# Experimental Studies on Polymer Modified Steel Fiber Reinforced Concrete

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**by**

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Transforming Education Transforming India

**SCHOOL OF CIVIL ENGINEERING**

**LOVELY PROFESSIONAL UNIVERSITY, PHAGWARA**

**2017**

# Certificate

This is to certify that the Dissertation-II entitled, "**Experimental Studies On Polymer Modified Steel Fiber Reinforced Concrete"** is a bonafide work done by "**AABID HUSSAIN BHAT, Reg. No.: - 11501341"** Student of Civil Engineering Department, Lovely Professional University, Phagwara, Punjab in partial fulfillment of the requirement for the Degree of Master Of Technology in Structural Engineering.

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I hereby declare that the Dissertation-II entitled, **"EXPERIMENTAL STUDIES ON POLYMER MODIFIED STEEL FIBER REINFORCED CONCRETE"** is a bonafide and genuine research work carried out by myself under the guidance of **Mr. R. Navaneethan**, Assistant Professor; Department of Civil Engineering, Lovely Professional University.

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# Acknowledgement

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**Signature of Student**

# Abstract

Steel fiber reinforced concretes and polymer based cement concretes are widely used in construction projects mainly in repair and rehabilitation and where the dynamic loading is acting. This work includes the concrete which is having effects of both i.e. the polymer as well as steel fiber, the steel fibres will arrest the crack propagation and the polymer will fill the pores at micro level thus will increase the durability properties like adhesion, flexural strength and permeability etc.

In this work the steel fibres to be used are end hooked and the polymer used was SBR (styrene butadiene rubber latex) manufactured by Dr. Fixit. A matrix of pure concrete with no addition and a concrete matrix with different percentages of steel fibres and polymer was made and different cubes and cylinders were casted. Which will be tested for compressive strength, flexural strength, and split tensile strength after 7, 14, 28 and 90 days as per IS code



**Key words:** Steel fiber reinforced concrete (SFRC), Polymer latex (SBR), Tensile strength, Adhesion.

# Table of contents

# List of symbols and abbreviations

| | |
|---|---|
| PMC/M | Polymer-modified concrete/mortar |
| FRC/M | Fibre-reinforced concrete/mortar |
| PC | Polymer concrete |
| PIC | Polymer impregnated concrete |
| PM-FRC | Polymer modified fibre reinforced composite (concrete/mortar) |
| SBR | Styrene butadiene rubber |
| EVA | Ethylene-vinyl acetate |
| PVA | Poly (vinyl acetate) fibre or powder |
| PAE | Poly-acrylic ester |
| EP | Epoxy |
| OPC | Ordinary Portland cement |
| IST | Initial setting time |
| FST | Final setting time |
| FA | Fine aggregates |
| W/C | Water to cement ratio |
| CA | Coarse aggregates |

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# Chapter 1

# Introduction

## 1.1 Background of the study

Fiber reinforced concrete is defined as a composite material which is made by adding certain proportions of discrete discontinuous fibres. Since the concrete is good in compressive strength but weak in tension thus the fibres are added so that they can increase the tensile strength of the composite made. The fibres include carbon fibres, steel fibres, human hair, glass fibres, and plastic fibres. But among these fibres the fiber which is providing large tensile strength besides being comparably economical is steel fiber. Steel fiber of small percentages between 0.25% and 2.5% by volume have been added to the plane concrete. These fibres are to be added during mixing so that the fiber gets dispersed uniformly throughout the volume. The steel fiber in the plane concrete improves the tensile and flexural strength to a greater extent i.e. why the SFRC is gaining interest at a large scale in the construction industry as the SFRC exhibits attractive tensile and compressive strengths, high toughness, low drying shrinkage etc. this is because the steel fiber arrests the micro crack formation as the concrete is bound in between these small discrete fibres. Thus the steel fiber reinforced concrete has superior resistance to cracks and crack propagation.

These properties of SFRC can be increased further by adding an appropriate polymer e.g. SBR, Epoxy, Vinyl Ester etc. the polymers in cement concretes form a 3-D network around the aggregates which increases the durability properties of polymer concretes especially tensile strength, permeability and high impact strength. This polymer addition to concrete also improves the transition zone (in concrete) due to adhesion of polymers. Thus SBR latex is incorporated into the SFRC in order to improve the ductile behavior and increase the flexural strength. The mechanical properties, microstructure, porosity and pore size distribution of polymer modified steel fiber reinforced concrete are studied.

## 1.2 Effects of polymers and fibres in concrete

Their beneficial physical properties and comparatively small price make cement-based materials the maximum, commonly used construction substances. But, these materials have a number of drawbacks like as brittleness and having a low failure strain, and are susceptible in tension. In order to diminish these weaknesses, the polymers and steel fibres were used.

### 1.2.1 Polymers in concrete

There are 3 predominant varieties of concrete which are made by adding polymers:

- Polymer Concrete (PC) — Polymer concrete is a composite made by adding polymers to the concrete instead of cement.

- Polymer Impregnated Concrete (PIC)—PIC is typically defined as a concrete which is precast and is then immersed into the polymer. The polymer goes inside the concrete and polymerises there.

- Polymer modified Concrete or Polymer Normal Cement Concrete (PMC or PPCC) — PMC is a type of concrete in which part of the cement is changed through an artificial natural polymer. It is produced with the aid of inducing a monomer, pre polymer-monomer blend, or a dispersed polymer into the concrete.

Among 3 kinds of polymeric substances, PMC, PPCC is most broadly used, due to its particularly low price, and easy to make.

Practical application of PMC became sizable during the early Nineteen Sixties. By now, thousands of initiatives, together with bridge deck construction or repair, etc. has been completed in the USA using SBR latex.

Lots of studies and research and construction experiences have proven that PMC when used as a repair material in the old structures, it shows good bonding with the conventional concrete and the reinforcement bars. Research also shows the PMC is having less permeability, more chemical resistance and less depth of carbonation compared to the normal concrete

### 1.2.2 Fibre reinforced concrete (FRC)

The properties of plain concrete can also be enhanced by addition of different fibres likewise steel fibres, PVA, polyethylene etc. the reason behind the increase in properties is that the fibres are bridging the micro cracks and thus arrests the crack propagation which in turn would have developed into a full-fledged crack. The fibre addition has increased different properties like ductility, impact resistance, and tensile strength.

Steel fibres and different synthetic fibres are mostly used in construction projects. The performance of whom in concrete depends on various factors such as elastic modulus, surface quality, matrix type and the bonding between fibre and cement matrix. The FRC is nowadays utilized in earthquake prone zones due to its high structural properties[2]. New trends in FRC generation have significantly extended the variety of applications[3], as shown in Table 1.1.

**Table 1.1 Application of various fibres in cement products**

| Fibre Type | Application |
|---|---|
| Glass fibres | Precast panels, Curtain wall facings, Sewer pipe, Thin concrete shell roofs, Wall plastic for concrete block. |
| Polypropylene, Nylon fibres | Pavement overlays, Bridge decks, Refractories, Concrete pipe, Airport runways, Pressure vessels, Blast-resistant structures, Tunnel linings, Ship-hull construction, Cellular concrete roofing units. |
| Asbestos fibres | Foundation piles, Pre-stressed piles, Facing panels, Floatation units for walk ways and Moorings in marines, Road patching material, Heavy weight coatings for underwater pipe. |
| Carbon fibres | Corrugated units for floor construction, Single and double curvature membrane structures, Boat hulls, Scaffold boards. |

## 1.3 PM-SFRC and its research importance

A depth understanding of PMSFRC is still not available as the progress in this area has been very low. Which may be due to certain reasons as described below:

- Due to high material cost which increases the overall cost of project thus discourages its application at large scale.
- Due to lack of research data of these materials thus we really don’t know their capabilities to enhance the properties of concrete.

Now the concretes containing both polymers and steel fires have showed so utilization in the construction industry. The concrete made with either steel fibres or polymers have a lot of limitations as described below:

Firstly, the PMC is having lower toughness, also some surveys (bridge decks in USA) have shown that the decks made of polymer modified concrete are having the large risk of failure due to low toughness[4]. The steel fibre reinforced concrete needed its durability to be enhanced particularly in coastal areas[5]. As the durability of SFRC is increased with increase in the steel fibre content, there is a decrease in the workability. Fibre balling, which actually occurs due to fibre inter-locking and improper distribution, also disturbs the hardened properties and thus reduces the durability. So if polymer is added to this SFRC which may increase the fresh and hardened properties of concrete thus will increase the life-span of the structure. So a concrete can be made with the modification of polymer (SBR) and which will also contain certain percentages of steel fibres thus will contain beneficial effects of both the additives.

Secondly, for the repair and rehabilitation of the old structures there is a need of a high strength concrete which will make bond easily and impart high strength to the combination. For the bonding effects the polymer will work and for strength the steel fibres are most effect and comparably economical. Thus the polymer modified steel fibre reinforced concrete may play a great role in repairing works[6].

# Chapter 2

# Terminology

**Steel fibres:** are discrete discontinuous fibres made of stainless steel. These fibres are thin wires of different dimensions.

**SBR LATEX:** is a carboxylated styrene butadiene copolymer latex admixture that is designed as an integral adhesive for cement bond coats, mortars and concrete to improve bond strength and chemical resistance.

**SFRC**: is a concrete in which the steel fibres have been added in order to increase the tensile strength of the concrete.

**PMC**: Polymer modified concrete is type of concrete which contains certain proportion of polymer in replacement of cement or in some cases replaces all the cement (polymer concrete).

**PMSFRC:** It is a concrete which contains both polymer as well as steel fibres in certain percentages.

**IST AND FST:** Initial setting time is also defined as the time at which cement paste starts losing plasticity and final setting time is said to be the time when the paste completely loses the plasticity. Here it must be kept in mind setting and hardening are two different entities

**Soundness**: It means the resistance of cement paste to expand

**Specific gravity:** Specific gravity is defined to be the ratio between the weight of given volume of cement to the weight of equal volume of water.

**Workability:** Workability can be defined as the ease with which the concrete can be placed and compacted.

# Chapter 3

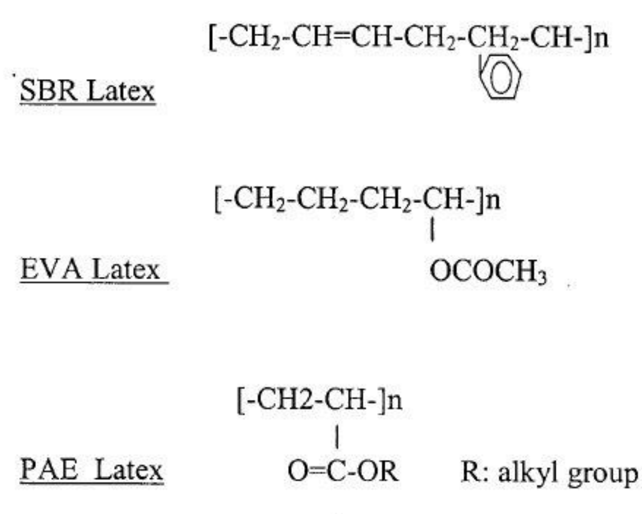
# Review of literature

The main principles underlying the use of PMC and FRC have been introduced in this chapter. The properties of PM-FRC composites are then reviewed, focusing on mechanical properties and durability, as well as the mechanisms for the improvement of bonding properties of steel fibres, polymers with cement matrix.

## 3.1 Principles of PMC and FRC

### 3.1.1 Polymers in concrete

In concrete polymer utilization is not new but has been used since decades.in 1930, various synthetic polymers have been tested and also have been used in concrete. Polymers used today are same but certain qualities have been improved. Now latexes and emulsions of polymers are a common and most cost effective materials used for improvement of superior properties. The various polymer latexes which have been used in construction projects are as polyethylene-vinyl-acetate latex, SBR latex, PAE latex etc. Their chemical formulations are shown as follows:




### 3.1.2 Mechanisms of PMC

The mechanism of polymer modified concrete for the freshly made polymer concrete involves two processes i.e. cement hydration and latex integration. When the cement starts to hydrate the polymer particles occupy the interstitial spaces. With the time the water content in concrete starts reducing due to its utilization in hydration as well as in evaporation. The polymer particles under goes polymerization and a new polymer is formed which is interlinked in the cement, thus forms a 3-D co-matrix[9] with cement, as shown in Fig 3.1 which surrounds the aggregate and fills the interstitial spaces[7]. Hydration of cement and the mechanism of co-matrix formation is observed by examination of PMC by using secondary electron imaging technology[10] as shown in Fig.3.2.

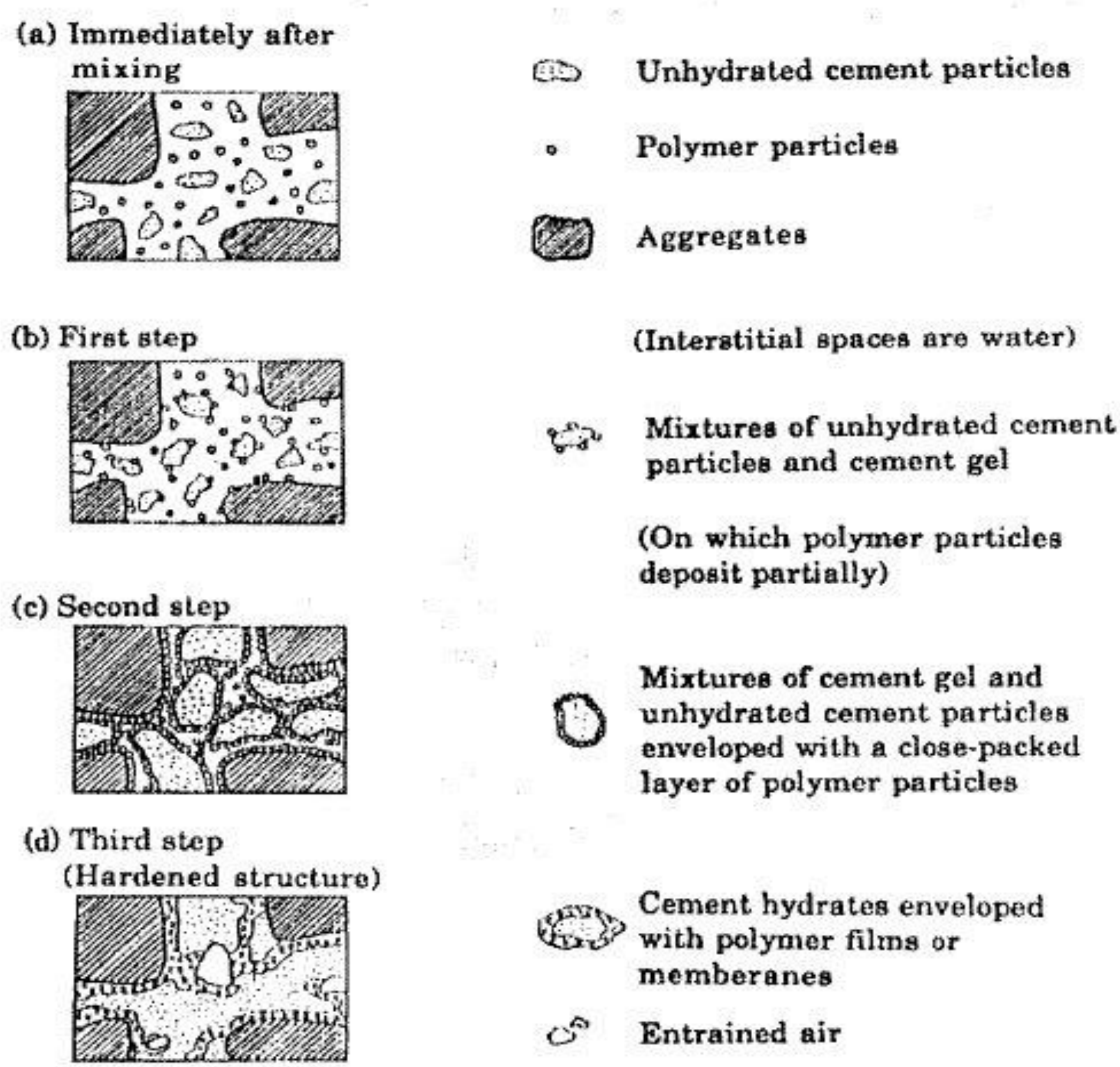



**Figure 3.1 Modal of formation of polymer-cement co-matrix**

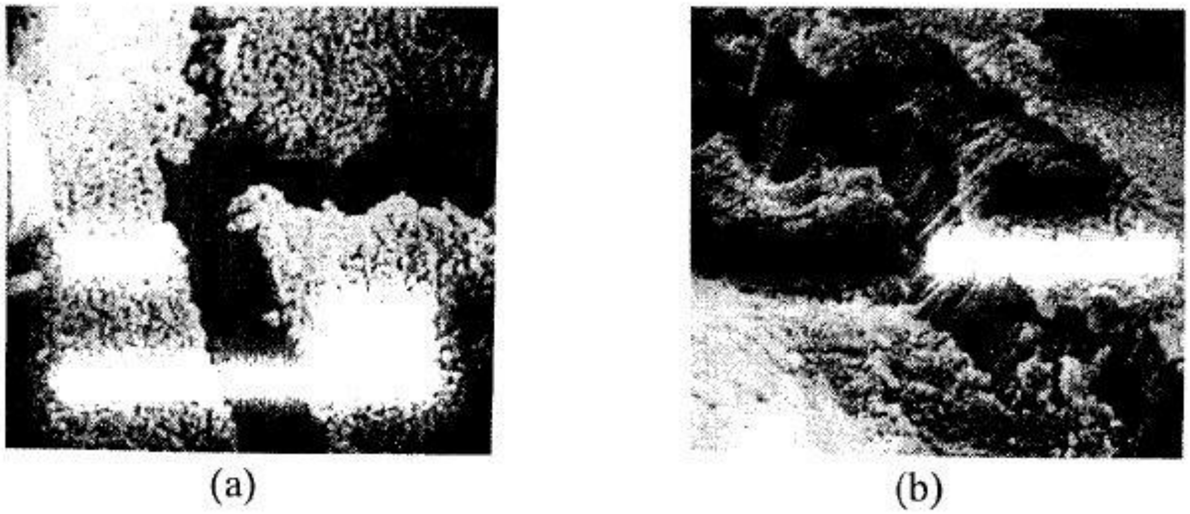


**Figure 3.2 Electron micrograph of (a) Plain concrete (b) polymer modified concrete [1]**

## 3.1.3 Properties of PMC

PMC has a superior property of bonding to the old concrete which may play a great role in repair and rehabilitation of old structures[11, 12, 13]. Besides the bonding nature of PMC it has comparably improved durability properties. Although the compressive strength may decreased, but the toughness and flexural strength increases in greater extent at the same consistency. Due to the addition of polymers of light weight the elastic modulus is less than plain concrete.

The conventional concrete is having drying shrinkage higher compared to the polymer modified concrete, though this is influenced by various factors such as the type of polymer, polymer/binder ratio, W/C ratio, and amount of cement and curing conditions.

## 3.2 Concrete with fiber reinforcement

Reinforcement of materials with fibres is not new but is a decades old concept. Various continuous fibres were used in different materials e.g. aluminum and titanium in aerospace etc. which has increased the mechanical properties to a large extent but the small discrete discontinuous fibre addition to concrete starts during 1960's, although the research has been carried out on this since 1910. The various fibres that have been added to concrete until now are steel fibres, glass fibres, carbon fibres and synthetic fibres.

Since the concrete is brittle in nature so as the load acts on the concrete, the concrete deflects and small cracks start to grow from this point. However the failure load has not reached yet. As the load is increased the cracks start to propagate and when the failure load acts the concrete collapses. Now if the fibres are added to concrete what they will do? They will arrest the cracks and their propagation but it should be in mind the modulus of elasticity of fibres should be larger than the concrete so that they can carry the load. Thus will increase the tensile strength of the concrete[2].

The main property of concrete which should be enhanced to a greater extent is the toughness since due to fibre pull out and de-bonding, fibres can enhance the toughness to a greater extent. Also the FRC is showing improvement in properties like impact resistance and fracture energy. E.g. a research study of SFRC shows that under flexural impact loading

## 3.3 Polymer-modified fibre reinforced concrete (PM-FRC)

### 3.3.1 Mechanical properties of PM-FRC

#### 3.3.1.1 Polymer modified steel fiber-reinforced concrete (PM-SFRC)

##### 3.3.1.1.1 Compressive strength and flexural behavior

Concrete which is made by the addition of both polymers (SBR EVA, AC, PAE) and steel fibres have different properties compared to conventional and the concretes which contain at least one of the additives[10].

**Ohama (1991)** in his research work used SBR and EVA polymer latexes combined with different fractions of steel fibres in mortar and checked the effects of each on the flexural strength. When the polymer to binder ratio was increased from 0 to 20% and steel fibre vol. fraction was increased from 0 to 2% the flexural strength was increased. The SBR was more effective than EVA latex at the same dosage[3].

The flexural toughness which is actually the ability of the material to absorb the energy also showed an increase with increase in polymer cement ratio and steel fibre content.it was shown that at peak load the mortar with polymer and steel fibre has resisted the deformation which occurs due to the pull out effect and bridging of fibres.

**Bentur (1995)** in his research used three different commercially available polymers i.e. acrylic copolymer (AC) Saran SA and SBR (DOW latex 460)[15] . He showed that when different polymers were added to concrete, they showed different properties when the workability was set constant. E.g. when the polymer was added with steel fibre the strength was increased by a factor of 4 to 5 while in those in which only one additive was added (polymer concrete or steel fibre concrete), the strength was not increased by a factor not greater than 2. The splitting tensile strength of concrete containing steel fibres with polymer (SBR and AC) were higher compared to with SA, for the same dosage less than 24%. At 18% of polymer cement ratio than strain capacity of PMSFRC was 2 to 6.5 times higher than SFRC.

**Naaman et al. (1996)** in their research used different polymers with fibres in order to increase the early strength gain in concrete which can be used for repair works[21]. They used different combinations and compared them with each other, they optimized a combination that showed an excellent results in modulus of rupture, toughness, and fatigue life in cracked state. Steel fibres (hooked end) and polymer latex have enhanced the load-deflection response in flexure and with time gain in flexural strength. Compared to plain concrete the flexural strength was increased by 15 to 30%. The energy absorption was increased in the combination in which the silica fume was used, but the flexural strength on the first day was not increase and in some cases was decreased.

**Wu et al (2000)** made a concrete at site with the addition of polymers and steel fibres the concrete showed good results when applied on cracks, on road surfaces. As the cracks formation in roads is at large, due to the sinking of the sub-base. A comparison was made between the PMSFRC and the other three i.e. PMC, SFRC, and normal concrete. The PMSFRC showed the remarkable results. The tensile strength was increased when the polymer/cement ratio was increased from 0 to 30%. Although the flexural strength was reached optimum level at 20% polymer addition. The toughness was increased by 35% compared to other three[22].

**V.M. Sounthararajan et al (2013)** in their research showed that there was remarkable increase in the compressive strength when the steel fibres content was 0.75%, around 38% after 28 days. But the polymer addition has decreased the compressive strength if cured by water otherwise by dry curing, it was increased. 0.75 % steel fibres with 4 percent SBR has increased the early compressive strength and flexural strength[20].

**Faraz khan et al (2016)** compared three different concretes (NC, SFRC, and PMSFRC) with each other. They have changed the steel fibre content from 0 to 1.25 % and the polymer was changed from 0 to 15% by weight of cement. After testing the different samples they concluded that the compressive strength in SFRC was increased by 17.96% flexural strength by 3.5% and tensile strength by 26.5% came at 1% of steel fibres .When the percentage was increased the strength decreased. And when the polymer (SBR (maximum at 10%)) was added there was further increase in strength i.e. compressive strength by23%, tensile strength by 38%nand flexural strength by 13.5% at the same steel fibre content of 1% when compared to the NC. And compared to SFRC the three were increased by4.3%, 9.09%, 9.54%, respectively[31].

### 3.3.1.1.2 Impact strength of PM-SFRC

Polymers are having high impact strength therefore when they are added to concrete they should increase the impact strength of the modified concrete. Since the impact strength also depends on the type of the polymer e.g. the elastomers are having high impact strength compared to thermoplastic resins. There is not much literature available on the combined effect of both polymers and steel fibres on the impact strength.

**Fujuchi et al (1978)** studied impact resistance on a sample of beam made of PMSFRC by dropping a steel ball at the mid span of the beam. The polymer used was PAE (poly- acrylic ester). Also antifoam about 1% by weight of PAE emulsion was used. Fujuchi concluded that the impact strength was increased when the polymer/cement ratio and steel fibre content was increased compared to the normal concrete as shown in Fig 3.3. There was a 60fold increase in the impact strength when the steel fibre content was increased to 2% and polymer to cement ratio was increased to 20%the other hardened properties were also enhanced like as the tensile strength was increased by 1.7%, flexural strength by 2.5% and toughness by 12.5%. But there was a decrease in compressive strength with increase in steel fibre content[14].

**Jiyrndrak et al. (1992)** showed that there was not much increase in the impact strength and toughness when the sample was tested by Hopkinson split-bar method, due to the addition of steel fibres. But the properties under dynamic loading has showed improvements when both polymer (acrylic ester based co-polymer) and steel fibres were added. About 1.5% of steel fibre content and a polymer with antifoam was added to concrete. The strength of the PMSFRC was improved compared to plain concrete, PMC, SFRC under dynamic loading significantly by 50%, 28% and 21%[21] respectively as shown in Fig 3.4

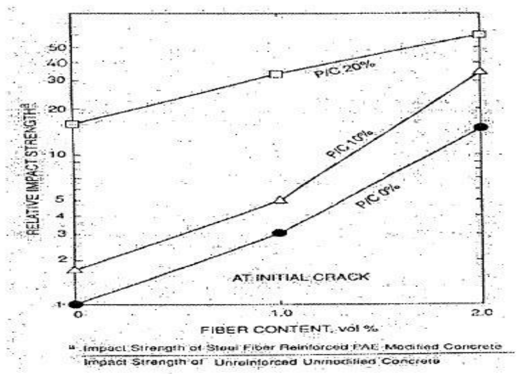



**Figure 3.3 Effect of polymer and steel fibre on impact resistance of concrete**

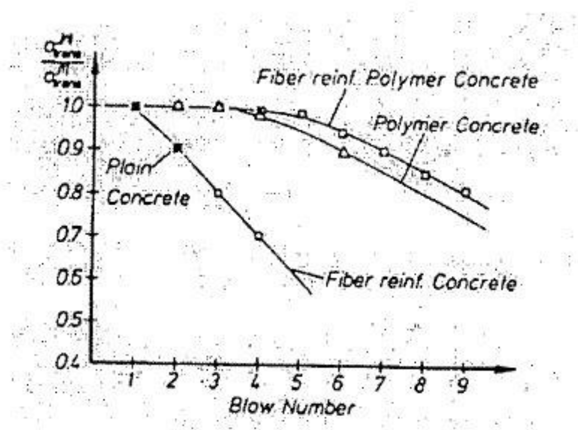



**Figure 3.4 Impact resistance of different types of concrete**

At last the impact strength can be increased significantly by the addition of steel fibre and polymers but the dynamic properties will depend on the method of measurement until now there is not a specific method which can be used to evaluate the dynamic properties of PMC, SFRC, and PMSFRC.

## 3.3.1.1.3. Bonding characteristics of PM-FRC

The polymer is having a property of adhesion i.e. it makes a bond quickly with different materials so, if it is added to concrete it will improve the bonding characteristics of the concrete b making bond with aggregates and even with the main reinforcement bars.

**Ohama (1991)** in his research paper, has concluded that at 20%polymer cement ratio adhesion is increased by 10 folds compared to the plain concrete[3].

**Banthia and Dubean (1994)** in their paper has showed that with the addition of fibre the adhesion of concrete can be increased. For this they made several samples by joining the old concrete with the newly made modified concrete and mortar (containing carbon and steel fibres) and were tested under tensile testing machine (UTM). The test samples were broken at the interface. The carbon fires were superior in concrete samples while as the steel fibres were good in mortar[12].

**Soroushian (1997)** stated in his paper that when the fibres (0.24% by volume) were added to the mortar, it has increased the bonding strength considerably and has made the bond more durable. The fibre effect can be concluded by the shrinkage crack reduction at the interface[25].

**Haung-yiun-yuan (2000)** in his report has stated that cationic polymer concrete develops greater bonding compared to the anionic, non-ionic polymer concretes and plain concretes.

**Banthia and Yan (2000)** in their research did a uniaxial tension test, they have showed that with the addition of polymer and steel fibre to the cement mortar, the bond strength and fracture energy have been enhanced. The steel fibre have showed better results than carbon fibres. The researcher has credited this achievement of steel fibre to the shrinkage reduction of new concrete. Below is the graph (Fig 3.5) which shows the effects of polymers and fibre on the bonding strength. The same results were reported in reference, which says that when 0.5% carbon fibres by weight were added, the bond strength was increased to 150%under tension and 110% under shear between bricks and mortar[29].

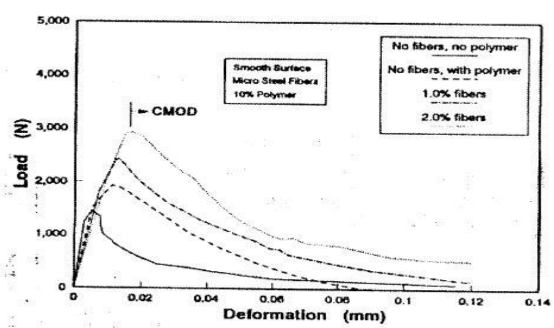



**Figure 3.5 Effect of polymer and fibre on the bond strength between old normal concrete and PM-FRM (direct tensile method)**

## 3.3.2. Durability of PM-FRC

The durability of FRC is totally dependent on fallowing factors such as the type of fibre used, design mix and the service conditions.

**Kosa et al (1991)** did a comparative analysis and used different fibres in mortar, she concluded that when the specimens containing different fibres were cured and exposed to the sea water conditions at 20$^{o}$C and 80$^{o}$C for about 2-10 months and then were tested. When the flexural tests were performed on samples containing poly-propylene, they showed maximum durability, while as the sample containing glass fibres showed least durability. And the samples containing steel fibres there was some noticeable reduction in the strength and flexural toughness, but the loss (20%) in strength, took five times longer than compared to other samples. Thus it may be concluded that FRC has durability better than normal concrete and may increase further if better modifications can take place[5].

**Ohama (1991)** did a joint analysis of polymers and fibres in concrete. The results showed that the chloride ion penetration and carbonation has decreased drastically. It takes 7 days for the penetration of ions into the normal sample but in modified sample it took 91 days when 10% of SBR was added and 182 days when 20% of SBR was used. Also due to the increase in polymer cement ratio the corrosion inhibiting properties were enhanced to a large[24].

**Razl (1991)** showed some practical examples in which the polymer modified fibre reinforced mortar were used, the examples showed were in some repairs of 6mm, thick layers of 12 to 18 mm and shotcrete of 50 to 130 mm. the durability along with some hardened properties were examined. PMFRM with some glass fibres and poly-propylene fibre showed increase in strength and durability. The freeze-thaw declining was not more than 1 percent and chloride-penetration-index was 310 to 670 coulombs[28].

**Rols et al. (1995)** did some flexural tests on polymer modified fibre reinforced concrete with under different speeded aging conditions. The conditions were a) in air at 20$^{o}$Cand the humidity was 60 percent b) under water at 60$^{o}$C c) repeated drying and wetting at 60$^{o}$ C and 20$^{o}$ C respectively. After the samples were tested it was concluded that modified concrete with (5% polymer, 1% polypropylene) retained ductility without affected by the environmental conditions. While in samples containing glass fibres there was a loss in ductility at large scale[27].

**U. B. kalwane et al (1999)** in their research paper stated that when the fibre volume was increased, the toughness of the polymer modified steel fibre reinforced concrete increased (after 28 days) as compared to the steel fibre reinforced concrete but the bond toughness decreased with increase in fibre percentage. The maximum bond toughness was at 3% of fibre content. The flexural toughness was maximum at 7% of fibre volume[30].

## 3.4 Summary of the literature review

Based on the literature review of comparison between FRC, PMC and PMFRC the fallowing conclusions can be made out as discussed below:

- There is a lot of research done on polymer modified concrete and fibre reinforced concrete, in which various polymers and fibres were used separately, but there is a very less research done on the combined effect of both polymers and fibres in concrete. And also there are few reports available which shows some increase in the mechanical properties of the PMFRC but the impact resistance and toughness was not discussed properly.
- PMFRC shows better mechanical properties and also the bonding is enhanced due to the polymer and fibre addition and the properties were dependent on the amount of the polymer and fibre addition.
- Impact resistance of polymer modified fibre reinforced concrete is increased, but due to the non-availability of test methods the material properties can’t be obtained properly.
- There was an increase in durability in the short period of testing but the life span of these structures is not properly mentioned but compared to the normal concrete it can be increased.
- Since there is an increase in overall cost of the project due to the additional cost of fibres and polymers, thus its usage has been limited to few works such as surface coating on highways, bridges and parking places, i.e. for those places where high water proofing and abrasion resistance is required. Thus, the high toughness and low permeability has made the PMFRC a best repairing material.

# Chapter 4

# Rationale and scope of the study

The aim behind this research work was to study the effects of different praportions of polymers and steel fibres with a fixed grade of concrete on the fresh properties (workability) and durability properties (tensile and compressive strength). The fallowing queries were inspected experimentally.

- How much the properties can be enhanced by different combinations of steel fibre and polymer as compared to plain concrete and single inclusion concretes (FRC OR PMC)?
- Do the fibres and polymers work together in a single unit with concrete so that the concrete made with their addition is tougher?

Steel fiber and the polymer styrene butadiene rubber emulsion were combined together with the concrete of M20 grade, and resulting composite properties were determined.

# Chapter 5

# Objective of study

The main purpose behind this study, was to study and analyse experimentally the various parameters affecting the tensile and compressive behaviour of concrete with steel fibres and polymer.

Comparatively PMC and SFRC have greater benefits over normal concrete and have been utilized in the various field applications. But the combination of both i.e. steel fibre and the polymer (SBR) in concrete have not been explored effectively. Thus the objective of this research was to make a steel fibre reinforced concrete with polymer modification, mainly aiming at high strength and high flexural toughness.

In addition, influence of steel fibres and polymer (styrene butadiene rubber latex) combinations on the fresh concrete properties (workability) and on the hardened concrete properties, mainly its compressive strength, flexural strength, and toughness are to be studied.

Another aspect of this research was to study the possible interaction between the steel fibres and the polymer styrene-butadiene latex. Previous research shows that the combination will have a considerable impact on the fresh and hardened properties however the synergistic effect of both the two materials on the properties have not been investigated thoroughly, Benefits of the two, if any can be determined through comparison with PMC and FRC.

# Chapter 6

# Materials and research methodology

## 6.1 Materials

## 6.1.1 Fibres

In this research, the deformed steel fibres were used of length 50mm. photographs of steel fibres have been shown. Deformed steel fibres have bought significant improvements in toughness in concrete. In this research end hooked steel fibres have been used.

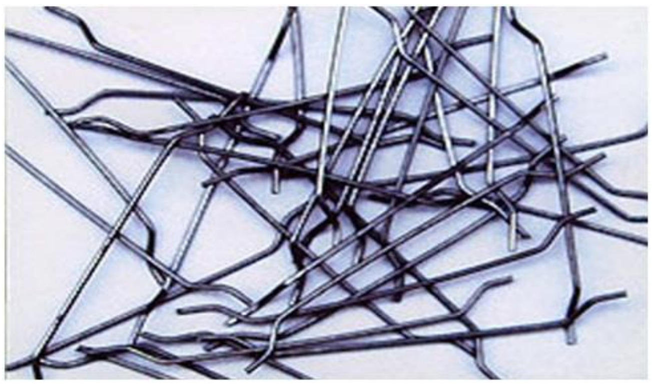


**Figure 6.1 Shape of Steel Fibres**

### 6.1.1.1 Properties of steel fibres

**Table 6.1 General properties of steel fibres used**

| Fibre | Type | Dimensions (mm) | | Elastic modulus (MPa) | Tensile strength ($N/mm^2$) | Density ($kg/m^3$) | Cross sectional shape | Aspect ratio |
|---|---|---|---|---|---|---|---|---|
| | | Length | Diameter | | | | | |
| Steel fibre | Hooked end | 50 mm | 0.75mm | $2\times10^5$ | 1100 | 7800 | circular | 67 |

## 6.1.2 Polymer system

The polymer used in this research was a kind of latex. The constituents of this latex was SBR emulsion with some additional admixtures. The physical properties of this latex have been enlisted in Table 6.2 below. This latex (SBR) is designed to be used as a bonding agent in concrete and cement based products in both internal and external application. Concrete and mortars have been modified to a greater extent by these types of latexes due to their bonding characteristics and the resistance to permeability of chlorides i.e.it decreases the permeability of the structure. These properties are very useful particularly for the cases which need proper protection from outside environment for example protection of mortar overlays on bridge decks etc.

**Table 6.2 Basic properties of latex**

| | |
|---|---|
| Nature and Appearance | Milky white, translucent, free flowing liquid |
| Total solids % by mass @ 105$^{o}$C | 37-39 |
| Specific gravity (27.5) | 1.01 |
| PH value | 7.7$^{o}$C |

## 6.1.3 Other raw materials

**Cement:** The cement was taken from the nearest dealer of ACC Company and the cement used is OPC[30] grade 43 .

**Aggregates**: The coarse aggregates[31] were 10-20 mm crushed stone with fineness modulus of 2.662 and the Fine aggregate was fine river sand with fineness modulus equal to 2.46.

## 6.2 Mix proportion

Different percentages of steel fibres and the polymer were proposed to be introduced so that the economical and high strength concrete can be made. The different percentages of steel fibres and polymer are shown.

**Table 6.3 Proportion of polymer and steel fibres in different concretes**

| Concrete mix | Polymer content (%) | Steel fibre content (%) | Days after strength is calculated |
|---|---|---|---|
| Control mix M20 | 0 | 0 | 7,14,28,90 |
| SFRC | 0 | 0.5 | 7,14,28,90 |
| PMC | 5,10,15 | 0 | 7,14,28,90 |
| PMSFRC | 5,10,15 | 0.5 | 7,14,28,90 |

## 6.3. Material testing

Various Lab[32] tests were performed on the materials (cement, sand, aggregates) and have been discussed below. The different properties of the polymer (SBR) and the steel fibres were already specified by the manufacturer.

## 6.3.1.1 Cement

## 6.3.1.1.1 Consistency test for cement

Standard consistency is defined as the consistency of cement paste at which the vicat plunger is allowed to penetrate up to 33-35mm from top of mould. The diameter of plunger is 10mm and length is 50mm. this test was done as per IS: 4031 (PART-4):1998

**Apparatus**

Vicat apparatus

Balance

Measuring cylinder 100ml

**Figure 6.2 Sample under Vicat Apparatus**

**Environmental conditions**

Temperature 28$^{o}$C

Humidity 77%

**Calculation**

The percentage of water by weight of cement was calculated which will make the cement paste of standard consistency. I did 3 consistency tests in order to calculate the exact constancy of the cement paste every time different results came and then the average of the 3 was taken as consistency of the cement.

**Table 6.4 Test results of consistency test**

| Test sample | Consistency |
|---|---|
| Sample 1 | 29.5 |
| Sample 2 | 27.5 |
| Sample 3 | 27 |

Therefore the consistency (P) of cement was taken as the average of the three and was 28%

**Discussion**

This test helps us to calculate the water content required for different tests like initial and final setting time and the soundness test

For initial and final setting time amount of water required is 0.85 P

For soundness test (le-chatelier method) water requirement is 0.78 P

## 6.3.1.1.2. Soundness of cement

In this test, a specimen of hardened cement paste is boiled at different temperatures so that the tendency to expand is checked out. Soundness means the resistance of cement paste to expand. This test is done as per IS: 4031-PART-3-1998

**Apparatus**

Le-chatelier apparatus

Water bath (100$^{o}$C), Caliper, Balance

**Figure 6.3 Making sample for soundness test**

**Environmental conditions**

Temperature 28$^o$C

Humidity 77%

**Calculations**

Soundness is ($L_2$-$L_1$)

**Table 6.5 Test results of Soundness test**

| Sample | $L_1$ cm | $L_2$ cm | Soundness cm |
|---|---|---|---|
| Sample 1 | 1.5 | 1.8 | 0.3 |
| Sample 2 | 1.5 | 1.7 | 0.2 |
| Sample 3 | 1.5 | 1.9 | 0.4 |

Therefore the soundness of the cement was taken as the average of the 3 and is equal to 0.3 cm

**Discussion**

The volume expansion in the cement paste is caused due to the presence of unburnt lime (CaO), dead burnt MgO and also $CaSO_4$. Due to the presence of unburnt lime in the cement, it may develop cracks due to the increase in volume

## 6.3.1.1.3. Fineness of cement by dry sieving

The fineness of cement is determined by sieving the cement through the 90-micron sieve and the weight retained on it after sieving continuously for 15 minutes is taken as the percentage of the total cement taken. This test was done as per IS: 4031(PART 1):1996

**Apparatus**

Sieve 90 micron,

Pan, Balance.

**Figure 6.4 Sieve 90 micron**

**Environmental conditions**

Temperature 28$^{o}$C

Humidity 77%

**Calculation**

The fineness of cement is taken as the average of at least 3 samples

**Table 6.6 Test results of fineness of cement**

| Sample | Weight of cement (g) | Weight left (g) | Average |
|---|---|---|---|
| Sample 1 | 200 | 4 | 6 |
| Sample 2 | 200 | 8 | |
| Sample 3 | 200 | 6 | |

Fineness = 3%

**Discussion**

The rate of hydration and the hence the strength gain depends on the fineness of cement when the cement it will provide greater surface area for the hydration process to take place

## 6.3.1.1.4. Initial and final setting time

This test is done as per IS: 4031(PART 5):1998

**Apparatus**

Vicat apparatus,

Balance tray and trowel

Measuring cylinder and stopwatch

**Figure 6.5 Sample under vicat apparatus for IST and FST**

**Environmental conditions**

Temperature 28$^o$C

Humidity 77%

**Calculation**

Initial setting time = $T_2 - T_1$

**Table 6.7 Test results of IST**

| Sample | $T_1$ (mints.) | $T_2$ (mints.) | Setting time ($T_2$-$T_1$) (mints.) |
|---|---|---|---|
| Sample a | 09:25 | 10:12 | 47 |
| Sample b | 10:15 | 11:10 | 55 |
| Sample c | 11:10 | 11:56 | 46 |

The initial setting time is taken as the average of the 3 samples and is 49.33minutes

Final setting time =$T_3$-$T_1$

**Table 6.8 Test results of FST**

| Sample | $T_1$ (mints.) | $T_3$ (mints.) | Setting time ($T_3$-$T_1$) (mints.) |
|---|---|---|---|
| Sample a | 09:25 | 19:10 | 610 |
| Sample b | 10:15 | 20:31 | 616 |
| Sample c | 11:10 | 21:15 | 605 |

The final setting time is taken as the average of the 3 samples and is 610

**Discussion**

It is very important that cement should not set quickly nor slowly, but should give some time for transportation of the concrete in former case and in later case too long the setting time will reduce the strength at the desired age.

## 6.3.1.1.5. Specific gravity

This test is to be done considering IS: 4031(PART 11):1988

**Apparatus**

Le-chatelier's apparatus

Balance and tray

**Figure 6.6 Le-chatelier's apparatus for specific gravity test**

**Environmental conditions**

Temperature 28°C,

Humidity 77%

**Calculation**

The density is calculated by the formula as under

Specific gravity $\frac{(W2-W1)}{(W2-W1)-(W3-W4)\times 0.83}$ =$\frac{(161-111)}{(161-111)-((389.5-349.5)\times 0.85)}$= 3.125

Where 0.85= specific gravity of diesel.

**Result**

The specific gravity of cement is equal to 2.97kg/m$^3$

**Discussion**

Specific gravity test was actually used to detect the adulteration and under burning in the Portland cement but now no more importance is given as other tests are giving superior results.

## 6.3.1.2 Aggregates

## 6.3.1.2.1 Fineness modulus of coarse and fine aggregates

Fine aggregate is the river sand and coarse aggregates are the crushed stone. The size of fine aggregates is limited by 4.75 mm beyond which the aggregates falls in coarse section. Fineness modulus is the numerical index value which is giving the mean size of particles in the entire body of concrete. The main objective behind the calculation of fineness modulus is to grade the aggregates for the economical mix and workability with minimum cement content. This test was done as compared to the IS: 2386(PART 1):1963.

**Apparatus**

IS-test sieve set for coarse aggregates and fine aggregates,

Balance,

Shaking machine,


**Figure 6.7 Sieving of CA for calculation of fineness**

**Calculation**

Coarse aggregates

Weight of coarse aggregates taken= 5 kg

**Table 6.9 Results of sieve analysis of CA**

| S.No. | Sieve size (mm) | Weight retained | % weight retained | Cu. % weight retained | % weight passing |
|---|---|---|---|---|---|
| 1 | 40 | 0 | 0 | 0 | 100 |
| 2 | 20 | 110 | 2.2 | 2.2 | 97.8 |
| 3 | 10 | 3340 | 66.8 | 69 | 31 |
| 4 | 4.75 | 1300 | 26 | 95 | 5 |
| 5 | 2.36 | 250 | 5 | 100 | 0 |
| Total | | 5000 | | 266.2 | |

Fine aggregates

Weight of fine aggregate taken=1kg

**Table 6.10 Results of sieve analysis of FA**

| S.No. | Sieve size | Weight retained (g) | % weight retained | % weight passing (g) | Cu. % weight retained (g) |
|---|---|---|---|---|---|
| 1 | 4.75 mm | 20 | 2 | 98 | 2 |
| 2 | 2.36 mm | 100 | 10 | 88 | 12 |
| 3 | 1.18 mm | 100 | 10 | 78 | 22 |
| 4 | 600 µm | 190 | 19 | 59 | 41 |
| 5 | 300 µm | 350 | 35 | 24 | 76 |
| 6 | 150 µm | 170 | 17 | 7 | 93 |
| 7 | Pan | 70 | 7 | 0 | |
| Total | | 1000 | | | 246 |

**Fineness modulus**

Sum of percentage cumulative weight retained/100

For crushed stone =266.2/100 = 2.662

For sand = 246/100 =2.46

**Results**

The fineness modulus of coarse aggregate is 2.662

The fineness modulus of fine aggregate is 2.46

**Discussion**

Thus from the results we concluded that if fineness is more the aggregate is coarser and vice versa.

## 6.3.1.2.2. Specific gravity of coarse aggregates

Specific gravity test of aggregates is carried out in order to measure the strength and quality of aggregates. Since the aggregates having low specific gravity are weak and vice versa. This test is done according to IS: 2386(PART 3):1963

**Apparatus**

Glass vessel or jar, container.

Oven (300$^{o}$C). Big container with water.

Balance, Tray, Absorbent clothes.

**Calculations and Result**

**Table 6.11 Test readings for Specific gravity of CA**

| | |
|---|---|
| Weight of jar + sample + water (W1) g | 3375 |
| Weight of jar + water (W2) g | 2754 |
| Weight of surface dried sample (W3) g | 992 |
| Weight of oven dried sample (W4) g | 986 |

Specific gravity = $\frac{W4}{W3-(W1-W2)}$ = 2.66

Apparent sp. gravity = $\frac{W4}{W4-(W1-W2)}$ = 2.701

Water absorption = $\frac{W3-W4}{W4} \times 100$ = 0.61%

## 6.3.1.2.3 Specific gravity of fine aggregates

This test is done according to IS: 2386(PART 3):1963

**Apparatus**

Balance, Pycnometer, well ventilated oven, tray.

Filter paper, funnel.

**Figure 6.8 Pycnometer used for specific gravity calculation of FA**

**Calculation and Result**

**Table 6.12 Test readings for Specific gravity of FA**

| Description | Weight (g) |
|---|---|
| Weight of saturated and surface dry aggregates (W) g | 500 |
| Weight of Pycnometer + sample + water (W1) g | 1826 |
| Weight of Pycnometer + water (W2) g | 1514 |
| Weight of oven dry sample (W3) g | 496 |

Specific gravity = $\frac{W3}{W-(W1-W2)} = \frac{496}{500-(1826-1514)}$ = 2.638

Apparent sp. gravity = $\frac{W3}{W3-(W1-W2)} = \frac{496}{496-(1826-1514)}$ = 2.696

Water absorption = $\frac{W-W4}{W4} \times 100 = \frac{500-496}{496} \times 100$ = 0.81%

## 6.4 Mix design M20

Design mix is done by taking IS: 10262-2009 into consideration[33]

**Requirements for proportionating:**

a) Concrete grade: M20

b) Cement used: OPC 43 Grade

c) Maximum size of coarse aggregates: 20mm

d) Exposure conditions: mild

e) Maximum cement content: 450 kg/m$^3$

f) Type of aggregate: crushed

**Test data for material**: All the data is based on the test results which were done in laboratory.

a) Specific gravity of cement = 3.125

b) Specific gravity of coarse aggregates =2.66

c) Specific gravity of fine aggregates =2.638

d) Water absorption of CA = 0.61%

e) Water absorption of FA = 0.81%

f) Fineness modulus of CA = 2.662

g) Fineness modulus of FA=2.46

h) Consistency of cement = 28%
i) Soundness of cement = 0.3
j) Initial setting time = 54 min.
k) Final setting time = 380 min

**1. Target strength for mix design**

$$F_{ck} = f_{ck} + (t \times s)$$

Where “$F_{ck}$” is target average compressive strength at 28 days and “$f_{ck}$” is the characteristic at 28 days, “s” is standard deviation and “t” is a statistic variable depending upon the accepted proportion of low results and the No. of tests.

$$F_{ck} = 20 + (1.65 \times 4.6) = 27.59 \text{ N/mm}^2$$

**2. Selection of W/C ratio**

W/C ratio for corresponding $F_{ck}$ value = 0.48

For mild exposure = 0.6

Take the min. = 0.48 [Table 5 IS: 10262-2009]

**3. Air content:**

For maximum size of 20 mm aggregates the entrapped air is 2% of the volume of concrete.

**4. Water content and fine to total aggregate ratio**

For nominal maximum size of 20 mm aggregates and concrete grade of M20 the water and sand content obtained are 186 kg/m$^3$ and 35% of total aggregate volume respectively.

Water content = 186 kg/m$^3$

**5. Adjustments of values in water content and sand percentages**

No corrections are required since aggregates used are not rounded and there is no increase or decrease in w/c ratio and compaction factor.

**6. Determination of cement content**

Water to cement ratio = 0.48

Water = 186 kg/m$^3$

Cement = 387.5 kg/m$^3$

**7. Check for minimum and maximum cement content**

The calculated cement content of 387.5 is adequate as per IS: 456:1978

**8. Determination of coarse and fine aggregate content**

**Fine aggregates:**

$$0.98 = (186 + \frac{387.5}{3.125} + \frac{1}{0.35} \times \frac{fa}{2.638}) \times \frac{1}{1000} = 618.611 \text{ kg}$$

**Coarse aggregates:**

$$0.98 = (186 + \frac{387.5}{3.125} + \frac{1}{1-0.35} \times \frac{\mathbf{Ca}}{2.66}) \times \frac{1}{1000} = 1158.43 \text{ kg}$$

**9. Total quantities of ingredients and mix proportions**

**Table 6.13 Total quantities of ingredients and mix proportions**

| cement | Fine aggregate | Coarse aggregate | water |
|---|---|---|---|
| 387.5 (kg) | 618.611 (kg) | 1158.43 (kg) | 186 (kg) |
| 1 | 1.597 | 2.99 | 0.48 |

# Chapter 7

# Results and discussion

## 7.1 Workability:

A good workability is very important for better compaction of the concrete which in turn will affect the strength of the concrete. The workability of concrete depends on various parameters such as water content, w/c ratio, type of aggregate. The water to cement ratio in this study was kept constant as 0.48. But when the polymer was added the water content was decreased as the polymer was in liquid form and contains 50% liquid content. It was observed that when the polymer content was increased the workability of concrete increases but decreases with the increase in steel fiber content. The workability tests were performed by conventional slump cone.

**Figure 7.1 Workability test using slump cone**

### 7.1.1 Polymer modified concrete:

**Table 7.1 Workability test readings of PMC**

| Polymer content | Slump value |
|---|---|
| 0 | 68.7 |
| 5 | 122 |
| 10 | 143.2 |
| 15 | 176.4 |
| 20 | 210.2 |

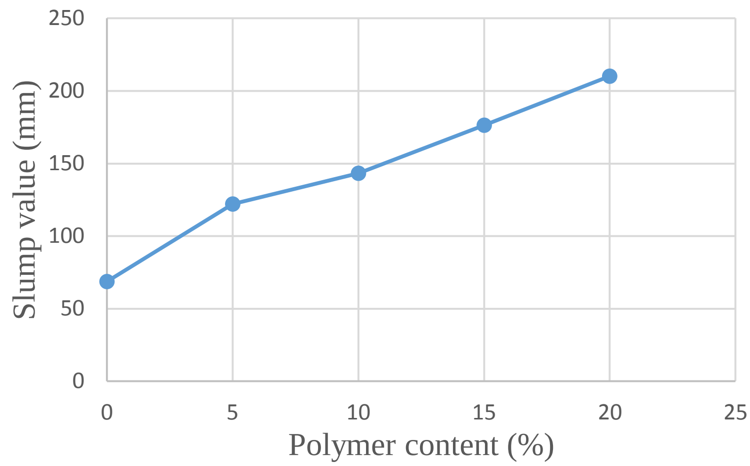



**Figure 7.2 Workability test of PMC at different polymer content**

## 7.1.2 Steel fiber reinforced concrete:

**Table 7.2 Workability test readings of SFRC**

| Fiber content | Slump value |
|---|---|
| 0 | 68.7 |
| 1 | 62 |
| 3 | 56 |
| 5 | 48 |

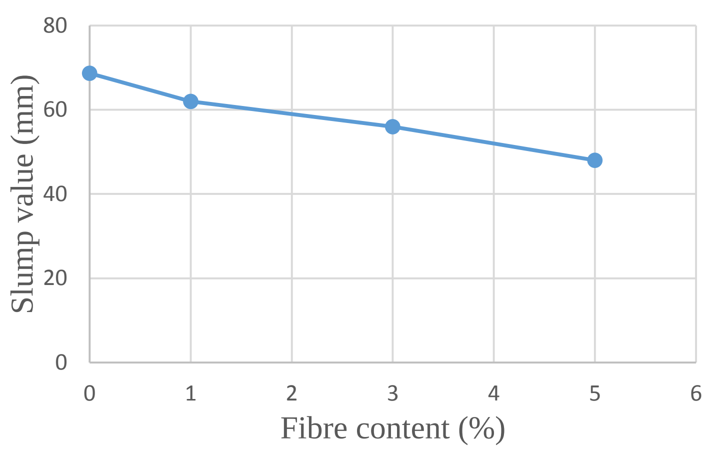



**Figure 7.3 Workability test of SFRC at different fiber percentages**

### 7.1.3 Polymer modified steel fiber reinforced concrete:

The PMSFRC made, constitutes the maximum percentages of polymer and the steel fiber at which the maximum strength was observed in PMC and SFRC respectively. When the workability test was performed on the said concrete it was observed that there was slight decrease in the slump value compared to the PMC (15%). The slump value was 187.7 mm.

## 7.2 Compressive strength[34]:

Standard cubes of size (150 x 150 x 150) mm were casted in order to calculate the strength after 7, 14, 28 and 90 days. The cube specimens were demoulded after 24 hours and were put into the curing tank up to the testing period. The compressive strength of different samples of with varying percentage of polymer and steel fibre contents is shown in Table No. 7.3. Figure No. 7.7 Shows the variation of compressive strength with change in fibre content when the steel fibre has been changed from 0 to 5% the compressive strength came out to be max at 3%. From figure No. 7.8, the compressive strength with change in polymer content, after changing polymer from 0 to 20 percent the optimum limit of polymer was about 15% at which the Compressive Strength  was maximum, beyond which there was slight reduction. Since cement is the primary material that contributes to superior compressive strength of concrete, therefore when the quantity of cement is relatively decreased it leads to decrease in compressive strength. Figure No. 7.9 shows the comparison of compressive strength between NC, SFRC(3%), PMC(15%), PMSFRC(3%S,15%P). the compressive strength of PMC and PMSFRC at the initial stage was less than the NC. It is majorly because, during first 7 days, polymer shows slightly slow reaction which leads to lower early strength. After 28 days there was an increase in strength compeared to NC. The 7 days compressive strength of SFRC was greater than the NC but slightly less than PMSFRC. In PMSFRC both polymer and steel fibres collectively improve the overall compressive strength.

**Figure 7.4 Casting and curing of concrete cubes**

**Table 7.3 Compression test results**

| DESIGNATION OF SAMPLE | | Average compressive strength Mpa | | | |
|---|---|---|---|---|---|
| | | 7days | 14days | 28days | 90days |
| NC | | 15.36 | 18.78 | 24.39 | 24.63 |
| SFRC | 1%SF | 16.07 | 23.41 | 25.69 | 25.9 |
| | 3%SF | 17.6 | 24.8 | 29.41 | 29.65 |
| | 5%SF | 16.72 | 21.56 | 23.24 | 23.42 |
| PMC | 5%P | 11.46 | 17.67 | 26.82 | 26.989 |
| | 10%P | 9.87 | 15.38 | 27.18 | 27.345 |
| | 15%P | 8.7 | 13.27 | 27.52 | 27.68 |
| | 20%P | 6.9 | 11.1 | 22.37 | 22.61 |
| PMSFRC | 3%SF 15%P | 18.92 | 26.12 | 30.06 | 30.27 |

**Figure 7.6 Sample under compression testing machine**

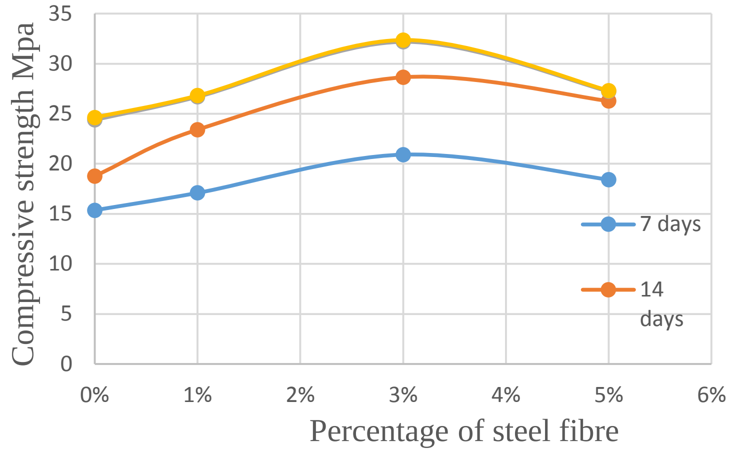



**Figure 7.7 Variation of compressive strength with Steel fibre**

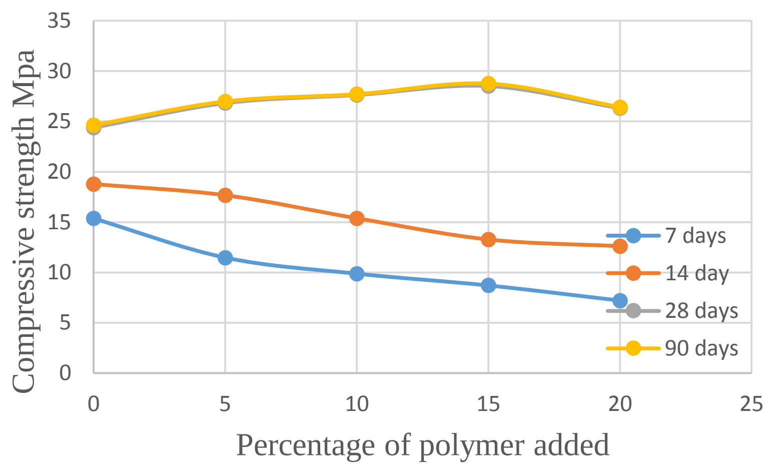



**Figure 7.8 Variation of compressive strength with polymer**

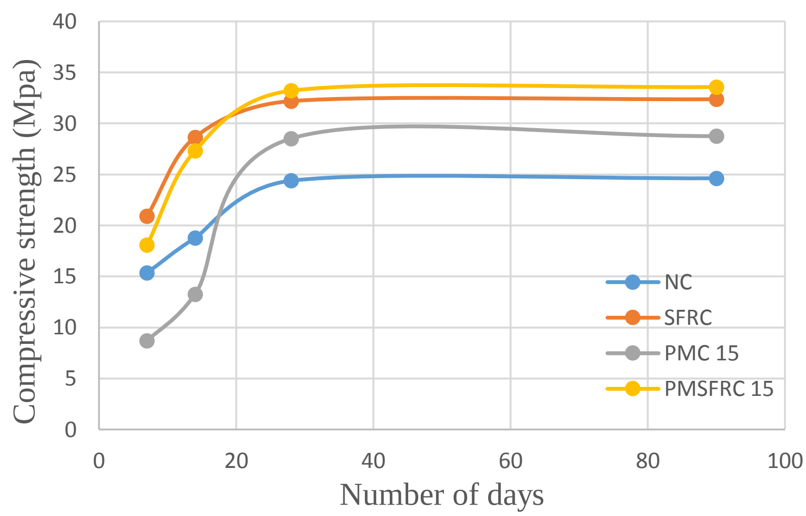



**Figure 7.9 Variation of compressive strength with age**

## 7.3 Tensile strength[34]:

For calculating the splitting tensile strength various cylinders of size 20mm and diameter 10mm were casted and strength after 7, 14,28 and 90 days were obtained. The tensile strength of various samples has been shown in Table No. 7.4. Below is a comparison shown and various conclusions have been drawn from them. Figure No. 7.11 shows the split tensile strength of SFRC with different percentages of steel fibre at different time periods. the max Splitting tensile strength came out be at 3% SFRC. Figure No. 7.12 shows the splitting tensile strength of PMC, at the 7 days the splitting tensile strength of PMC was less than NC beyond which the increase in strength was observed and the maximum strength was recorded at 15% polymer content. Figure No. 7.13 shows the splitting tensile strength of NC, SFRC(3%), PMC(15%), and PMSFRC. The maximum strength was showed by the PMSFRC at 3% steel fibre and 15% polymer content when compeared with NC, SFRC, and PMC. As the strain capacity of concrete is low because of its brittle nature, therefore addition of steel fibres increases tensile capacity of concrete due to crack arrest mechanism of steel fibres. Therefore the ductility of concrete is improved so this exploration can be quite useful, for the structures subjected to earthquake tremours.

| DESIGNATION OF SAMPLE | | Average tensile strength Mpa | | | |
|---|---|---|---|---|---|
| | | 7days | 14days | 28days | 90days |
| NC | | 1.07 | 1.41 | 1.57 | 1.62 |
| SFRC | 1%SF | 1.1 | 1.52 | 1.71 | 1.74 |
| | 3%SF | 1.21 | 1.71 | 1.97 | 2.04 |
| | 5%SF | 1.14 | 1.56 | 1.76 | 1.81 |
| PMC | 5%P | 0.97 | 1.27 | 1.68 | 1.71 |
| | 10%P | 1.09 | 1.33 | 1.77 | 1.82 |
| | 15%P | 1.16 | 1.36 | 1.86 | 1.89 |
| | 20%P | 1.13 | 1.35 | 1.81 | 1.82 |
| PMSFRC | 3%SF 15%P | 1.38 | 1.82 | 2.18 | 2.22 |


**Figure 7.10 Sample during tensile test**

**Table 7.4 Tensile test results**

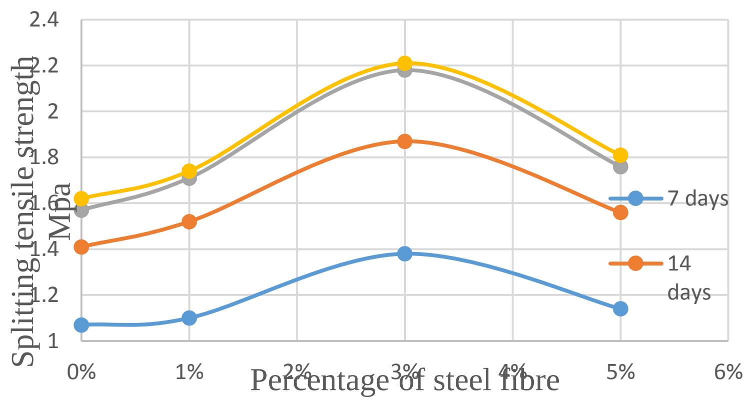



**Figure 7.11 Variation of splitting tensile strength with Steel**

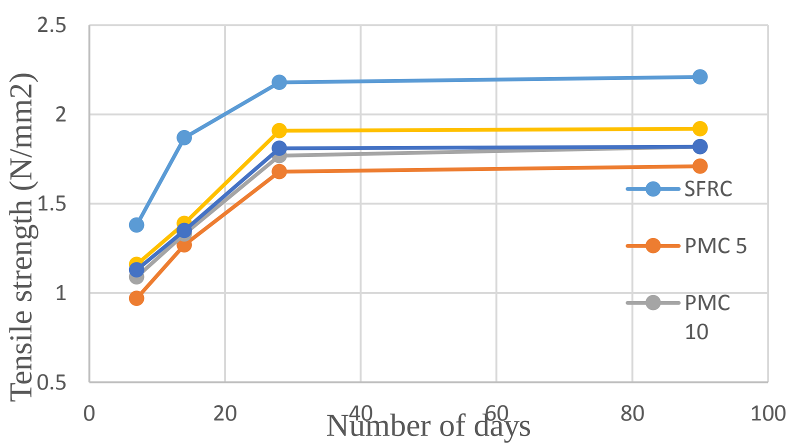



**Figure 7.12 Variation of split tensile strength of PMC with age**

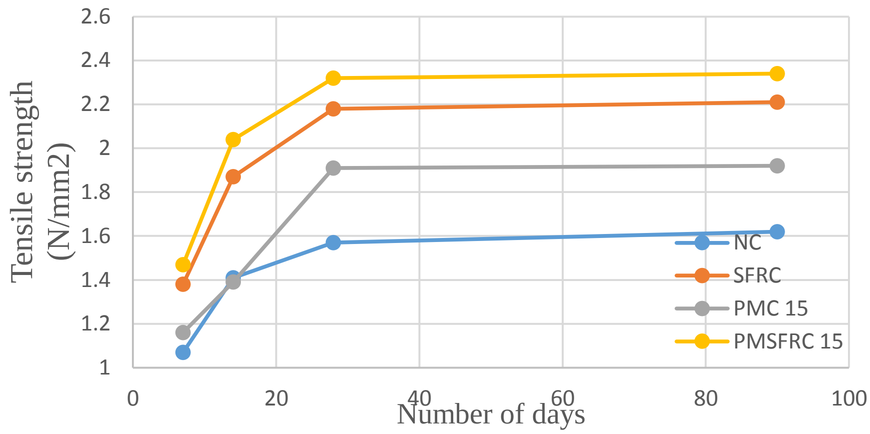



**Figure 7.13 Variation of splitting tensile strength with age.**

# Chapter 8

# Conclusion and future scope

## 8.1 Conclusion

1. With increase in the polymer content the workability increases, as the SBR also acts as an admixture while as when the fibre was increased the workability decreases as it causes the obstruction and increases the friction in the concrete.
2. The optimum quantity of steel fibre and polymer was 3% and 15% respectively.
3. The compressive strength in SFRC was maximum at 3% and was about 31.98% more than the NC. The maximum compressive strength in PMC was observed at 15% polymer content and was about 16.93% more than NC. The increase in compressive strength in PMSFRC was about 36.16% compeared to NC.
4. The splitting tensile strength of SFRC was observed maximum at 3% and was about 38.85% more than NC. And in the case of PMC, the maximum strength was observed at 15% polymer replacement and was about 21.65 % more than the NC. While the maximum strength was observed in PMSFRC and was about 47.77% more than NC
5. The porosity of the PMC was increased with the increase in polymer content due to the pore filling effect of the polymer at micro pore level.

## 8.2 Future Scope

The present study can be used as a basis or a supporting document for the future research work to be done in this area.

The fallowing parameters can be analyzed and studied for future work.

- The fiber type and aspect ratio can be changed and affects can be studied.
- Type of polymer and its quantity can be changed and analyzed.
- The effect of elevated temperatures and the effects of sudden, gradually and intermitted cooling on the properties of PMSFRC can be studied.
- Effect of different grades of concrete and different types of aggregates on the properties can be studied.

# References

[1] ACI committee 548, State of the Art Report on Polymer Modified Concrete, ACI 548.3 R-95, 1995.

[2] ACI committee 544, Fibre reinforced Concrete, ACI 544.1 R-96, 1997.

[3] Beaudoin, J.J., Fiber-reinforced concrete, Canadian Building Digest CBD-223, http: //irc.nrc-cnrc.gc.ca/cbd/cbd223e.html., 2003.

[4]. Abdul Shafi, O., kvammen, B. and Kaloush, K., Premature failure of latex modified concrete bridge deck overlays in Ohio (Final report), C T L Engineering Inc., June, 1990.

[5] Kosa, K., Naaman, A. E. and Hansen, W. 'Durability of fibre reinforced mortar', ACI Material s Journal, Vol. 88, No.3, May-Jun, 1991, pp310-319.

[6] Balaguru, P .N. and Shah, S.P., Fiber reinforced cement composites, 1992, McGraw- Hill Inc. pp279-281.

[7] DLP redispersible polymer powders, product for high performance applications, CD-ROM, Dow Company, July, 2002.

[8]. Rebeiz, K .S. , Yang, S. and Fowler, D.W., 'Polymer mortar composites made with recycled polymer plastics, ACI Materials Journal, Vol. 91, No.3, May-Jun, 1994, pp313- 319.

[9]. Ohama, Y. , 'Principle of latex modification and some typical properties of latex- modified m ortars and concretes', ACI Materials Journal, Vol. 84, No.6, Nov-Dec, 1987, pp511-518.

[12]. Ohama, Y., Handbook of polymer-modified concrete and mortars: properties and process te chnology, No yes publication, 1995.

[13]. Zhong, L., 'Effect of P V A powder on aging resistance of glass fibre-reinforced extrudate', CONSEC, Proceedings of concrete under severe condition, Vol.2, 2001, ppl384-1391. 157

[14]. Chung, D.D.L.,'A comparative study of concretes reinforced with carbon, polyethylene, and steel fibres and their improvement by latex addition', ACI Materials Journal, Vol. 93, No.2, Mar-Apr, ppl29-133.

[15]. Ohama, Y., 'Properties of steel and polyethylene fibre hybrid reinforced polymer- modified concrete', the 28th Japan congress on materials research, March 1985, pp151 - 155.

[16] Ohama, Y. Hashimoto, H. and Suqiyama, M. 'Properties of steel fiber reinforced polymer-modified concrete', the 21st Japan congress on materials research- nonmetallic materials, 1978, p pl63-165.

[17]. Bentur, A., 'Properties of polymer latex-cement-steel fibre composites', the International Journal of Cement Composites and Lightweight Concrete, Vol.3, No.4, 1981, pp283-289.

[18]. Shirai, A. and Ohama, 'Flexural behavior of polymer-ferrocements with polymer modified mortars as matrices', the 6th International Conference on Mechanical Behaviour of Materials, To kyo, 1991, pp405-410.

[19] Shirai, A. And Ohama, 'Develepment of polymer-ferrocements with steel and carbon fibres', in T.Chandra. A.k.Dhingra (eds), Advanced Composites '93, Material conference on advanced co mposite materials, 1993, ppl73-179.

[20]. V.M. Sounthararajan et. al. “strain hardening properties of steel fibre reinforced latex concrete composite” vol. 5 no. 2 Apr. may 2013

[21]. Naaman, A. E. And Al -khairi, K., 'Bending properties of high-early-strength fibre reinforced concrete', ACI 159-24, 1996, pp351-361.

[22]. Wu, S., Nan, C. -W. and Huang, X. , 'Super thin coating materials for high grade highway', in Christopher K. Y. Leung , High performance concrete, workability, strength and durability, Honkong, 2000, pp412-415.

[23]. Jitendra, K. and Ake, R., 'Synergistic strength of fibre concrete by polymer emulsion', the 3rd International Congress of Polymers in Concrete, 1981, pp239-249.

[24]. Banthia, N. And Dubeau, S., 'Carbon and steel fibre micro fibre-reinforced cement based composites for thin repairs', J. Of Materials in Civil Engineering, ASCE Vol .6, 1994, pp88-99

[25]. Soroushian, P. 'Secondary reinforcement-adding cellulose fibres', Concrete International, vol .19, No.6, Jun 1997, pp28-34.

[26]. Ohama,Y.and Shirai, A . , 'Durability of polymer-Ferro cement, International symposium on Ferro cement', Havana, Cuba, 1991, pp27-34.

[27]. Rols, S., Ambroise, J. and J. Pera, 'Behavior of polymer modified cement matrix reinforced by polypropylene fibres', The 8th International Congress on Polymer In Concrete, ICPIC, Belgium, 1995, pp403-408.

[28] Raz l , I., 'Novel materials for concrete restoration', in N. Banthia (ed), First Canadian university-industry workshop on fibre reinforced concrete, Quebec, Canada, 199l , pp18-128.

[29] Banthia, N. And Yan C, 'High-performance micro-fibre-reinforced concrete for thin repairs', ACI SP-185-05, Feb 2000, pp69-80. 160

[30] IS: 8112-1989: Specification for 43 Grade Ordinary Portland cement.

[31] IS: 383-1970: Specification for coarse and fine aggregates from natural sources for concrete.
[32] IS: 2386 (Part I, IV, and VI)-1988”. Indian standard Method of test for aggregate for concrete, Bureau of Indian Standards, Reaffirmed, New Delhi, 2000
[33] IS: 10262-198”. Recommended guidelines for concrete mix design, Bureau of Indian Standa rds, reaffirmed, New Delhi 1999 and IS: 456:2000 Indian standard recommended guidelines for concrete mix design
[34] IS: 516-1959”. Method of test for strength of concrete, Bureau of Indian Standards, New Delhi, 1959.