 mm in equal fractions by weight of cement increased the compressive strength at 7 days by 7.67% and at 28 days by 6.35% as compared with mono fibres maximum results.

- So it can be observed that increase in percentage addition of human hair micro fibres firstly increased the compressive strength upto 2% fraction and further addition resulted in the reduction of compressive strength.
- Long Fibres are always well oriented between the two imaginary borders. If casting of concrete in layers is applied (these borders may also be the walls of the moulds). With such positions, the long Fibres form a kind of a barrier for short Fibres, and limit their space for rotation.
- The short Fibres will therefore be somewhat better oriented than long Fibres**.** Hence, more Fibres distribute in each direction.

4.3 SPLIT TENSILE STRENGTH

To study the effect of tensile strength, 66 cylinder (size 150mm x 300mm) each for calculated material weight for different percentage and length of human hair were casted and tested at 7 days and 28 days as per IS code 5816 : 1999. The load shall be applied without shock and increased continuously at a nominal rate within the range 1.2N/mm^2/min to 2.4N/mm^2/min.

Table 4.2: Split Tensile Strength results at 7 Days and 28 Days

Sr. No.	Specimen Description	Average Split Tensile Strength(N/mm^2) 7 Days	Average Split Tensile Strength (N/mm^2) 28 Days
1	H_0 C	2.31	2.57
2	$H_1 L_{12}$	2.22	2.64
3	$H_1 L_{24}$	1.87	2.23
4	$H_1 L_{36}$	2.55	2.90
5	$H_2 L_{12}$	2.01	2.48
6	$H_2 L_{24}$	2.42	2.92
7	$H_2 L_{36}$	1.86	2.12
8	$H_3 L_{12}$	2.12	2.47
9	$H_3 L_{24}$	1.79	2.06
10	$H_3 L_{36}$	2.16	2.64
11	H_2L_m	2.67	3.14

The average split tensile strength results at 7 days and 28 days curing are shown in **Table 4.2, Fig.4.3 (a)** and **Fig.4.3 (b)** respectively. Variation of split tensile strength using different fibre length and at different percentage fractions at 28 days is shown graphically in **Fig.4.4**

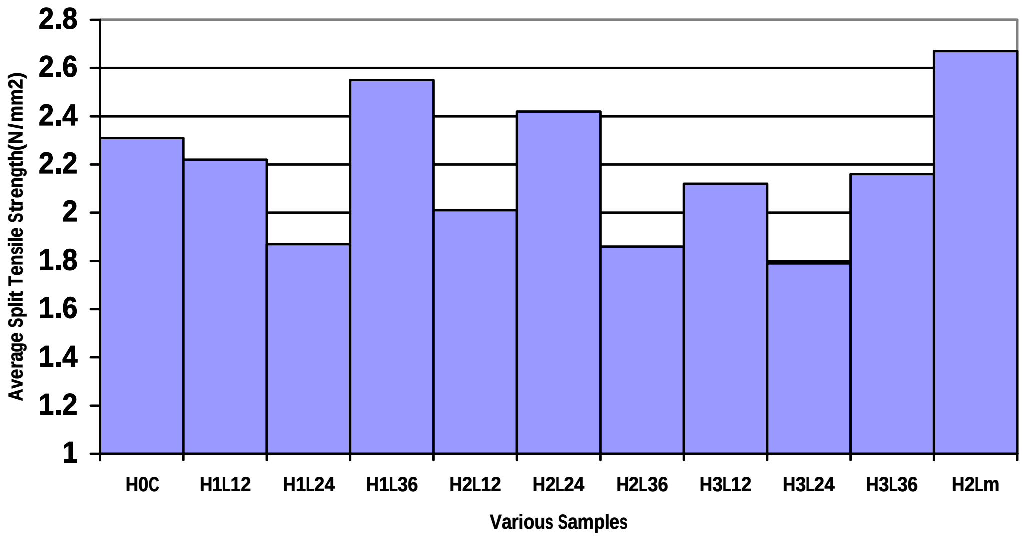


Fig. 4.3 (a): Graph Showing Comparison between Split Tensile Strength with Different Percentage and Length of Human Hair MFRC at 7 days.

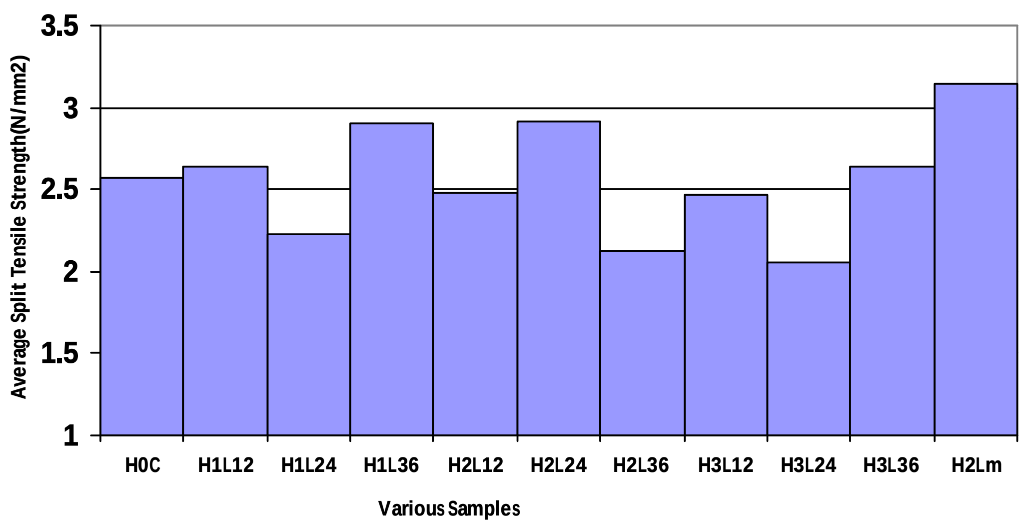


Fig. 4.3 (b): Graph Showing Comparison between Split Tensile Strength with Different Percentage and Length of Human Hair MFRC at 28 days.

Average results of three specimens of the split tensile strength test on MFRC mix at the age of 7 days and 28 days are given in the **Table 4.3** and shown graphically in **Fig. 4.3 and Fig.4.4.**

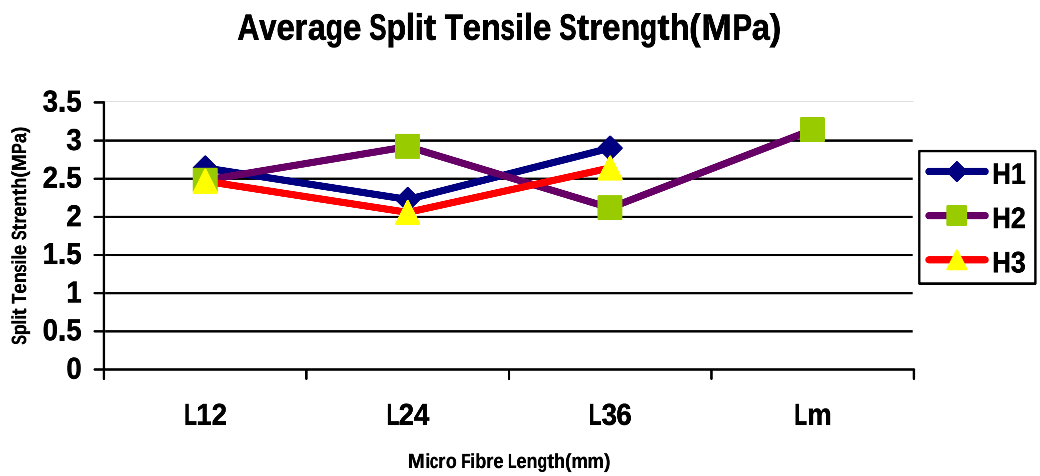


Fig. 4.4 Variation of Split Tensile Strength using Different Aspect Ratio and at Different Percentage Fractions (28 days).

The variation of 7 days and 28 days split tensile strength for mixes under examination are evaluated from Table and graphs it is observed that:-

- The addition of 12 mm long human hair micro fibre @ 1%, 2% and 3% by weight of cement decreased the split tensile strength at 7 days by 4.05%, 12.98% and 8.22% respectively and at 28 days increased by 2.72%, decreased by 3.50% and 3.89% respectively as compared controlled sample.
- The addition of 24 mm long human hair micro fibre @ 1%, 2% and 3% by weight of cement the split tensile strength at 7 days decreased by 19.05%, increased by 4.76% and decreased by 22.51% respectively and at 28 days decreased by 13.23%, increased by 13.62% and decreased by 19.84% respectively as compared with controlled sample.
- The addition of 36 mm long human hair micro fibre @ 1%, 2% and 3% by weight of cement the split tensile strength at 7 days increased by 10.39%, decreased by 19.48% and 6.49% respectively and at 28 days increased by 12.84%, 13.62% and 2.72% respectively as compared with controlled sample.

- During the experiment, it was observed that at 2% addition of human hair micro fibre by weight of cement the increase in split tensile strength was maximum, Thus an experiment was conducted with the addition of 2% human hair micro fibre of length 12, 24 and 36 mm in equal fractions by weight of cement increased the split tensile strength at 7 days by 4.70% and at 28 days by 7.53% as compared with mono fibres maximum results.
- Long Fibres are always distributed in direction parallel to imaginary borders. This means they are more strong in one plane and weak in another plane.

4.4 FLEXURAL STRENGTH

To study the effect of flexural strength, 66 no. of beams (size 150mm x 150 mm x 700mm) each for calculated material weight for under different percentage and length of human hair were casted and tested at 7 days and 28 days as per IS code 9399: 1979.

Table 4.3: Flexural Strength Results at 7 Days and 28 Days

Sr. No.	Specimen Description	Average Flexural Strength (N/mm^2) 7 Days	Average Flexural Strength (N/mm^2) 28 Days
1	H_0 C	3.09	3.53
2	$H_1 L_{12}$	3.59	4.18
3	$H_1 L_{24}$	3.38	4.02
4	$H_1 L_{36}$	3.51	4.08
5	$H_2 L_{12}$	3.64	4.19
6	$H_2 L_{24}$	3.60	4.50
7	$H_2 L_{36}$	3.14	3.69
8	$H_3 L_{12}$	2.68	3.09
9	$H_3 L_{24}$	3.21	3.57
10	$H_3 L_{36}$	2.88	3.47
11	H_2L_m	4.03	4.88

The average flexural strength results at 7 days and 28 days curing are shown in **Table 4.3, Fig.4.5 (a)** and **Fig.4.5 (b)** respectively. Variation of flexural strength using different fibre length and at different percentage fractions at 28 days is shown graphically in **Fig.4.6**.

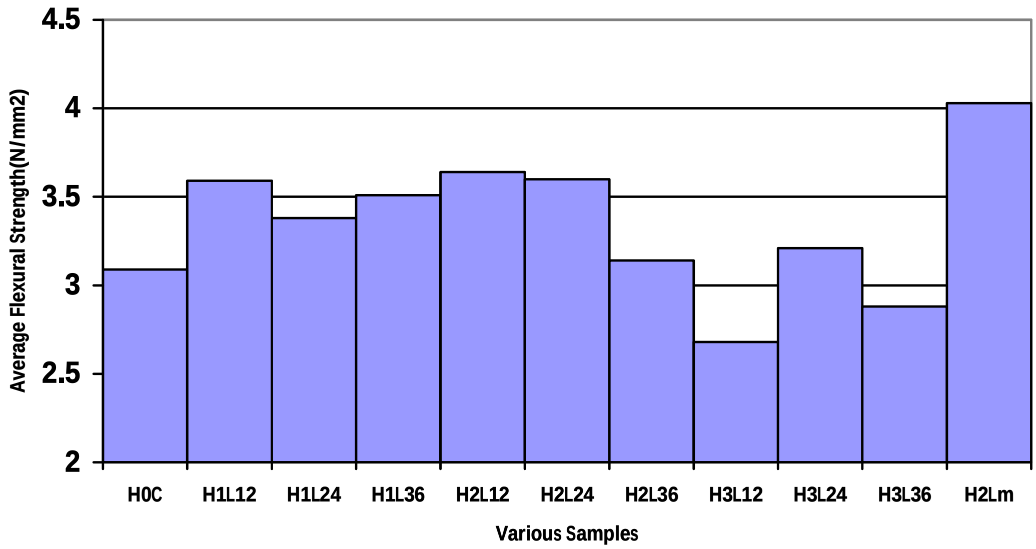


Fig. 4.5 (a): Graph Showing Comparison between Flexural Strength with Different Percentage and Length of Human Hair MFRC tested at 7 days.

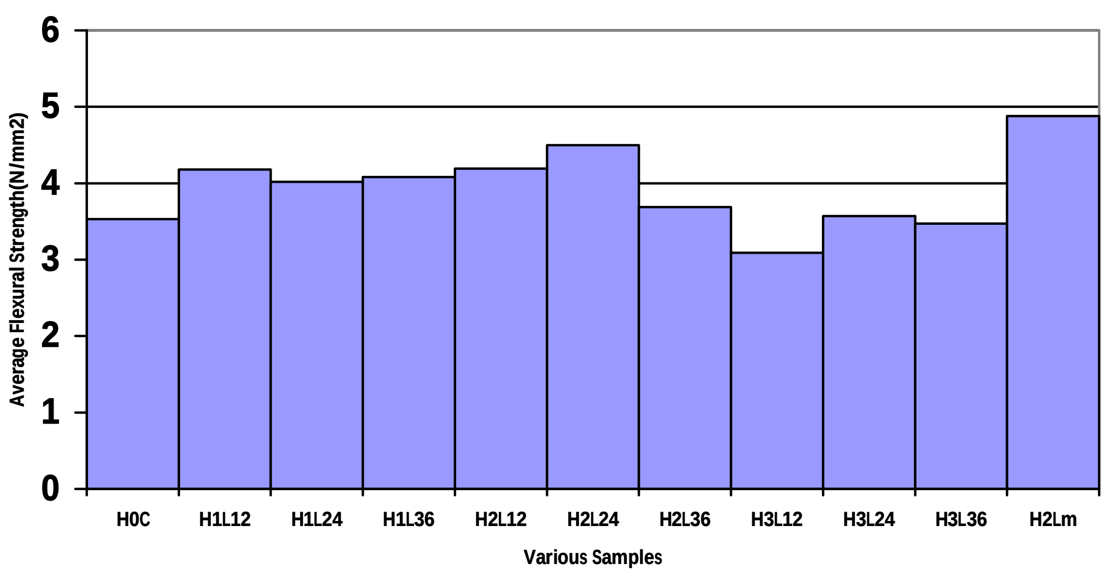


Fig. 4.5 (b): Graph Showing Comparison between Flexural Strength with Different Percentage and Length of Human Hair MFRC tested at 28 days.

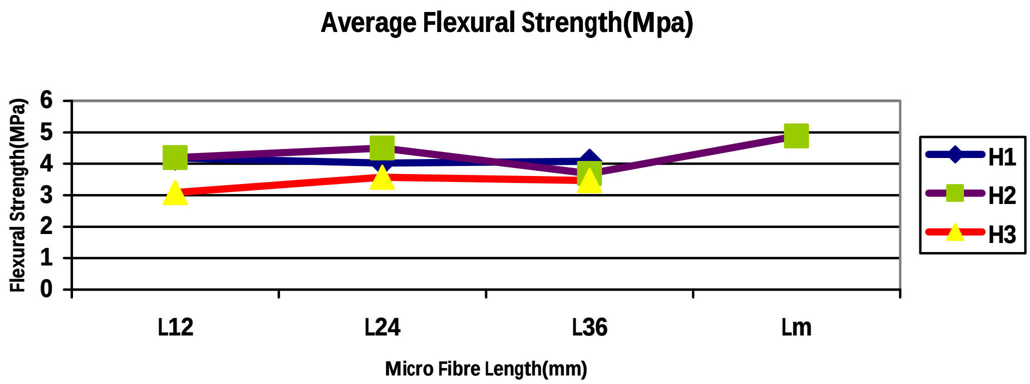


Fig. 4.6 Variation of Flexural Strength using Different Aspect Ratio and at Different Percentage Fractions (28 days).

The variation of 7 days and 28 days flexural strength for mixes under examination are evaluated from Table and graphs it is observed that:-

- The addition of 12 mm long human hair micro fibre @ 1%, 2% and 3% by weight of cement the flexural strength at 7 days increased by 16.18%, 17.80% and decreased by 13.27% respectively and at 28 days increased by 18.41%, 18.70% and decreased by 12.46% respectively as compared controlled sample.
- The addition of 24 mm long human hair micro fibre @ 1%, 2% and 3% by weight of cement increased the flexural strength at 7 days by 9.38%, 16.50% and 3.88% respectively and at 28 days by 13.88%, 27.48% and 1.13% respectively as compared with controlled sample.
- The addition of 36 mm long human hair micro fibre @ 1%, 2% and 3% by weight of cement the flexural strength at 7 days increased by 13.59%, 1.62% and decreased by 6.80% respectively and at 28 days increased by 15.58%, 4.53% and decreased by 1.70% respectively as compared with controlled sample.
- During the experiment, it was observed that at 2% addition of human hair micro fibre by weight of cement the increase in flexural strength was maximum, Thus an experiment was conducted with the addition of 2% human hair micro fibre of length 12, 24 and 36 mm in equal fractions by weight of cement increased the flexural strength at 7 days by 10.71% and at 28 days by 8.44% as compared with mono fibres maximum results.

- So it can be observed that increase in percentage addition of human hair micro fibres firstly increased the flexural strength upto 2% fraction and further addition resulted in the reduction of flexural strength.
- The main reason of increasing the flexural strength as the micro-cracks grow and merge into larger macro-cracks, the long Fibres become more and more active in crack bridging.
- By bridging primarily ductility can be improved, and partly also the flexural strength. Long Fibres can therefore provide a stable post-peak response.
- The flexural strength of MFRC is very high as compared to the conventional concrete. Main reason of high flexure strength due to presence of human hair (Fibre) in MFRC. This should be attributed to the fact that the additional fibers can bridge cracks and absorb energy which could change the fracture mode of concrete from brittle fracture to plastic fracture and significantly increase the ultimate flexural strength of concrete.

4.5 RAPID CHLORIDE PERMEABILITY TEST

Table 4.4: Results for Rapid Chloride Permeability Test at 28 Days

Sr. No.	Specimen Description	Charge Passed (in coulombs)	Permeability
1	H_0 C	3318	Moderate
2	$H_1\,L_{12}$	2382	Moderate
3	$H_1\,L_{24}$	1413	Low
4	$H_1\,L_{36}$	1513	Low
5	$H_2\,L_{12}$	1467	Low
6	$H_2\,L_{24}$	1214	Low
7	$H_2\,L_{36}$	1311	Low
8	$H_3\,L_{12}$	1522	Low
9	$H_3\,L_{24}$	1224	Low
10	$H_3\,L_{36}$	1366	Low
11	H_2L_m	883	Very Low

To study the effect of permeability, 33 no. of cylindrical specimens (size 100 mm diameter x 200mm long) each for calculated material weight for under different percentage and length of human hair were casted and tested after 28 days as per ASTM C1202-15. The results of RCPT for the specimens under different percentage and length of human hair at the age of 28 days are shown in **Table 4.4 and** graphically in **Fig. 4.7**.

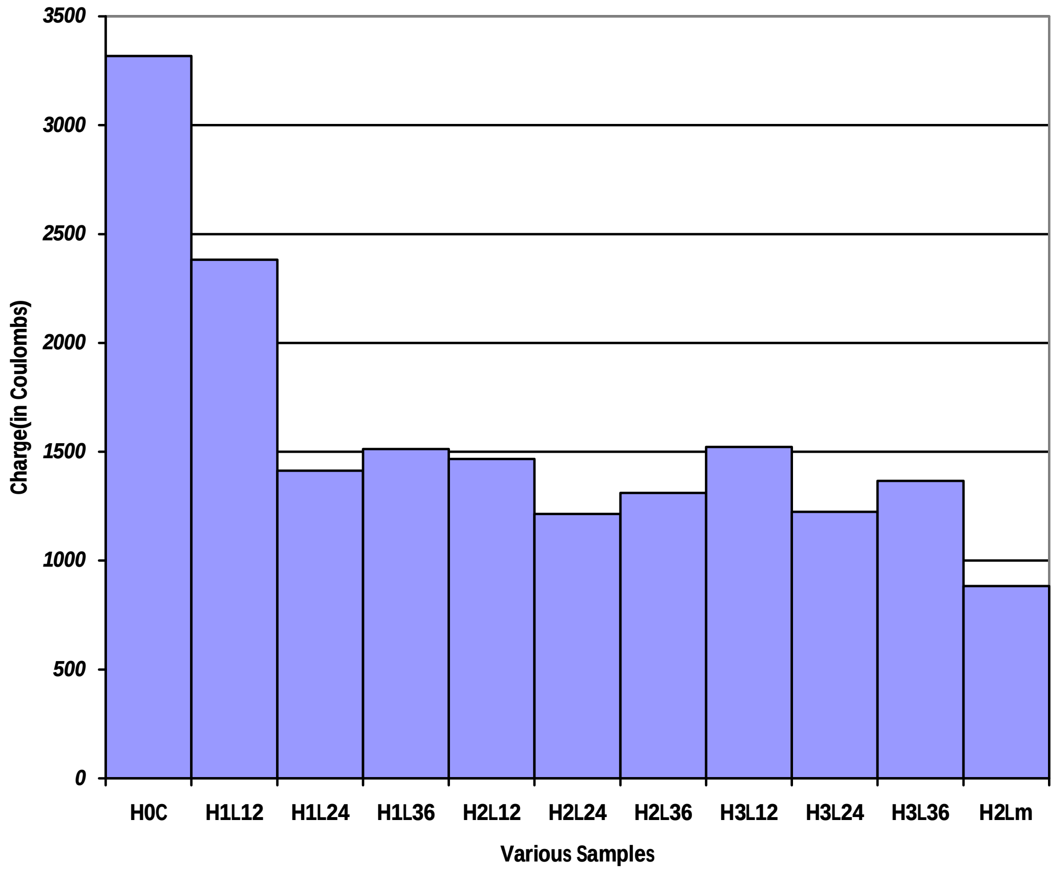


Fig. 4.7: Graph Showing Comparison for Rapid Chloride Permeability test of Different Percentage and Length of Human Hair MFRC at 28 days.

From the **Table 4.5** and graphically in **Fig.4.7,** It is observed that:-

- In specimen having 2% of human hair of 12,24,36 mm length(equal fraction) after 28 days curing , chloride ions passed were very less as compared to other specimens.

- However, all the specimens except H_1L_{12} show less chloride ion permeability over the controlled specimen.

4.6 SCANNING ELECTRONIC MICROSCOPY (SEM)

To assess the effect of human hair Micro Fibre on the Microstructure in the Concrete matrix, a scanning electronic microscopy was carried out.

Fig 4.8 (a-w) shows the images obtained with SEM of all the samples.

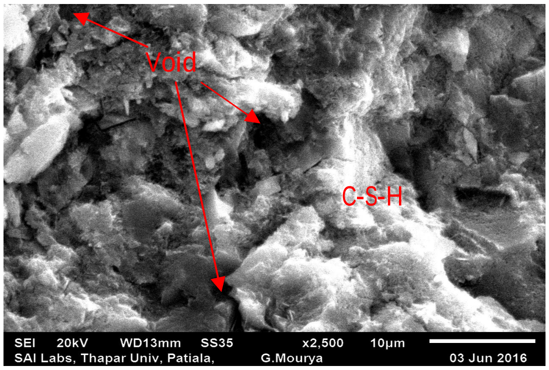


Figure 4.8 (a) SEM H_0C

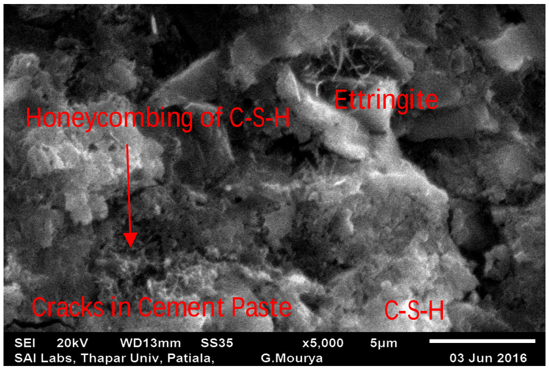


Figure 4.8 (b) SEM H_0C

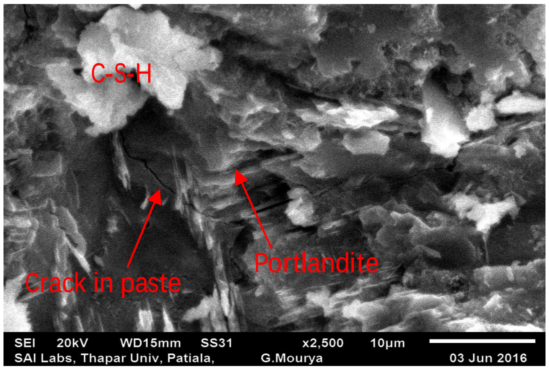


Figure 4.8 (c) SEM H_1L_{12}

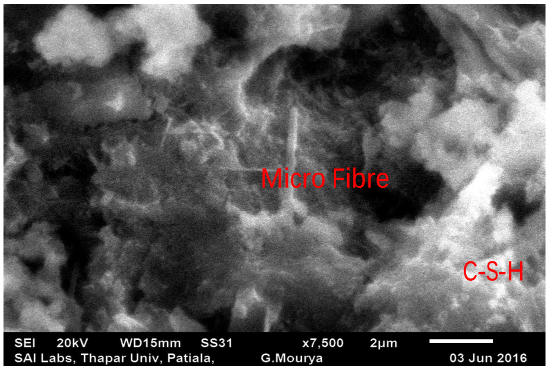


Figure 4.8 (d) SEM H_1L_{12}

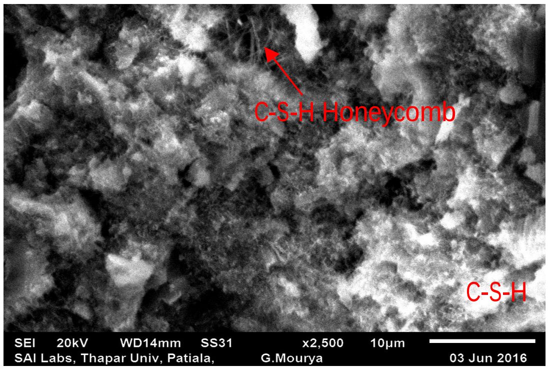


Figure 4.8 (e) SEM H_1L_{24}

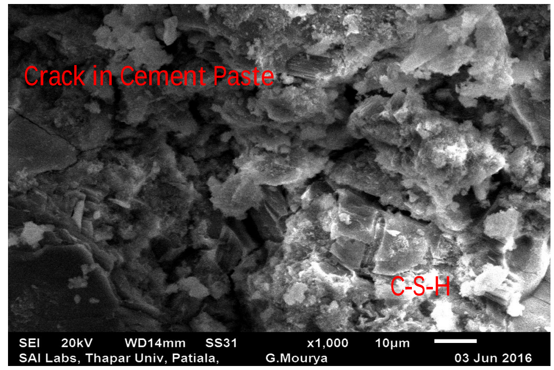


Figure 4.8 (f) SEM H_1L_{24}

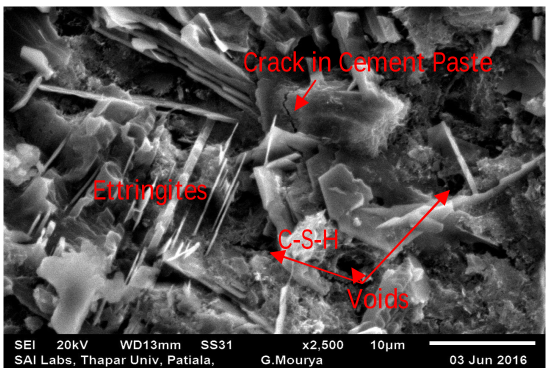


Figure 4.8 (g) SEM H_1L_{36}

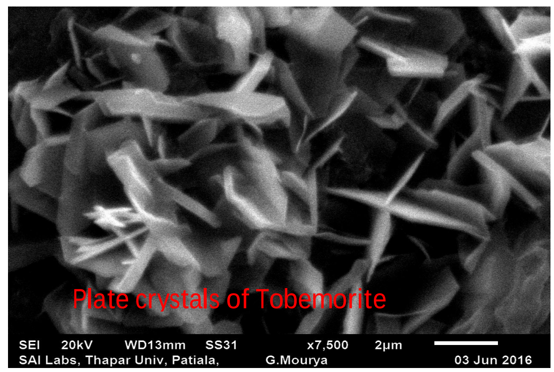


Figure 4.8 (h) SEM H_1L_{36}

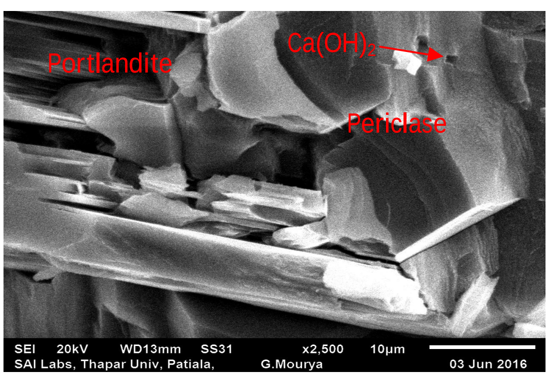


Figure 4.8 (i) SEM H_2L_{12}

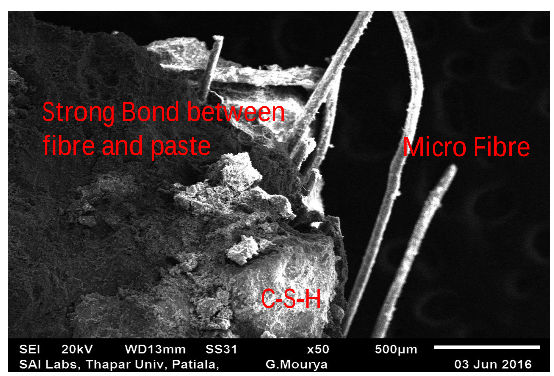
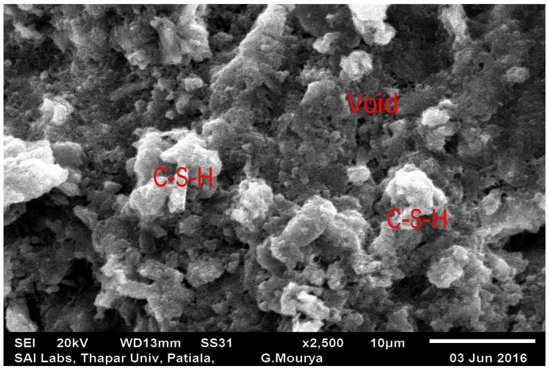


Figure 4.8 (j) SEM H_2L_{12}



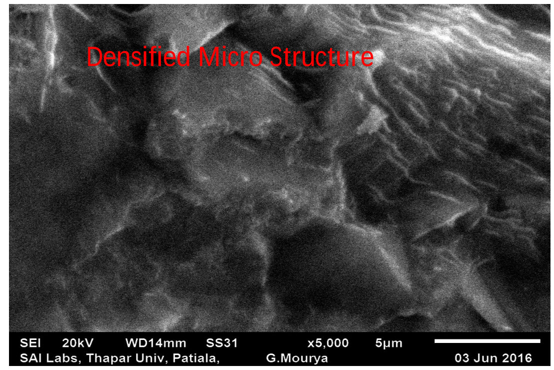
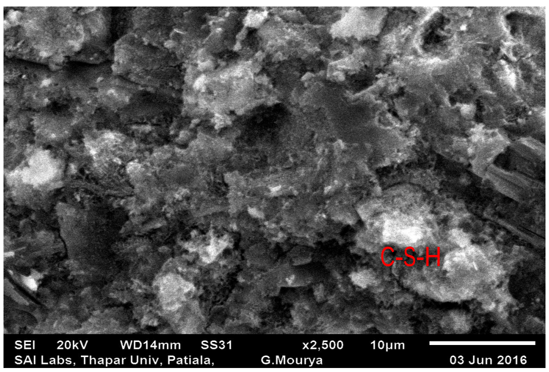


Figure 4.8 (k) SEM H_2L_{24}

Figure 4.8 (l) SEM H_2L_{24}



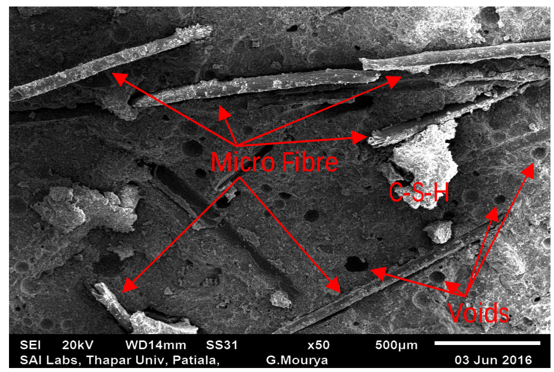
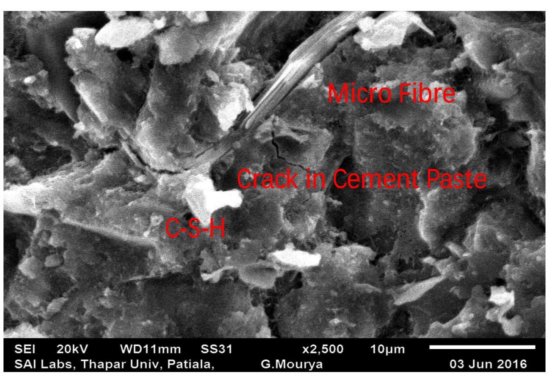


Figure 4.8 (m) SEM H_2L_{36}

Figure 4.8(n) SEM H_2L_{36}



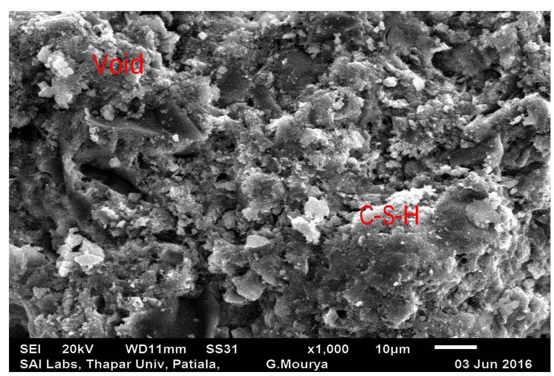


Figure 4.8 (o) SEM H_3L_{12}

Figure 4.8 (p) SEM H_3L_{12}

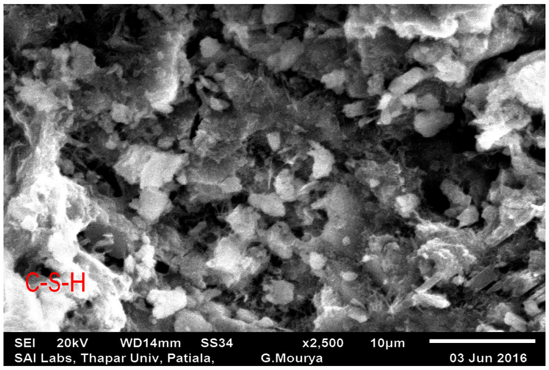


Figure 4.8 (q) SEM H_3L_{24}

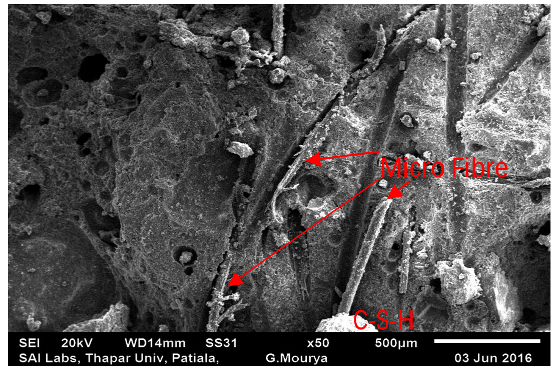


Figure 4.8 (r) SEM H_3L_{24}

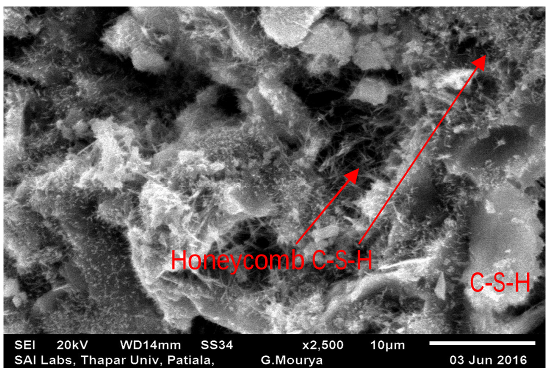


Figure 4.8 (s) SEM H_3L_{36}

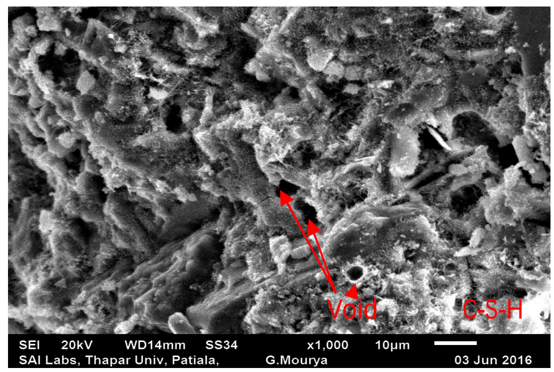


Figure 4.8 (t) SEM H_3L_{36}

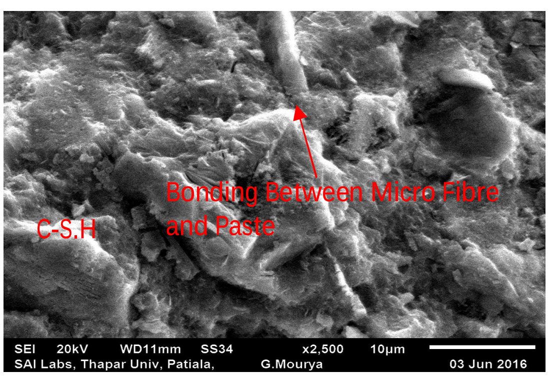


Figure 4.8 (u) SEM H_2L_m

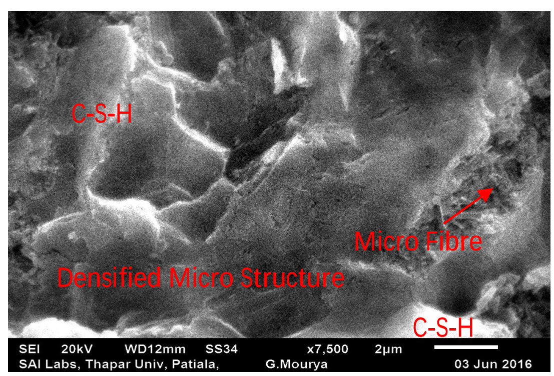


Figure 4.8 (v) SEM H_2L_m

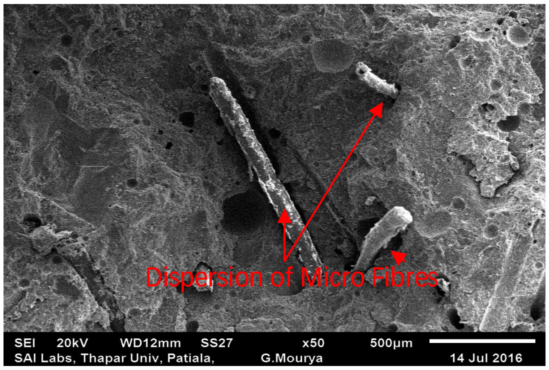


Figure 4.8 (w) SEM H_2L_m

From the above SEM images it is observed that:

- The Ettringite formation and voids in controlled sample **[Figure 4.8 (a-b)]** makes micro structure weak and majority of treated samples exhibit lesser voids and lesser Ettringite formation.
- Addition of 12 mm long human hair micro fibre @ 1%, 2%, 3% by weight of cement shows the strong bonding of micro fibres with paste however, existence of Portlandite, Cracks within paste **[Figure 4.8 (c-d)]**, C-S-H Honeycombing and Periclase **[Figure 4.8 (i-j)]** and Voids **[Figure 4.8 (o-p)]** restrained the samples to perform very well but as compared with controlled sample the compressive strength is higher.
- From the 24 mm length micro fibre samples the 2% is the best observed percentage for obtaining the higher strength. But 1% and 3% amount decreased the split tensile strength. The same trend was observed in compressive strength and flexural strength also. As from the SEM images the **Figure 4.8 (e-f)** and **Figure 4.8 (q-r)** shows the voids and the cracks within the paste for samples H_1L_{24} and H_3L_{24} respectively. However H_2L_{24} **Figure 4.8 (l)** shows dense micro structure, less voids.
- The 36 mm long micro fibre is the longest fibre used in this experimental program. It is observed that the maximum amount of 1% exhibit improvement in the performance of concrete except compressive strength. The long length micro fibres bridge the cracks and strong bond improves the tensile strength, fatigue strength and RCPT performance. But as the percentage of 36 mm

length micro fibres further increased, the performance of concrete becomes poor; it may be due to boaling effect of long micro fibres.

- The dense micro structure of hybrid human hair MFRC is the evidence for the improvement in performance of this sample. The formation of C-S-H Gel and the ability of fibres to bridge the gap in the microstructure reduced the pores of **[Figure 4.8 (v)]**. In addition, the strong bond was observed between the micro fibre and paste of the matrix **[Figure 4.8 (u)]**. The improvement in the performance is the consequences of the improved microstructure due to addition of 2% of different length micro fibres. The different length or Hybrid micro fibres restrained the crack at different level is also one of the reason for the maximum improvement as observed during the studies of mechanical properties of MFRC.
- The C-S-H Gel formation is closely observed with minimal voids in sample H_2L_{24} **[Figure 4.8 (k)]**. The Figure 4.8(i) shows the densified micro structure, which is the reason of the improvement in the mechanical performance of concrete matrix. The presence of micro fibre bridges the cracks and delays the formation of micro cracks. The H_2L_{24} specimen exhibit better performance than other samples except hybrid microfiber specimen H_2L_m, because the mono fibre can resist the crack and corresponding strain at one level only. The comparison of sample H_2L_{24} with H_2L_m establishes the fact that hybrid micro fibre can perform effectively and improve the performance of concrete than mono fibre containing concrete matrix.
- Not much difference was observed in specimens H_1L_{36} and H_2L_{24}. As compared to controlled specimen H_0C improvement was observed in these samples. Beyond 1% of 36 mm length micro fibres even the specimen performs significantly poor than the controlled specimen (see figure 4.3).
- From the SEM images it can be observed that $H_2L_{36}$and H_3L_{36} shows the increment of long length micro fibre increased the voids in micro structure. Due to this reason the flexural strength was also affected as it was 3.69 N/mm^2 for H_2L_{36} and 3.47 N/mm^2 for H_3L_{36}. The performance of H_3L_{36} is even lower than the controlled sample.

CHAPTER 5

CONCLUSIONS

5.1 GENERAL

The present study was undertaken to investigate the durability properties of different percentage and length of human hair were casted and tested after 7 days and 28 days.

On the basis of present study, following conclusions can be drawn:-

- The addition of human hair as micro fibre increases the compressive strength, split tensile strength and flexural strength of concrete. However, 2% addition of human hair as micro fibre gives the higher increase in strength irrespective of length of fibres.
- Similarly, with the addition of 1%, 2% and 3% human hair as micro fibre decrease the permeability of concrete drastically.
- Addition of 12, 24 and 36 mm long human hair as micro fibre with different percentage fraction improved the mechanical properties of concrete however, 24 mm length of human hair as micro fibre performed better, irrespective of content of fibres.
- Addition of 12, 24 and 36 mm micro fibres with different percentage fractions reduce the permeability of concrete.
- The addition of human hair as micro fibre using 12, 24 and 36 mm of length in equal fraction @ 2% by weight of cement gives the best results as compared to mono fibres.
- SEM images shows that the human hair micro fibre provides a strong bonding with the matrix arresting cracks efficiently and providing densified micro structure thus improving the properties of cement concrete.

5.2.1 SCOPE FOR FUTURE WORK

- In the present study only 7 days and 28 days old specimens has been considered. The other 56 days, 90 days and long term performance of dry and wet curing conditions are need to be study.
- Further study is needed to investigate the performance of ultra-high performance concrete reinforced with human hair micro fibre.
- Need to investigate the micro structure and chemical reaction of MFRC mix conducting XRD for different mix compositions of MFRC.
- Further research is needed for determining the optimum human hair fibre dosage and cost effectiveness of MFRC.

CHAPTER 6

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