# MECHANICAL PROPERTIES OF FLUOROPOLYMER MODIFIED MORTAR

*A dissertation submitted*
*in partial fulfillment of the requirements for*
*for the award of degree of*

**MASTERS OF ENGINEERING**
IN
**CIVIL (STRUCTURES) ENGINEERING**

*Submitted by*

**DIPANKER**
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**JULY 2014**

# CERTIFICATE

Certified that the dissertation **"Mechanical Properties of Fluoropolymer Modified Mortar"** which is submitted by me (**Dipanker, Regn. No. 821122012**), in partial fulfillment of the requirement for the award of the degree of **Master of Engineering** in **Civil (Structures) Engineering** in the **Department of Civil Engineering (CED), Thapar University, Patiala**, is a record of the my own independent and original research work carried out under supervision and guidance of **Dr. Prem Pal Bansal, Assistant Professor**. The matter embodied in this thesis has not been submitted in part or full to any other University or Institute for the award of any degree.

**Date:** 15-07-2014 **Dipanker**

It is certified that the above statement made by the student concerned is correct to best of my knowledge and belief.

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And above all, I pay my regards to the **Almighty** for his love and blessings.

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# ABSTRACT

In past lot of experimental studies were carried out on polymer modified cement (PMC) mortar and concrete modified using polymers such as SBR, acrylic, VAE and integral waterproofing agents. The advantages of PMC mortars such as good bond strength, decrease in water cement ratio, higher strength, lower permeability etc. makes it suitable for use as repairing and water proofing material. Fluoropolymers are fluorocarbon based product which is used as water repellent in fabric industry. These are widely used for water and oil repellence and offer good resistance to degradation when exposed to UV light, accelerated weathering, elevated temperatures and fluids.

In the present study the effect of addition of different percentages of fluoropolymers on the properties of mortar such as workability, compressive strength, flexural strength and permeability under different curing conditions i.e. dry and wet curing has been studied. Commercially available fluoropolymer based product Asahi-Guard E-series (AG-E400) was added in different quantities viz. 5, 10, 15 and 20 percent by weight of cement in cement mortar. On addition on fluoropolymers in the mortar it has been observed that the workability of the mortar increase with increase in percentage of fluoropolymers in the mortar and on addition of 20 percent the workability increases to a limit that the flow of mortar increases beyond the limits of flow table. Other properties of the fluoropolymer modified mortar were studied keeping workability of the mortar constant by adjusting the water content in the mortar. From the results it has been observed that compressive strength and flexural strength of the fluoropolymer modified mortar, for both dry and wet curing conditions, decreases with addition of fluoropolymers upto 10 percent thereafter an increasing trend was observed. However, with the addition of the fluoropolymers the permeability of the mortar decreases and this decrease is much more under wet curing conditions as compared to dry curing conditions. From the experimental programme carried out it can be concluded that fluoropolymer modified mortar can be used as good waterproofing material without much loss in mechanical properties by selecting suitable quantity of fluoropolymer in mortar.

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# CHAPTER - 1

# INTRODUCTION

## 1.1 GENERAL

Concrete has been called artificial stone, cast stone, reconstructed stone and reconstituted stone. However, concrete must be thought of as a distinct material to stone. It has its own characteristics in terms of durability, weathering and repair. Modifications have been made from time to time to overcome the deficiencies of cement concrete yet retaining the other desirable characteristics In spite of its adaptability and usefulness, cement concrete suffers from several drawbacks, such as low tensile strength, permeability to liquids and consequent corrosion of reinforcement, susceptibility to chemical attack and low durability. As much of the constituents of concrete come from stone, it is often thought that concrete has the same qualities and will last forever.

Recent developments in the material and construction technology have led to significant changes resulting in improved performance, wider and more economical use. Also continuous research by concrete technologies to understand, improve and develop the properties of concrete has resulted in a new type of concrete known as, "Polymer Concrete".

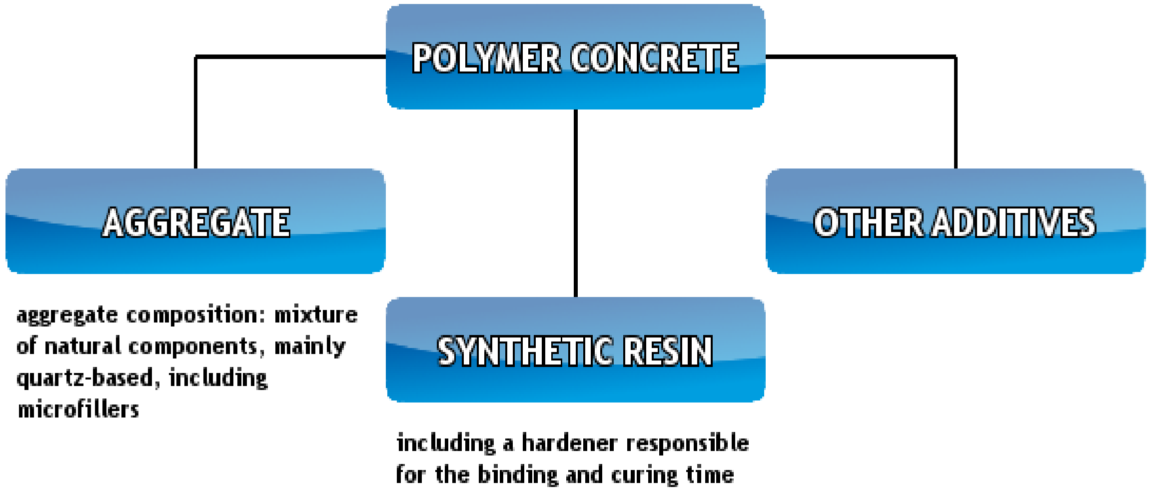

Fig. 1.1 Main Components of Polymer Concrete

Polymer concrete, known also as resin concrete, is a constructional composite, a variation of concrete, in which traditional binder - cement, has been completely replaced with synthetic resins with a hardening agent and filler: mixture of sand-and-gravel and quartz powder. Binder of polymer concrete is crucial for improved strength in relation to ordinary concrete, and particularly for chemical resistance. The weakest part of standard concrete - the hydraulic mineral binder was eliminated from polymer concrete.

It is referred time and again that the concrete is porous. The porosity is due to air-voids, water voids or due to the inherent porosity of gel structure itself. On account of the porosity the strength of concrete is naturally reduced. It is conceived by many research workers that reduction of porosity results in increase of strength of concrete. Therefore process like vibration, pressure application spinning etc., have been practiced mainly to reduce porosity. All these methods have been found to be helpful to great extent, but none of these methods could really help to reduce the water voids and the inherent porosity of gel, which is estimated to be about 28%. The impregnation of monomer and subsequent polymerization is the latest technique adopted to reduce the inherent porosity of the concrete, to improve the strength and other properties of concrete. Polymer concretes represents a new generation of efficient and chemically resistant materials where mineral fillers and aggregates account for 90 to 95% by weight. The quantity of the polymer binder is about 6 to 11% of the total weight of the polymer concrete. Polymer concretes have high density, strength and are chemically resistant.

Depending upon the type of mineral fillers and aggregates light polymer concretes with a density upto 1750-2050 kg/m$^3$ and very heavy polymer concretes with a density upto 5000 kg/m$^3$ can be produced. Polymer concretes were initially used for decorative and finishing purposes and chemically stable structure members. But the areas of their use have enlarged tremendously and are being used in buildings, electrical industries and other engineering industries etc. Various types of monomers are used these days, but the monomers commonly used are those based on polyesters and expoxide resins, vinyl esters and methyl methacrylate. Polymer concretes are also used in making of body components of reduces, centrifugal pumps, frames of high precision lathes etc. Polymer concreters are 5 to 6 times superior to cast iron and can with stand the action of oils and cooling liquids well and do not require additional painting. (Siddique 2000)

**Terminology used in Polymer Concrete**

i. **Monomer :** Low viscosity low molecular weight organic materials from which polymers are made (‘mer’ in Greek means unit: mono-mer = Single unit).
ii. **Polymers :** They are high molecular weight materials formed by the polymerization of the monomer (Polymer: Many units).
iii. **Catalyst :** Chemical agents added to initiate the polymerization.
iv. **Promoters :** Chemicals used to accelerate the polymerization process.
v. **Polymerization:** Chemical process by which a monomer is converted into a polymer.
    a) Thermal: Catalytic Polymerization: Heat is used to bring about conversion of monomer into polymer.
    b) Radiation: Gamma radiations from radioactive sources are utilized for polymerization
vi. **Latex :** A milk like emulsion of polymer in water phase

Polymer-modified concrete (mortar) comprise of repair systems for deteriorated reinforced concrete structures, strengthening (or retrofitting) methods and exfoliation (or delimitation) prevention methods for existing reinforced concrete structures, liquid-applied membrane waterproofing systems, advanced polymeric admixtures such as high-grade re-dispersible polymer powders and hardener-free epoxy resins, intelligent repair materials, application of accelerated curing, semi flexible pavements, and drainage pavements with photo catalyst. Polymer mortar and concrete are related to new liquid resins, setting shrinkage control, thermal properties and temperature dependence, lightweight or porous polymer mortars and concretes, artificial marble products and precast products. The polymer-impregnated mortar and concrete are mainly concerned with field polymer impregnation techniques using silane-based barrier penetrates. Some fiber composite materials may be preferred over traditional construction materials as environmental sustainability becomes more important in the long-term.

The following are the some examples of polymer materials used in construction applications:-

| **Polymer Type** | **Applications** |
|---|---|
| Epoxy resins | Solid resin and Terrazzo flooring, Anchor fixings, Adhesives |
| Ethyl vinyl acetate (EVA) | Solar panel encapsulates |
| Expanded polystyrene (EPS) | Concrete moulds, Insulation, Packaging |
| Polycarbonate | Lighting housings, Fittings in hot water systems, Glazing |
| Polyester (thermosetting) | FRP Bridge sections, Cladding Panels, Sinks, Surfaces, Coatings |
| Polyethylene | Foam underlay, Damp-proof membranes, Coatings |
| Polyisobutylene (PIB) | Glazing sealants, Waterproof membranes |
| Polymethylmethacrylate / Acrylic (PMMA) | Surfaces, Sinks |
| Polypropylene (PP) | Sound insulation, Water pipes, Waste pipes |
| Polyurethane (PU) | Sealants, Concrete jointing |
| Polyvinylchloride (PVC) | Sealants, Concrete jointing |
| Rubber | Bridge bearings, Flooring |

## 1.2 CLASSIFICATION OF POLYMER CONCRETE

Concrete based on polymers are divided into five categories.

i. Polymer impregnated concrete
ii. Polymer cement concrete
iii. Polymer concrete
iv. Polymer sulphur concrete
v. Polymer modified concrete

Polymer concretes are based on synthetic resins or monomers and fillers and aggregates without using mineral binders and water. The composition of polymer concretes consists of three fractions of fillers and aggregates: finely dispersed fillers with a particle size of less than 0.16 mm: aggregates sand with a grain size upto 5 mm and coarse aggregate upto 40-50 mm is size. The main objective of polymer concrete depends upon the chemical nature of the synthetic resin, content and type of finely dispersed filler fraction. Coarse fractions of aggregate influence the physical and mechanical properties to some extent.

Polymer cement concretes are cement concretes during the making of which organosilicon or water soluble polymers, aqueous emulsions of the type of polyvinyl acetate are added to the mix at 3-4 to 19-21%. Whereas polymer sulphur concretes are based on a sulphur binder during the production of modifying additives such as dicyclopentadiene or chloroparaffin are mixed to the molten sulphur at 1.5 to 2.5 to 13 to 16%.

Concrete polymers are cement concretes which are subjected to drying and impregnated with various monomers in the porous structure of the concrete followed by thermo catalytic or radiation polymerization. The workability of polymer concrete depends upon the type and quantity of the synthetic resin used, dispensability of filler, and the ratio between the fractions of the fillers and the aggregates. The properties of polymer concretes are determined by the type of polymer binder and its compatibility and high adhesive bond with concretes based on inorganic binders. The classification of polymer concrete mixes on the basis of workability.

These are determined by the type of binder and the type of hardening system. Classification of polymer concretes based on type of binders and hardeners.

### 1.2.1 Polymer Impregnated Concrete

It is precast conventional concrete cured and dried in oven or by dielectric heating from which the air in the open cell is removed by vacuum. Then monomer (such as methyl methacrylate (MMA) and styrene are commonly used for penetration because of relatively low viscosity, high boiling point (less loss due to volatilization), and low cost) is diffused through the open cell and polymerized by using radiation application of heat or by chemical initiation.

In the case of Polymer Impregnated Concrete, by effectively sealing the micro cracks and capillary pores, it is possible to produce a virtually impermeable product which gives an ultimate strength of the same order as that of Polymer Concrete. Polymer Impregnated Concrete has been used for the production of high strength precast products and for improving the durability of bridge deck surfaces.

This can be accomplished in one of three ways.

i. A combination of promoter chemical and catalysts can be used for room-temperature polymerization; but it is not favored because the process is slow and less controllable.
ii. Gamma radiation can also induce polymerization at room temperature, but the health hazard associated with it discourages the wide acceptance of this process in filed practice.
iii. The third method, which is generally employed, consists of using a monomer-catalyst mixture for penetration, and subsequently polymerizing the monomer by heating the concrete to 70° C with steam, hot water or infrared heaters.

### 1.2.2 Polymer Cement Concrete

Polymer cement concrete is made by mixing cement, aggregate, water and monomer. Such plastic mixture is cast in moulds, cured, dried polymerized. The monomer that are used in PCC are:-

1. Polymer-styrene
2. Epoxy-styrene
3. Furans
4. Vinyldene chloride

PCC produced in this way have been disappointing. In many cases material poorer than ordinary concrete is obtained. This is because organic materials are incompatible with aqueous systems and sometimes interfere with the alkaline cement hydration process. Russians developed a superior polymer by incorporation of furfuryl alcohol and aniline hydrochloride in the wet mix. This material is dense and non-shrinking and to have high corrosion resistance, low permeability and high resistance to vibration and axial extension. PCC can be cast in situ for field application.

### 1.2.3 Polymer Concrete

Polymer concrete is an aggregate bound with a polymer binder instead of Portland cement as in conventional concrete. The main technique in producing PC is to minimize void volume in the aggregate mass so as to reduce the quantity of polymer needed for binding the aggregate. This is achieved by property grading and mixing the aggregate to attain maximum density and minimum voids. Polymer concrete (PC) is a composite material in which the binder consists entirely of a synthetic organic polymer. It is variously known as synthetic resin concrete, plastic resin concrete or simply resin concrete. Because the use of a polymer instead of Portland cement represents a substantial increase in cost, polymers should be used only in applications in which the higher cost can be justified by superior properties, low labor cost or low energy requirements during processing and handling.

### 1.2.4 Polymer Sulphur Concrete

The impregnation of hardened, dry specimens of Portland cement concrete with melted elemental sulphur increases the compressive strength by a factor of 2.7. The compressive strength of sulphur-impregnated concrete (SIC) with 8.4 per cent sulphur by weight is 174 $MN/m^2$ (25,300 psi). Due to the large surplus of sulphur and the low price, SIC might be a useful alternative to polymer-impregnated concrete, PIC. The degradation of reinforced concrete may be caused by the corrosion of the reinforcing steel or the concrete or by the simultaneous corrosion of the reinforcing steel and the concrete. The considerable porosity of concrete and cracks in or damage to the concrete cover contribute to the diffusion, absorption and adsorption of gases and to the diffusion of the substances dissolved in the pore liquid deep into the concrete. All kinds of aggressive substances from the surrounding environment diffuse into the concrete and directly or indirectly cause the corrosion of the reinforcing steel which usually ends in the loss of adhesion of the concrete to the steel, manifesting itself in the fracturing, loosening and spalling of the concrete cover.

### 1.2.5 Polymer Modified Concrete

Although its physical properties and relatively low cost make it the more widely used construction material, conventional Portland cement concrete has number of limitations, such as low flexural strength, low failure strain, susceptibility to frost damage and low resistance to chemicals. These drawbacks are well recognized by the engineer and can usually be allowed for in most applications. In certain situations, these problems can be solved by using materials which contain an organic polymer or resin (commercial polymer) instead of or in conjunction with Portland cement. These relatively new materials offer the advantages of higher strength, improved durability, good resistance to corrosion and reduced water permeability.

## 1.3 ADVANTAGES OF POLYMER CONCRETE

Advantages of polymer concrete include:-

- Virtually indestructible material.
- Very high pressure and torsional rigidity.
- Rapid curing at ambient temperatures.
- High tensile, flexural, and compressive strengths.
- God adhesion to most surfaces almost impossible to vandalize.
- Good long-term durability with respect to freeze and thaw cycles.
- Low permeability to water and aggressive solutions.
- Good chemical resistance.
- Good resistance against corrosion.
- Absolutely weather-proof , resistant to ultra-violet light and frost.
- Quiet safe, long-lasting, lightweight and best possible smooth-running surface.

## 1.4 DISADVANTAGES OF POLYMER CONCRETE

- Polymer concretes cost significantly more than conventional concrete.
- Some safety issues arise out of the use of polymer concrete. The monomers can be volatile, combustible, and toxic. Initiators, which are used as catalysts, are combustible and harmful to human skin.

## 1.5 FLUOROPOLYMER EMULSION

Fluoropolymers are the polymer materials containing fluorine atoms in their chemical structures. From general organic polymer concepts, there are two types of fluoropolymer materials, i.e. perfluoropolymers and partially fluorinated polymers. In the former case, all the hydrogen atoms in the analogous hydrocarbon polymer structures were replaced by fluorine atoms. In the latter case, there are both hydrogen and fluorine atoms in the polymer structures. Fluoropolymers possess excellent properties such as outstanding chemical resistance, weather stability, low surface energy, low coefficient of friction, and low dielectric constant. These properties come from the special electronic structure of the fluorine atom, the stable carbon-fluorine covalent bonding, and the unique intramolecular and intermolecular interactions between the fluorinated polymer segments and the main chains. Due to their special chemical and physical properties, the fluoropolymers are widely applied in the chemical, electrical/electronic, construction, architectural, and automotive industries.(Teng 2012)

Fluoropolymers are currently being used in textiles industry as fabric protectors and also to impart water repellence properties for textiles. The fluoropolymer used, perfluroalkylacrylate copolymer, has a chemical structure similar to an acrylic resin. Its action on cement particles is similar to acrylics in that it reacts with cement hydration products, resulting in the formation of bonds between the cement particles and the waterproofing material. The strength parameters, bond strength between the base concrete and the modified cement mortar, water permeability and capillary absorption were determined before and after exposure to UV light and accelerated weathering conditions.(Krishnan et al. 2013)

(Honda et al. 2005) systematically investigated the effects of side chain length on the molecular aggregation states and surface properties of poly(fluoroalkyl acrylate) [PFA-C$y$, where $y$ is the fluoromethylene number of the Rf groups] thin films. They have been revealed that PFA-C$y$ with $y \geq 8$ showed high dynamic water repellency. The Chemical Structure of perfluoroalkyl acrylate copolymer was shown in fig. 1.2.

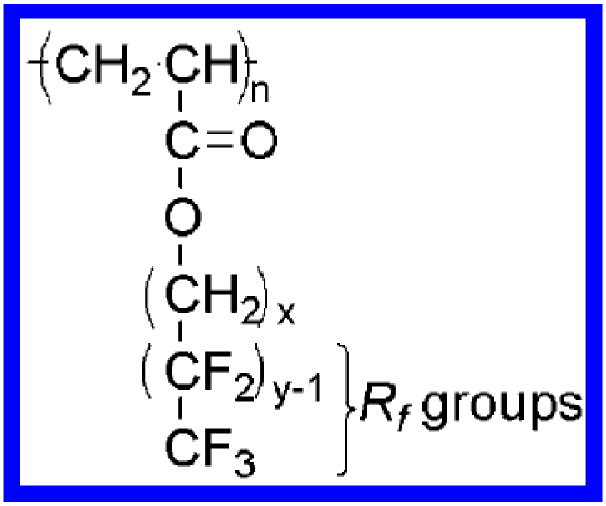

**Fig. 1.2: Chemical Structure of Poly (perfluoroalkyl acrylate)s [PFA-Cy, Where y is the Fluoromethylene Number of the Rf Groups] (x = 1 for y = 1 and 2, x = 2 for y = 4, 6, 8, and 10) (Honda et al. 2005)**

## 1.6 OBJECTIVE OF RESEARCH

As various experimental studies were carried out on polymer modified mortar and concrete by using different types polymers such as SBR, acrylic, VAE and integral waterproofing agents because the advantages of these polymers such as good bond strength, decrease in water cement ratio, higher strength, lower permeability etc. There is another fluorocarbon based fluoropolymer which is used as water and oil repellent in fabric industry. These fluoropolymers can also be used as mortar modified polymer because these are highly water repellant and their resistance against deterioration when they are exposed to weathering conditions, high temperature and fluids.

After studying about the properties of fluoropolymer, its scope in use as modifier for cement mortar world can be well judged. In the present study the effect of addition of different percentages of fluoropolymers [with commercially available fluoropolymer based product Asahi-Guard E-series (AG-E400)] on the properties of mortar has been studied. The objectives of the work are as under:-

1) To study the effect of addition of fluoropolymer by 5%, 10%, 15% and 20% by weight of cement on workability of mortar.

2) To study the effect of addition of fluoropolymer by 5%, 10%, 15% and 20% by weight of cement on compressive strength and flexural strength of mortar at the age of 7 days & 28 days under:-
    i. Dry curing conditions
    ii. Wet curing conditions
3) To study the effect of addition of fluoropolymer by 5%, 10%, 15% and 20% by weight of cement on permeability of mortar at the age of 28 days under:-
    iii. Dry curing conditions
    iv. Wet curing conditions

# CHAPTER – 2
# REVIEW OF LITERATURE

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## 2.1 GENERAL

The concept of polymer modification for cement mortar and concrete is not new, since considerable research and development of polymer modification have been performed for the past 70 years or more. As a result, various polymer-based admixtures have been developed, and polymer modified mortar and concrete using them are currently popular construction materials because of their good cost-performance balance (Ohama, 1998).

Polymer modified mortar and concrete has been used primarily for repair and overlays. Several limitations have slowed the use of mortar and concrete polymer materials. However, there are many current and future uses for these materials that will effectively use their unique properties. Improved automated repair methods, improvements in materials, replacements for metals, structural applications and architectural components will prove to be popular uses of mortar and concrete polymer materials. Simultaneously these materials have been used in machine construction also where the vibration damping property of polymer mortar and concrete has been exploited. Among them, the polymer concrete is well known for its versatile and beneficial structural applications compared to the other types.

The concrete-polymer composites, typically, can be classified into three types in terms of principles of the process technology, i.e. polymer cement concrete, polymer concrete, and polymer impregnated concrete. Polymer-impregnated concrete was the first concrete polymer composite to receive widespread publicity. Polymer-impregnated concrete has excellent strength and durability properties, but it has few commercial applications.

Various researches have worked on different aspects of polymer mortar and concrete starting from its proper preparation with different materials to studying its properties. A brief review of the work carried out in the subject area is presented in subsequent sections.

## 2.2 MECHANICAL PROPERTIES

### 2.2.1 Compressive Strength

**Krishnan et al. (2013)** carried out the investigation of the performance of a fluoropolymer modified cement mortar was compared with the performance with the unmodified cement mortar because there was rare studies had been done upto now by using fluoropolymer as mortar modified polymer. The tests were carried out by them in comparison with different type of polymers with ratio of cement mortar was maintained as 1:3, mortars were made with the same workability (constant flow) and the w/c values for each mortar are given in Table 2.1.

**Table 2.1: WPM Dosage and w/c for Different Mortars having same Flow [Krishnan et al (2013)]**

| Mortar designation | Description | WPM dosage for 50 kg of cement | w/c for flow table spread of 20 cm |
|---|---|---|---|
| UMM-OPC | Unmodified cement mortar | None | 0.50 |
| N-SBR | SBR based cement mortars | 9 litres | 0.37 |
| N-AR | Acrylic based cement mortars | 10 litres | 0.37 |
| F-IWP | IWP based cement mortars | 200 ml | 0.48 |
| F-ASAH | Fluoropolymer based cement mortars | 5 kg | 0.39 |

In all cases, they had casted 50 x 50 x 50 mm cubical specimens for compressive strength testing. They put the specimens for 30 days weathering (after 8 days of moist curing) & control conditions (no weathering for 28 days); then the specimen had been tested and evaluated the compressive strength of various cement mortars.

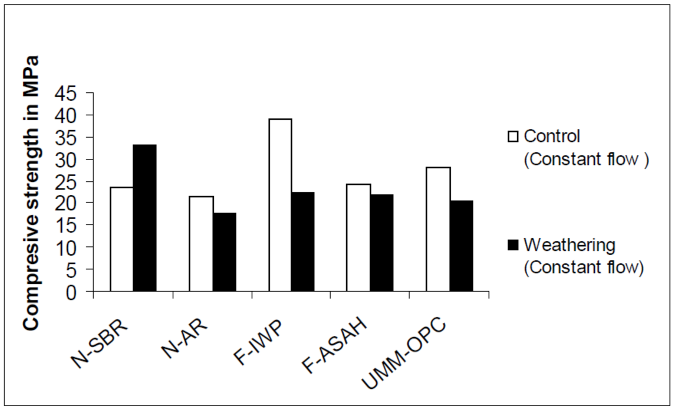

**Fig. 2.1: Compressive Strength of Mortars before and after Weathering [Krishnan et al (2013)]**

They found that weathering decreases the strength substantially in the case of the OPC and the F-IWP mortars as shown in fig. 2.1. Interestingly, the strength increases for the mortar with the SBR latex when subjected to accelerated weathering conditions. They observed that the decrease in compressive strength due to weathering of the unmodified mortar (26%) and the F-IWP (43%) mortar was higher than in the case of the other polymer modified mortars. The higher values of compressive strength of the latex based mortar after weathering might probably be due to the bridges and plugs formed by the polymer in the cement microstructure. In the case of the fluoropolymer based F-ASAH mortar, the decrease in strength (about 10%) after accelerated weathering was slightly less than that of the reference mortar.

**Golestaneh et al. (2010)** used Silica powder as filler in preparation of polymer concrete. Utilization of waste silica powder as a filler in polymer concrete was promising, it may enhances the physical properties and mechanical strength of the polymer concrete. The mechanical properties of polymer concrete with variation of filler compositions (100, 150 and 200%) and resin (10, 15 and 20%) were investigated. The compressive strength of polymer concrete with silica powder as filler in comparison with cement concrete was enhanced by four folds. They had also investigated the compressive strength of the casted polymer concrete. They found that the samples with 15% and 20% epoxy resin and 200% filler (15% fine silica powder, 25% medium size silica powder and 60% coarse silica powder) had maximum compressive strength of 128.9 MPa.

**Barbutta and Hajra (2008)** presented the results of some experimental researches concerning polymer mortars and concretes realized of epoxy resin, silica fuma and crushed aggregates. The compressive strength of hardened concrete was determined. The silica fuma content varied between 6.5% and 30% to polymer mortar and 6.4% and 9.6% to polymer concrete. The obtained results show maximum characteristics for a dosage of 24% resin and maximum dosage of silica fuma to the polymer mortar and for the polymer concrete the compressive strength was influenced by all mixture factors: the compressive strength increases with the increase of silica fuma dosage.

**Aggarwal et al. (2007)** investigated the properties of epoxy-modified mortar in comparison with those of unmodified cement mortar and acrylic-modified mortar because there was very little information available on the use of epoxy emulsion in making polymer modified mortar (PMM).

For experiments, they had used similar dosages of both epoxy emulsion (density of 1.00–1.05 g/cm3 & total solids of 60 ± 2%) and acrylic emulsion (density of 1.05–1.10 g/cm3 & total solids 38 ± 2%). Properties of the ordinary portland cement (grade 43) and sieve analysis of the quartz sand No. 10 used in the study by them were reported in tables 2.2 and 2.3 respectively.

**Table 2.2: Properties of Cement used [Aggarwal et al (2007)]**

| Sr. No. | Property | | Value |
|---|---|---|---|
| 1 | Density (g/cm$^3$) | | 3.08 |
| 2 | Specific surface area (cm$^2$/g) | | 2540 |
| 3 | Chemical analysis (%) | | |
| | i | Silica, $SiO_2$ | 21.40 |
| | ii | Lime, CaO | 62.25 |
| | iii | Alumina, $Al_2O_3$ | 8.95 |
| | iv | Iron Oxide, $Fe_2O_3$ | 2.80 |
| | v | Magnesia, MgO | 1.46 |
| | vi | Loss on ignition | 1.52 |

**Table 2.3: Sieve Analysis of Quartz Sand [Aggarwal et al (2007)]**

| Sr. No. | IS-Sieve Size | Mass Retained (%) | Cumulative Mass Retained (%) |
|---|---|---|---|
| 1 | 4.75 mm | - | - |
| 2 | 2.36 mm | - | - |
| 3 | 1.18 mm | - | - |
| 4 | 600 µm | 40 | 40 |
| 5 | 300 µm | 30 | 70 |
| 6 | 150 µm | 30 | 100 |

They had prepared the specimens of 40 x 40 x 40 mm size with varying polymer–cement ratio from 0% to 30% by mass of cement to study the effect of polymer–cement ratio on various properties. A cement–sand ratio of 1:3 and water–cement ratio (w/c) with constant flow between 110 and 120 mm was adjusted by them. The specimens were allowed to cure in the mould for one day and next 27 days dry curing while one set of control specimens, i.e., specimens without polymer were water cured and another was air cured by them.

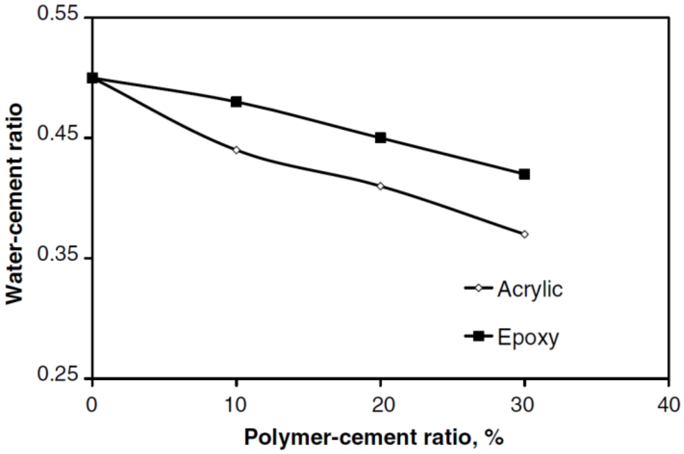

**Fig. 2.2. Effect of Polymer addition on w/c Ratio required to maintain Flow [Aggarwal Et Al (2007)]**

They had shown the effect of polymer addition on water–cement ratio required to maintain the desired flow (110–120 mm) in fig. 2.2 and found that the addition of polymer to cement mortar improves workability.

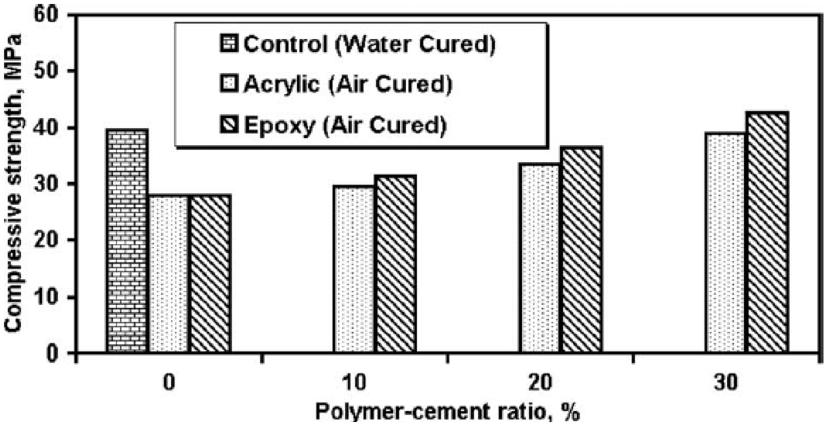

**Fig. 2.3: Comparison of 28 days Compressive Strength of Control Specimens and PMM with different Polymer–Cement Ratios [Aggarwal Et Al (2007)]**

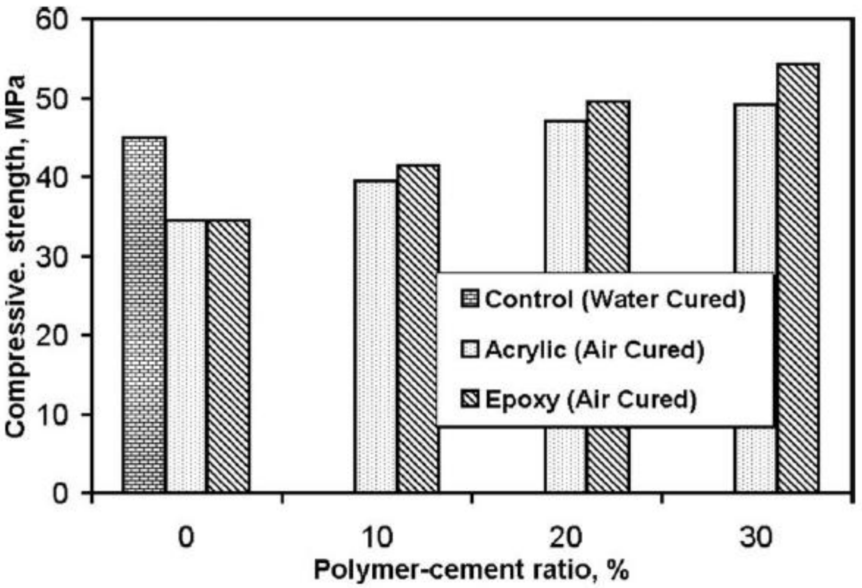

**Fig. 2.4: Comparison of 90 days Compressive Strength of Control Specimens and PMM with different Polymer–Cement Ratios [Aggarwal Et Al (2007)]**

They presented the results of polymer addition on compressive strength of the mortar at 28 and 90 days in figs. 2.3 and 2.4 respectively. They found that at both 28 and 90 days compressive strengths of the mortar increase with polymer–cement ratio. However, the compressive strength of PMM was less than that of water cured control specimens when the polymer–cement ratio was less than 20%. They also found that at the same polymer–cement ratio the epoxy emulsion modified mortars have better compressive strength than acrylic modified mortars as shown in figs. 2.3 and 2.4.

**Barluenga and Olivares (2004)** conducted experimental study on SBR latex modified mortar. Percentages of Latex were used as 0%, 5%, 10%, 15%, 20% and 25% with respect to weight of cement. Cement sand ratio 1:3 used and Flow value of 180, 200 and 220 mm±10mm fixed. They presented the result of WC ratio in fig. 2.5 and the result showed that with increasing percentage of latex, WC ratio was going down, that was due to fact that latex improved consistency of cement mortar by providing ball bearing action of polymer particles.

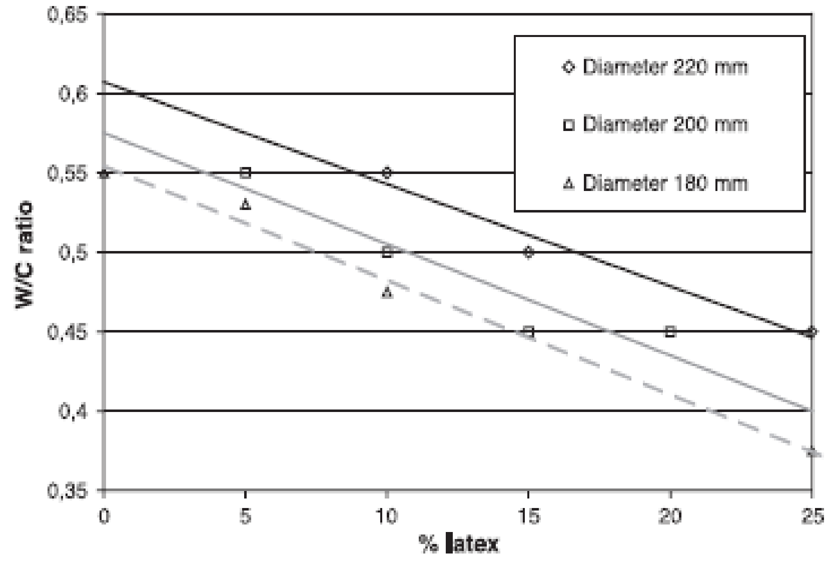

**Fig.2.5: w/c Ratio of LMM with varying percentage of Latex for varying Flow Value [Barluenga and Olivares (2004)]**

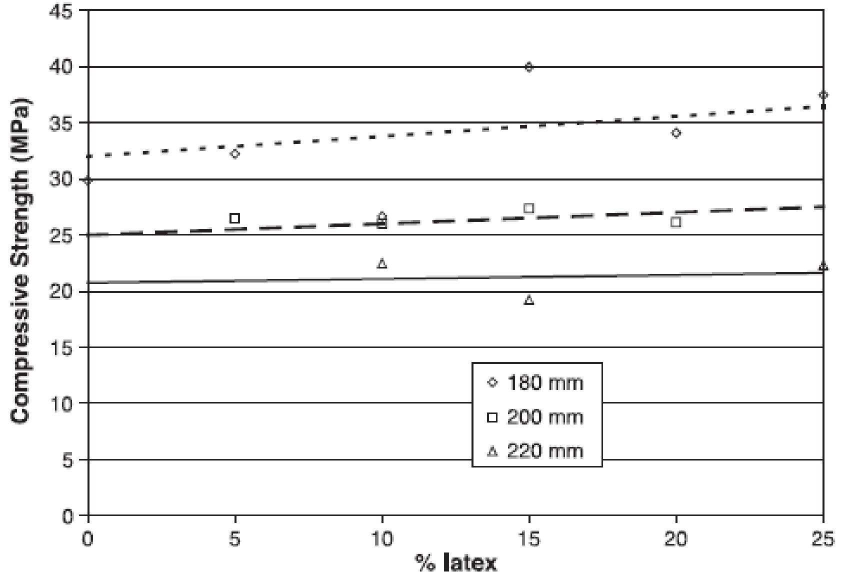

**Fig.2.6: Compressive Strength of LMM with varying percentage of Latex for varying Flow Value [Barluenga and Olivares (2004)]**

They presented the compressive test results of LMM with fixed flow value at 28 days in the fig. 2.6 and found that the compressive strength was nearly constant as shown in fig. 2.6 for any percentage of latex; though decrease for large flow value. They concluded that in the hardened state LMM stiffness decreased with increase of latex, as Latex stiffness is lower than mortar stiffness. The inclusion of SBR latex in cement mortar produces a decrease of compressive strength, due to the lower mechanical capacity of latex with regard to cement mortar, for a fixed consistency. This decrease is compensated by the reduction of WC due to the plasticizer effect of latex. Both phenomena together maintain compressive strength nearly constant for any percentage of latex.

**Gorninski et al. (2004)** have assessed and compared polymer concrete with Portland cement concrete. The modulus of elasticity of polymer concrete compounds has been measured. There was an increase in axial compressive strength as concentrations of fly ash increased. Furthermore, high modulus of elasticity values was obtained and the peak value was 29 GPa.

**Kim et al. (1999)** reported the structure and properties of mortars and concretes containing up to 2 wt% (based on cement) of poly (vinly alcohol) (PVA) were examined and compared with those without PVA. Among changes occurring with the addition of PVA were increases in air void content and apparent fluidity and a reduction in the bleeding of fresh mortar and concrete. The increase fluidity caused increased slump for fresh concrete. The microstructure was examined by polarizing optical microscopy and scanning electron microscopy in backscattered mode of cut surfaces after hardening. The porous interfacial transition zones around sand grains and coarse aggregate were significantly reduced, and the cement particles were uniformly distributed without significant depletion near aggregate surfaces. For mortars, using a pre-wetting mixing technique the compressive strength was deceased moderately. For concretes, with the same mixing technique the compressive strengths after 28 days of hydration were relatively unchanged but the post peak area of the compression stress strain curve was reduced accompanying a change in fracture behavior from de-bonding to cohesive failure of the coarse aggregate. When concrete having the same air void content with PVA as without was made, the compressive strength was moderately increased.

**Schulze (1999)** studied that the influence of the water-cement ratio and cement content on the compressive strength. He was carried out the tests with modified and unmodified cement mortars. The details of the mixes were described in the table 2.4

**Table 2.4: Percentage of material used for Tests [Schulze (1999)]**

| Component | Percentages | | | |
|---|---|---|---|---|
| Cement | 20 | 23 | 26 | 29 |
| Sand mixture | 72.7 | 69.4 | 66.1 | 62.9 |
| Vinnapas LL512 | 2 | 2.3 | 2.6 | 2.9 |
| Fly ash | 4 | 4 | 4 | 4 |
| Defoamer | 0.2 | 0.2 | 0.2 | 0.2 |
| Microsilica | 1 | 1 | 1 | 1 |
| Wetting agent | 0.1 | 0.1 | 0.1 | 0.1 |
| Shrinkage reducing agent | 0.1 | 0.115 | o.13 | 0.145 |

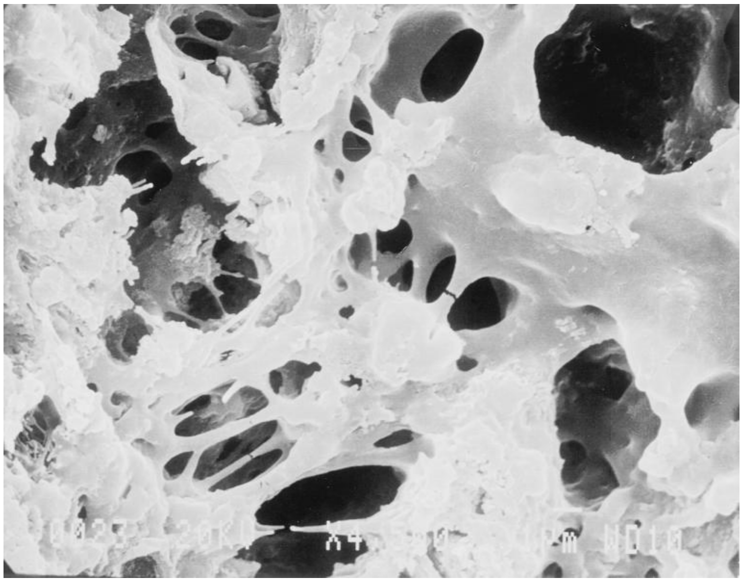

**Fig. 2.7: SEM photograph of Mix with Vinnapas LL 512 after 90 days in Normal Climate. (Magnification 45003) [Schulze (1999)]**

In the experiments he varied the cement content between 20–29% of the mix. The data concerning workability (air content and slump characteristics) were given in table 2.5. He had shown the photograph (fig. 2.7) of mix with Vinnapas LL 512 after 90 days in normal climate in his experimental programme.

**Table 2.5: Workability Calculated for Tests [Schulze (1999)]**

| | Water-cement ratio | Air content (%) | Slump characteristics (cm) without/with strokes |
|---|---|---|---|
| Cement 20% | 0.49 | 7.5 | 10/14.5 |
| | 0.53 | 5.8 | 10/15.5 |
| | 0.57 | 5.0 | 10/17 |
| | 0.61 | 4.1 | 11/18.5 |
| Cement 23% | 0.42 | 6.0 | 10/14 |
| | 0.46 | 5.8 | 10/15 |
| | 0.50 | 5.6 | 10/17 |
| | 0.53 | 5.0 | 10.5/18 |
| Cement 26% | 0.38 | 7.0 | 10/13 |
| | 0.41 | 6.5 | 10/14 |
| | 0.44 | 5.8 | 10/15 |
| | 0.47 | 5.2 | 10/16.5 |
| Cement 29% | 0.34 | 7.0 | 10/12 |
| | 0.37 | 6.0 | 10/13 |
| | 0.39 | 5.2 | 10/14.5 |
| | 0.42 | 5.5 | 10/16 |
| Without LL 512, cement 20% | 0.49 | 5.0 | 10/12.5 |

He was casted 40 x 40 x 160 mm size specimens for compressive strength testing. The modified mortars were subjected to four different curing conditions by him and tested at various ages for compressive strength.

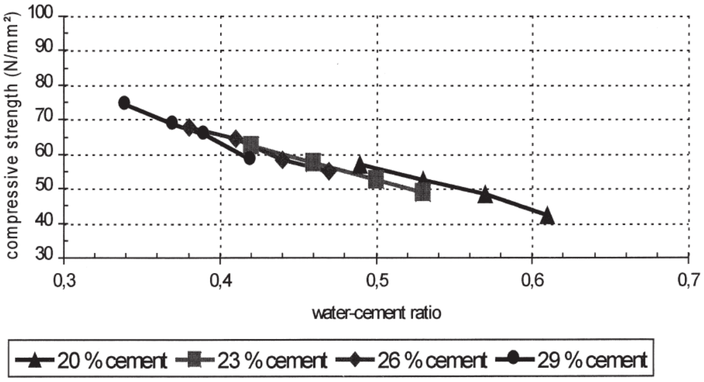

**Fig. 2.8 : Compressive strength (N/mm$^2$) with different Percentage of Cement and varying w/c Ratio at Normal Climate [Schulze (1999)]**

### Table 2.6 : Compressive strength (N/mm$^2$) with different percentage of Cement and varying w/c Ratio [Schulze (1999)]

| | Water-cement ratio | 28 days in normal climate (N/mm$^2$) | 21 days in normal climate, 7 days in water (N/mm$^2$) | 28 days at normal climate* (N/mm$^2$) |
|---|---|---|---|---|
| Cement 20% | 0.49 | 51.4±1.2 | 45.6±1.9 | 59. 0±2.4 |
| | 0.53 | 47.0±2.1 | 40.9±2.3 | 56.6±2.1 |
| | 0.57 | 43.2±0.3 | 37.0±0.9 | 42.3±0.9 |
| | 0.61 | 37.2± 0.6 | 30.1±1.9 | 43.3±0.9 |
| Cement 23% | 0.42 | 55.6±1.7 | 50.1±0.6 | 64.3±4.4 |
| | 0.46 | 51.4±1.7 | 45.3±1.3 | 60.6±1.9 |
| | 0.50 | 47.1±0.7 | 41.1±0.8 | 55.5±1.2 |
| | 0.53 | 44.5±0.5 | 36.6±0.6 | 51.5±1.5 |
| Cement 26% | 0.38 | 61.9±0.9 | 55.9±2.2 | 73.4±2.8 |
| | 0.41 | 57.3±1.4 | 52.2±1.6 | 68.3±0.7 |
| | 0.44 | 53.3±1.2 | 46.6±0.7 | 63.6±1.5 |
| | 0.47 | 48.9±0.4 | 41.8±2.0 | 59.8±1.5 |
| Cement 29% | 0.34 | 66.8±1.3 | 56.7±2.8 | 80.5±1.6 |
| | 0.37 | 61.9±1.7 | 54.9±1.4 | 72.6±1.7 |
| | 0.39 | 58.9±0.7 | 52.2±0.9 | 69.4±1.1 |
| | 0.42 | 52.0±0.4 | 44.2±0.5 | 60.1±2.1 |
| Without LL 512, cement 20% | 0.49 | 55.7±1.2 | 53.9±1.2 | 67.8±4.3 |

* $Ca(OH)_2$, 28 days at normal climate, 28 days in saturated $Ca(OH)_2$ solution at 50°C, 34 days in normal climate. Normal climate = 23 °C, 50% relative humidity.

He found that a decreasing water-cement ratio leads to an increase of the compressive strength of the modified mortars at all storage conditions as shown in fig. 2.8 & table 2.6. Also he compared the mix with re-dispersible powder incorporated and without powder LL 512 at the same water cement ratio of 0.49, in absolute values; he found that the thermoplastic polymer reduces the compressive strength of the mortar. Also he found that compressive strength was decreased with increasing water cement ratio and the cement content was of minor influence.

He explained the reason for that with an increasing water-cement ratio of the mortar at the same polymer level, the concentration of the polymer per volume was decreased. He found that was true in the dry status also, because the higher water content leads to a higher pore volume in the dry mortar. Due to the lower polymer concentration in the hardened mortar, the effect of the polymer was reduced. In wet status (storage underwater) a second effect had to be taken into consideration by him. With decreasing water-cement ratio, the water absorption of the mortars was reduced, meaning that the mortars contain less water. The forces between the polymeric material in the mortar and the mineral material in nature were more or less of acid/base, or of ionic character and were very much influenced by water with high di-electrical power.

### 2.2.2 Flexural Strength

**Krishnan et al. (2013)** carried out the investigation of the performance of a fluoropolymer modified cement mortar was compared with the performance with the unmodified cement mortar because there was rare studies had been done upto now by using fluoropolymer as mortar modified polymer. The test was carried out by them in comparison with different type of polymers with ratio of cement mortar was maintained as 1:3, mortars were made with the same workability (constant flow) and the w/c values for each mortar has already given in table 2.1.

In all cases, they had casted 40 x 40 x 160 mm size specimens for flexural strength testing. They put the specimens for 30 days weathering (after 8 days of moist curing) & control conditions (no weathering for 28 days); then the specimen had been tested and evaluated the flexural strength of various cement mortars.

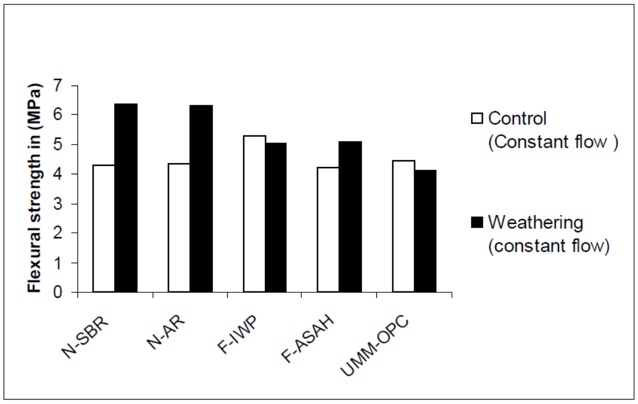

**Fig. 2.9 : Flexural Strength of Mortars before/after Weathering [Krishnan et al (2013)]**

The values they obtained for flexural strength followed a trend similar to that of the compressive strength and they found that the decrease in flexural strength after weathering was about 5% in the IWP mortar and about 8% in the case of the unmodified cement mortar as shown in fig. 2.9. They had also seen that the addition of latex increases the resistance to cracking even after weathering; the strength of the latex based cement mortars after weathering was about 1.5 times that of the control mortar. They confirmed that there was an increase in the resistance to deformation under stress after weathering when a latex emulsion was added to cement mortar. A significant increase was also observed for the F-ASAH samples though not as much as the latexes.

**Golestaneh et al. (2010)** used Silica powder as filler in preparation of polymer concrete. Utilization of waste silica powder as a filler in polymer concrete was promising, it may enhances the physical properties and mechanical strength of the polymer concrete. The mechanical properties of polymer concrete with variation of filler compositions (100, 150 and 200%) and resin (10, 15 and 20%) were investigated. They found that the samples with 15% and 20% epoxy resin and 200% filler (15% fine silica powder, 25% medium size silica powder and 60% coarse silica powder) had maximum flexural strength of 22.5 MPa.

**Barbutta and Hajra (2008)** presented the results of some experimental researches concerning polymer mortars and concretes realized of epoxy resin, silica fuma and crushed aggregates. The flexural strength of hardened concrete was determined. The silica fuma content varied between 6.5% and 30% to polymer mortar and 6.4% and 9.6% to polymer concrete. The obtained results show maximum characteristics for a dosage of 24% resin and maximum dosage of silica fuma to the polymer mortar and for the polymer concrete the flexural strength was influenced by all mixture factors: the flexural strength increases with the increase of silica fuma dosage.

**Aggarwal et al. (2007)** to investigate the flexural properties of epoxy-modified mortar in comparison with those of unmodified cement mortar and acrylic-modified mortar they had used similar dosages of both epoxy emulsion (density of 1.00–1.05 g/cm3 & total solids of 60 ± 2%) and acrylic emulsion (density of 1.05–1.10 g/cm3 & total solids

38±2%). Properties of the ordinary portland cement (grade 43) and sieve analysis of the quartz sand No. 10 used in the study by them have already reported in tables 2.2 and 2.3 respectively.

They had prepared the specimens of 40 x 40 x 160 mm size with varying polymer–cement ratio from 0% to 30% by mass of cement to study the effect of polymer–cement ratio on various properties. A cement–sand ratio of 1:3 and water–cement ratio (w/c) with constant flow between 110 and 120 mm was adjusted by them. The specimens were allowed to cure in the mould for one day and next 27 days dry curing while one set of control specimens, i.e., specimens without polymer were water cured and another was air cured by them. The effect of polymer addition on water–cement ratio required to maintain the desired flow (110–120 mm) has already reported in fig.2.2 and they were found that the addition of polymer to cement mortar improves workability.

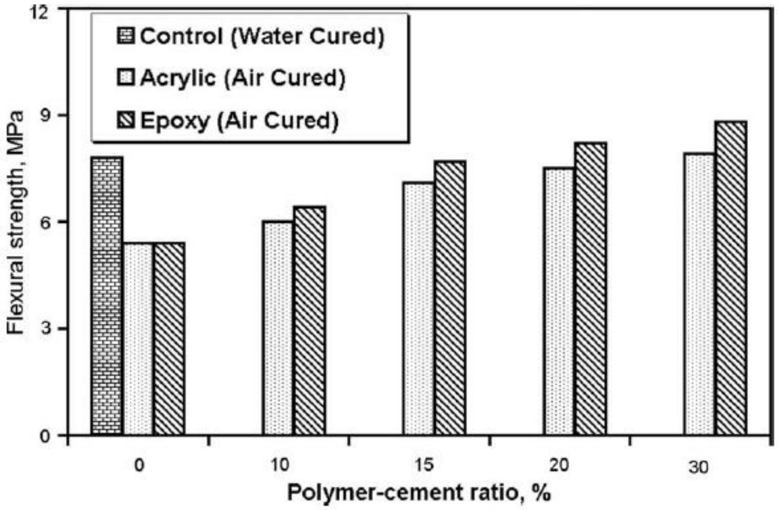

**Fig. 2.10: Comparison of 28 days Flexural Strength of Control Specimens and PMM with different Polymer–Cement Ratios [Aggarwal et al (2007)]**

They had shown the effect of polymer–cement ratio on 28 days flexural strength of different compositions as shown in fig. 2.10. They were found that the flexural strength of air cured PMM specimens was less than water cured unmodified mortar samples when polymer–cement ratio was less than 20%. However, for both polymer systems the flexural strength was better than that of the water cured control specimens at 30% polymer–cement ratio. The flexural strength of epoxy modified mortar samples with 30%

Polymer–cement ratio was about 10% higher as compared to wet cured samples. They had also studied that in case of air cured samples; the increase in strength of acrylic modified mortars was up to 40% as compared to unmodified mortar samples while it was about 60% for epoxy modified mortar samples. That showed that epoxy modified mortars should behave better than acrylic modified mortars under flexural loading.

**Barluenga and Olivares (2004)** conducted experimental study on SBR latex modified mortar. Percentages of Latex were used as 0%, 5%, 10%, 15%, 20% and 25% with respect to weight of cement. Cement sand ratio 1:3 used and Flow value of 180, 200 and 220 mm±10mm fixed. The result of WC ratio was already shown in fig. 3.7 and from result they found that with increasing percentage of latex, WC ratio was going down, that was due to fact that latex improved consistency of cement mortar by providing ball bearing action of polymer particles.

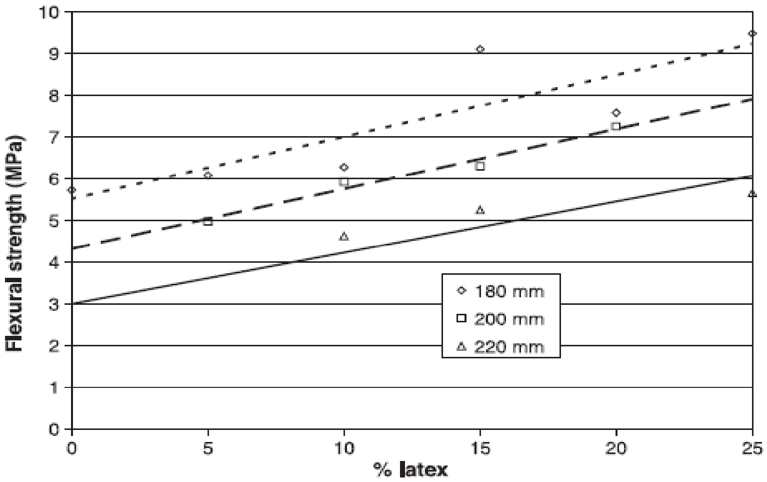

**Fig.2.11 Flexural Strength of LMM with varying percentage of Latex for varying Flow Value [Barluenga and Olivares (2004)]**

They presented the bending test results of LMM with fixed flow value at 28 days in the fig. 2.11. They found that the flexural strength increase with any percentage of latex and decrease for large flow value.

**Adbel-Fattah and El-Hawary (1999)** have studied the flexural behavior of epoxy and polyester polymer concretes. It was found that the modulus of rupture was 3 times higher than ordinary concrete.

**Kim et al. (1999)** reported the structure and properties of mortars and concretes containing up to 2 wt% (based on cement) of poly (vinly alcohol) (PVA) were examined and compared with those without PVA. Among changes occurring with the addition of PVA were increases in air void content and apparent fluidity and a reduction in the bleeding of fresh mortar and concrete. The increase fluidity caused increased slump for fresh concrete. The microstructure was examined by polarizing optical microscopy and scanning electron microscopy in backscattered mode of cut surfaces after hardening. The porous interfacial transition zones around sand grains and coarse aggregate were significantly reduced, and the cement particles were uniformly distributed without significant depletion near aggregate surfaces. For mortars, using a pre-wetting mixing technique the flexural strength was unchanged.

**Schulze (1999)** studied that the influence of the water-cement ratio and cement content on the flexural strength. He was carried out the tests with modified and unmodified cement mortars. The details of the mixes he had taken for experiment, has already shown in the table 2.4. In the experiments he varied the cement content between 20–29% of the mix. The data concerning workability (air content and slump characteristics) was given in table 2.5 already. He had shown the photograph (fig. 2.7) of mix with Vinnapas LL 512 after 90 days in normal climate in his experimental programme. He was casted 40 x 40 x 160 mm size specimens for flexural strength testing. The modified mortars were subjected to four different curing conditions by him and tested at various ages for flexural strength.

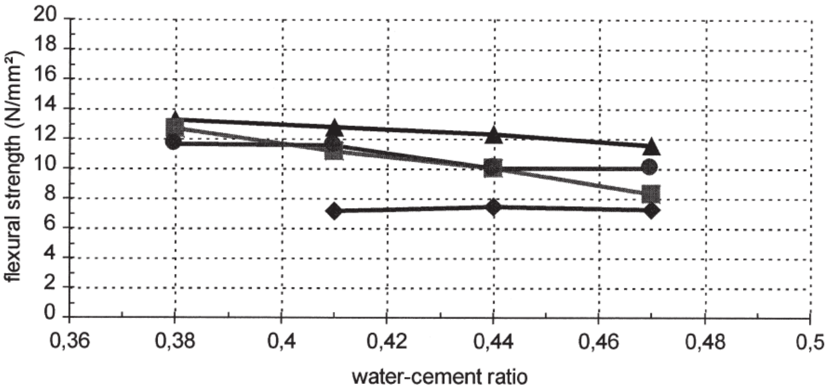

**Fig. 2.12: Flexural strength (N/mm$^2$) with different percentage of Cement and varying w/c Ratio [Schulze (1999)]**

**Table 2.7: Flexural Strength (N/mm$^2$) with different Percentage of Cement and varying w/c Ratio [Schulze (1999)]**

| | Water-cement ratio | 28 days normal climate (N/mm$^2$) | 21 days normal climate, 7 days water (N/mm$^2$) | 90 days normal climate (N/mm$^2$) | 28 days normal climate* (N/mm$^2$) |
|---|---|---|---|---|---|
| Cement 20% | 0.49 | 12.1±0,3 | 9.3±0.8 | 12.6±1.5 | 9.5±1.3 |
| | 0.53 | 10.9±0,9 | 8.3±1.7 | 11.5±1.1 | 9.4±1.4 |
| | 0.57 | 10.9±0.7 | 7.0±0.8 | 10.4±0.9 | 8.7±0.7 |
| | 0.61 | 9.6±0.3 | 7.0±0.8 | 10.4±0.9 | 6.4±2.6 |
| Cement 23% | 0.42 | 12.7±1.1 | 10.2±0.6 | 12.9±1.4 | 9.8±1.3 |
| | 0.46 | 12.3±0.6 | 9.3±0.9 | 12.3±0.6 | 9.6±0.9 |
| | 0.50 | 11.1±1.6 | 8.1±0.8 | 11.2±1.0 | 8.6±1.5 |
| | 0.53 | 11.0±1.6 | 7.4±0.7 | 11.5±0.6 | 7.6±2.9 |
| Cement 26% | 0.38 | 13.2±1.0 | 12.7±0.5 | 12.9±2.5 | 11.6±1.6 |
| | 0.41 | 12.8±1.5 | 11.1±0.9 | 11.8±1.2 | 11.5±1.4 |
| | 0.44 | 12.3±1.5 | 10.0±0.8 | 11.0±0.3 | 10.0±1.2 |
| | 0.47 | 11.5±0.2 | 8.3±1.5 | 11.6±0.9 | 10.0±1.3 |
| Cement 29% | 0.34 | 13.3±1.0 | 13.1±0.8 | 13.1±0.8 | 12.0±1.8 |
| | 0.37 | 12.6±1.8 | 11.3±1.4 | 12.1±1.6 | 11.8±0.8 |
| | 0.39 | 13.0±1.7 | 11.1±0.6 | 13.6±1.3 | 10.9±1.3 |
| | 0.42 | 12.6±1.8 | 9.1±1.0 | 13.0±1.5 | 9.3±0.9 |
| Without LL 512, cement 20% | 0.49 | 7.3±0.4 | 7.8±0.2 | 7.4±0.5 | 6.7±0.4 |

* Ca $(OH)_2$ 28 days at normal climate, 28 days in saturated Ca $(OH)_2$ solution at 50°C, 34 days in normal climate. Normal climate = 23°C, 50% relative humidity.

He found that the influence of the water-cement ratio on the flexural strength of the highly modified mortars varies under the different storage conditions as shown in fig. 2.12 & table 2.7. He also evaluated that in dry condition (28 days normal climate, 90 days normal climate) there was only a small increase of the flexural strength with decreasing water-cement ratio at a constant cement level in the formulation. After storage in water and Ca $(OH)_2$, there was a pronounced increase with decreasing water-cement ratio. He also found that the flexural strength of unmodified mortars at water cement ratios of 0.4–0.6 is nearly independent of water cement ratio and cement content.

He explained the reason for that with an increasing water-cement ratio of the mortar at the same polymer level, the concentration of the polymer per volume was decreased. He found that was true in the dry status also, because the higher water content leads to a higher pore volume in the dry mortar. Due to the lower polymer concentration in the hardened mortar, the effect of the polymer was reduced. In wet status (storage underwater) a second effect had to be taken into consideration by him. With decreasing water-cement ratio, the water absorption of the mortars was reduced, meaning that the mortars contain less water. The forces between the polymeric material in the mortar and the mineral material in nature were more or less of acid/base, or of ionic character and were very much influenced by water with high di-electrical power.

**Zulkarnain and Suleiman (2008)** carried out investigation to evaluate the characteristics of polymer-modified ferrocement under static flexure. That includes load-deflection characteristics, first crack strength, crack width and crack spacing of ferrocement elements exposed to air and salt water environments. The structural properties of ferrocement were determined from the test specimens having size 125 mm x 350 mm x 30 mm, reinforced with 3 layer of square welded mesh with volume fraction of 0.65% and the diameter is 1.0 mm. A four-point loading was used over a simply supported span of 300 mm to determine the load-deflection properties, crack width and crack spacing of the polymer modified ferrocements specimens.They concluded that the polymer modification has significantly improved the mechanical properties of the cement mortars particularly, their flexural strengths and their resistance to crack development. Based on the test result, polymer modified ferrocements show higher first crack load, maximum load and deflection than that of the unmodified control ferrocement. The result also indicates that, the first crack load, maximum load and a deflection values are found to increase with the increasing age of curing. The higher first crack loads in the polymer modified specimens are attributed to the increased in flexural capacity as result of polymer film formation, which bind the aggregate and cement particles into a durable matrix. Polymer modification has led to the increase in the maximum load, the first crack load and the deflection value increase with the increasing age of curing.

**Garas and Vipulanandan (2003)** reported that Polymer Concrete (PC) composites posses a unique combination of properties that depend upon the formulation. This study reviewed the variations in polyester polymer concrete mixture components that affected the properties. The effect of resin content, aggregates, fibres and coupling agents were critically reviewed. It was found that the optimum polymer content varied from 12% to 14% (w/w). Using fibres and coupling agents showed further enhancement of the mechanical properties of PC. Also a new database was designed to document different properties of PC. The overall objective is to determine the effects of different components in the PC mixtures on their properties and building an informative database for documenting different properties of polymer concrete.

a) **Effect of polyester resins:** There are three classes of polyester used in polymer concrete mixtures. Class I resins, resist mild corrodents and non oxidizing mineral acids. Class II resins, isophthalic type, are more resistant as compared to class I. Class III resins are based on bisphenol-A and have the best overall resistance to corrosive solutions.

   Increasing polymer content resulted in increasing flexural strength and flexural modulus while the compressive strength decreased. In general the lowest polymer content at which compressive strength/modulus was maximum represented the optimum polymer content for polymer concrete. Reviewed literature indicated a (60-70 MPa) range for PC compressive strength and a (6.5-8.0 MPa) range for tensile strength. It also indicated that the optimum polymer content to get a workable with the best mechanical properties mixture should be in the range of 12% to 14% (w/w).

b) **Effect of aggregates:** Aggregates composed primarily of silica, quartz, granite, good limestone and other high quality material have been used successfully in the production of PC. Aggregates used must be usually dry and free of dirt to get the best bond between aggregates and resin. Fig. 2.13 shows some aggregate systems used in PC mixtures.

Blasting sand aggregate systems showed an increase in the flexural modulus with the increase in the polymer content. With 18% polymer content, crushed sand had a relatively high flexural strength of 32 MPa m½. Polyester polymer concrete with well graded blasting sand has better fracture properties than uniform Ottawa sand systems.

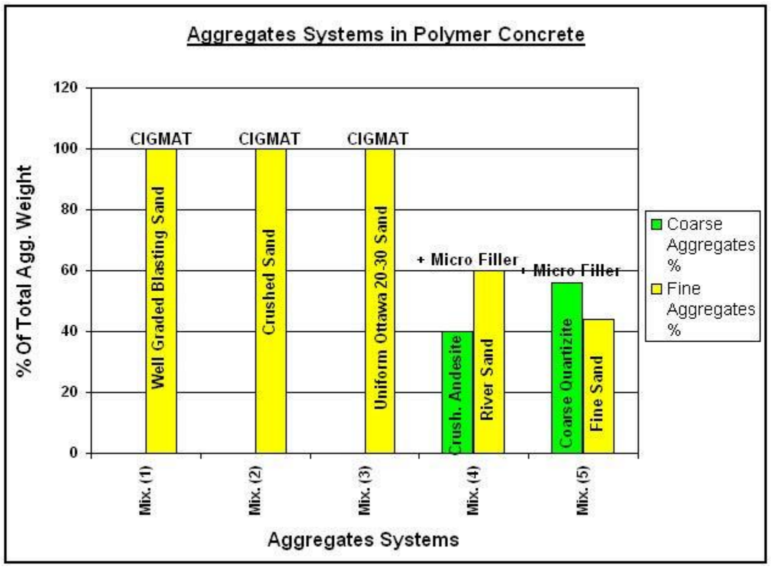

**Fig.2.13: Most Common Aggregate Systems used in Polymer Concrete [Garas and Vipulanandan (2003)]**

**c) Effect of fibres:**

i. **Carbon Fibres:** PAN bases carbon fibers up to 6% (w/w) were used to reinforce PC. In compression it increased the failure strain but the strength and modulus decreased. In tension the addition of carbon fibres increased failure strain, strength and modulus.

ii. **Glass Fibres:** The addition of glass fibres enhanced flexural strength and toughness fracture properties. Treatment glass fibers further enhanced flexural properties of PC. (Mebarkia and Vipulanandan, 1990).

iii. **Steel Fibres:** Different steel fibres of sizes varied from (0.5x0.5x30mm) to (F0.35x25) were used for studying the effect of steel fibres in a PC system and an increase in compressive flexural and impact strengths was noted (Ohama and Nishimura, 1979).

d) **Effect of coupling:** The coupling process is a chemical bond at the interface between the organic polymer and the inorganic substrate. The most common used coupling agent is “Methacryloxypropyltrimethoxysilane, MPS”. Also an effective coupling method is to treat aggregates and fibres by wetting them with an aqueous solution of the coupling agent and then drying prior to mixing with the polyester polymer (Fig. 2.14.)

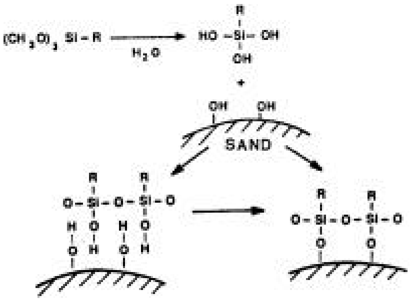

**Fig. 2.14: Coupling Process for Mixing of Aggregates & Fibres with Polyester Polymer [Garas and Vipulanandan (2003)]**

Silane treatment resulted in more than 35% increase in the flexural strength (Mebarkia and Vipulanandan, 1990). Desai and Nair (1987) reported an improvement in compressive strength of about 4 to 6% due to silane treatment. Also silane treatment reduced water uptake into PC specimens so it showed the least decrease in compressive strength (7%) after emersion in water for a month (Mebarkia and Vipulanandan, 1995).

Based on the reviewed literature it is concluded that using certain polymer content, well graded aggregates, fibers and coupling agents strongly improve different properties of polyester polymer concrete.

## 2.3 DURABILITY PROPERTIES

### 2.3.1 Permeability

**Krishnan et al. (2013)** carried out the investigation of the performance of a fluoropolymer modified cement mortar was compared with the performance with the unmodified cement mortar because there was rare studies had been done upto now by using fluoropolymer as mortar modified polymer. The test was carried out by them in comparison with different type of polymers with ratio of cement mortar was maintained as 1:3, mortars were made with the same workability (constant flow) and the w/c values for each mortar has already given in table 2.1.

In all cases, they had casted the specimens for testing of surface water permeability by using Germann water permeability testing apparatus. They put the specimens for 30 days weathering (after 8 days of moist curing) & control conditions (no weathering for 28 days); then the specimen had been tested and evaluated the water permeability of various cement mortars.

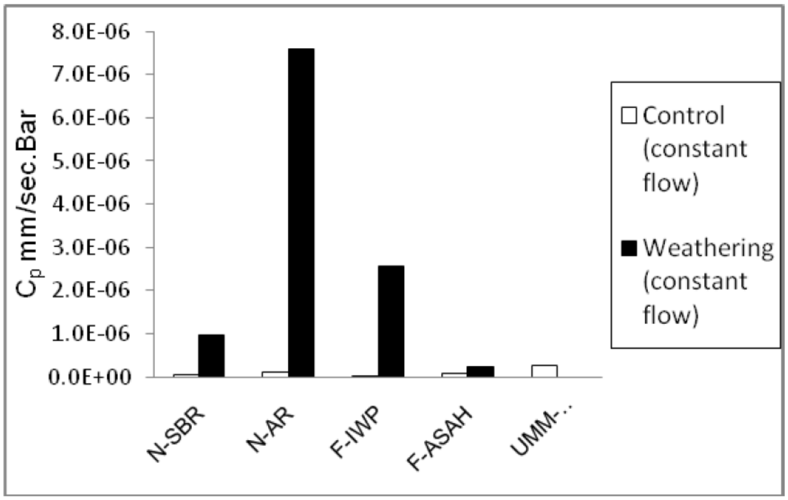

**Fig. 2.15 : Water permeability of the Mortars before and after Weathering [Krishnan et al (2013)]**

They found that the coefficient of water permeability (Cp) increases in both unmodified and WPM modified cement mortars after exposure to accelerated weathering as shown in fig. 2.15. On weathering, specimens of UMM-OPC, N-AR and F-IWP mortars exhibited a drastic increase in permeability compared to the control specimens. On the other hand, it was observed that the increase was low for the SBR latex and fluoropolymer based cement mortars. That was possibly because the SBR was generally resistant to degradation on exposure to UV radiation and, therefore, the partial filling of micro pores and voids by the polymer continues to prevent the ingress of water. The F-ASAH mortar exhibited the lowest water permeability even after exposure to accelerated weathering. In the unmodified cement mortars, the permeability increases to a greater extent due to the damage caused by the stresses induced by the alternate wet and dry cycles during weathering. It was observed that no value could be reported for the UMM-OPC mortar subjected to weathering since it was highly permeable. The fluoropolymer also yielded better water repellent characteristics and the least water permeability among all the WPMs tested.

**Aggarwal et al. (2007)** to investigate the permeability properties of epoxy-modified mortar in comparison with those of unmodified cement mortar and acrylic-modified mortar they had used similar dosages of both epoxy emulsion (density of 1.00–1.05 g/cm3 & total solids of 60 ± 2%) and acrylic emulsion (density of 1.05–1.10 g/cm3 & total solids 38 ± 2%). Properties of the ordinary portland cement (grade 43) and sieve analysis of the quartz sand No. 10 used in the study by them has already reported in tables 2.2 and 2.3 respectively.

They had prepared the specimens of 40 x 40 x 80mm size with varying polymer–cement ratio from 0% to 30% by mass of cement to study the effect of polymer–cement ratio on various properties. A cement–sand ratio of 1:3 and water–cement ratio (w/c) with constant flow between 110 and 120 mm was adjusted by them. The specimens were allowed to cure in the mould for one day and next 27 days dry curing while one set of control specimens, i.e., specimens without polymer were water cured and another was air cured by them. The effect of polymer addition on water–cement ratio required to maintain the desired flow (110–120 mm) has already reported in fig. 2.2 and they were found that the addition of polymer to cement mortar improves workability.

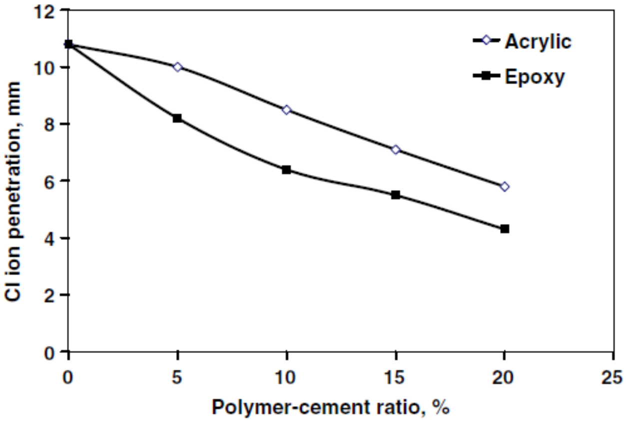

**Fig. 2.16: Effect of Polymer addition on Chloride Ion Penetration [Aggarwal et al (2007)]**

They had shown that the chloride ion penetration also decreases with the addition of polymer in the polymer cement mix as shown in fig. 2.16. They were found that the reduction was up to 60% at 20% epoxy loading in the mix. The reduction in chloride ion penetration was about 40% at 10% epoxy or 20% acrylic latex loading in the mix. That indicated that epoxy emulsion mortar should have more resistant towards chloride ion attack. The increased resistance to penetration of $CO_2$ and Chloride ions makes PMM very useful in application in corrosion prone areas. They were also reported that with the addition of polymer to cement mortar decreases water absorption, carbonation and chloride ion penetration.

**Afridi et al. (1995)** after evaluation compared the water retention in the fresh state and adhesion or bond strength in the hardened state of powdered and aqueous polymer-modified mortars. The polymer modified mortars using various powdered and aqueous cement modifiers were prepared with different polymer-cement ratios and tested for water retention in the fresh state and adhesion in tension in the hardened state. They concluded that the powdered as well as aqueous polymer-modified mortars show markedly improved water retention and adhesion in tension, which increase with a rise in the polymer-cement ratio regardless of the type of cement modifiers used. The magnitude of improvement in the water retention and adhesion in tension of the powdered and aqueous polymer modified mortar however depends upon the type of cement modifiers used, polymer-cement ratios or both. Moreover the failure mode distribution of the powdered and aqueous polymer-modified mortars depends on the type of cement modifiers used, polymer-cement ratio or both.

# CHAPTER-3

# EXPERIMENTAL PROGRAMME AND METHODOLGY

## 3.1 GENERAL

The present chapter deals with the presentation of results obtained from various tests conducted on material used for the cement mortar. In order to achieve the objectives of present study, an experimental program was planned to investigate the effect of fluoropolymer emulsion on compressive strength, flexural strength and permeability of cement mortar.

## 3.2 MATERIALS

The properties of material used for making cement mortar mix are determined in laboratory as per relevant codes of practice. Different materials used in present study were cement, fine aggregates, fluoropolymer emulsion. The aim of studying of various properties of material is used to check the appearance with codal requirements and to enable an engineer to design a cement mortar mix for a particular strength. The description of various materials which were used in this study is given below:

### 3.2.1 Cement

Although all materials that go into cement mortar mix are essential, cement is very often the most important because it is usually the delicate link in the chain. The function of cement is first of all to bind the sand together and second to fill up the voids in between sand particles to form a compact mass. It is the active portion of binding medium and is the only scientifically controlled ingredient of mortar. Any variation in its quantity affects the compressive strength of the mortar mix.

#### 3.2.1.1 Pozzolana

An essentially silicious material which while in itself possessing little or no cementitious properties will, in finely divided form and in the presence of water, react with calcium hydroxide at ambient temperature to form compounds possessing cementitious properties. The term includes natural volcanic material having pozzolanic properties as also other natural and artificial materials, such as diatomaceous earth, calcined clay and fly ash.

### 3.2.1.2 Portland Clinker

Clinker, consisting mostly of calcium silicates, obtained by heating to incipient fusion, a predetermined and homogeneous mixture of materials principally containing lime (CaO) and silica ($SiO_2$) with a smaller proportion of alumina ($Al_2O_3$) and iron oxide ($Fe_2O_3$).

### 3.2.1.3 Portland Pozzolana Cement

An intimately inter-ground mixture of Portland clinker and pozzolana with the possible addition of gypsum (natural or chemical) or an intimate and uniform blending of Portland cement and fine pozzolana.

Portland Pozzolana Cement (PPC) of ACC 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: 1489-1991(part 1) are listed in table 3.1. Cement was carefully stored to prevent deterioration in its properties due to contact with the moisture. The various tests conducted on cement are initial and final setting time, specific gravity, fineness and compressive strength. The results of above said tests are given below in table 3.1.

**Table 3.1: Properties of Portland Pozzolana Cement (PPC)**

| Sr. No. | Characteristics | Values Obtained Experimentally | Value Specified By IS : 1489-1991 (part 1) |
|---|---|---|---|
| 1. | Standard Consistency, (percent) | 34.5 | - |
| 2. | Fineness of Cement as retained on 90 Micron Sieve (percent) | 2 | 2 - 5 |
| 3. | Specific Gravity | 3.02 | - |
| 4. | Soundness of cement (mm) by Le-Chatelier apparatus | 2 | 10 mm |
| 5. | Initial Setting Time (minutes) | 120 | 30 (minimum) |
| 6. | Final Setting Time (minutes) | 410 | 600 (maximum) |
| 7. | Compressive Strength ($N/mm^2$) | | |
| | 7 days | 28.64 | 22 (minimum) |
| | 28 days | 44.28 | 33 (minimum) |

It can be observed from tables that all the results satisfy the standard criteria.

### 3.2.2 Fine Aggregates:

The aggregates most of which pass through 4.75 mm IS sieve are termed as fine aggregates. The fine aggregate may be of following types:-

| | | |
|---|---|---|
| i. | Natural sand : | Fine aggregate resulting from natural disintegration of rocks. |
| ii. | Crushed stone sand : | Fine aggregate produced by crushing hard stone. |
| iii. | Crushed gravel sand : | Fine aggregate produced by crushing natural gravel. |

According to size, the fine aggregate may be described as coarse, medium and fine sands. 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.

**Table 3.2: Sieve Analysis of Fine Aggregate**

Weight of sample taken =1000 gm.

| Sr. No. | IS-Sieve (mm) | Weight Retained (gm) | %age retained | %age Passing | Cumulative % retained |
|---|---|---|---|---|---|
| 1 | 4.75 | 0 | 0 | 100 | 0 |
| 2 | 2.36 | 42 | 4.2 | 95.8 | 4.2 |
| 3 | 1.18 | 172 | 17.2 | 78.6 | 21.4 |
| 4 | 600 μ | 168 | 16.8 | 61.8 | 38.2 |
| 5 | 300 μ | 303 | 30.3 | 31.5 | 68.4 |
| 6 | 150 μ | 216 | 21.6 | 9.9 | 90.1 |
| 7 | Pan | 99 | | | |
| | Total | 1000.00 | | SUM | 222.3 |
| | | | FM = 222.3 / 100 = | | 2.22 |

In the experimental program**,** fine aggregate was locally procured and conformed to Indian Standard Specifications IS: 383-1970. The sand was sieved through 4.75 mm sieve to remove any particles greater than 4.75 mm and conforming to grading zone III. It was coarse sand light brown 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: 3.3 Physical Properties of Fine Aggregate**

| **Sr. No.** | **Characteristics** | **Value** |
|---|---|---|
| 1 | Type | Natural Sand |
| 2 | Specific Gravity | 2.62 |
| 3 | Water Absorption | 1.02 % |
| 4 | Moisture Content | 0.12% |
| 5 | Fineness Modulus | 2.22 |
| 6 | Grading Zone | III |

### 3.2.3 Water

Generally, water that is suitable for drinking is satisfactory for use in cement mortar. Water from lakes and streams that contain marine life also usually is suitable. When water is obtained from sources mentioned above, no sampling is necessary. When it is suspected that water may contain sewage, mine water, or wastes from industrial plants or canneries, it should not be used in mortar unless tests indicate that it is satisfactory. Water from such sources should be avoided since the quality of the water could change due to low water or by intermittent tap water is used for casting. The potable water is generally considered satisfactory for mixing and curing of mortar.

Accordingly potable water was used for making cement mortar available in Material Testing laboratory. That was free from any detrimental contaminants and was good potable quality.

### 3.2.4 Fluoropolymer Emulsion

Fluropolymers are widely used for water and oil repellence in many industries because these chemicals possess good resistance to degradation when exposed to UV light and accelerated weathering. There is rare studies have been done upto now by using fluoropolymer as mortar modified polymer. Asahiguard E 400 (AG-400) is a commercially available fluorocarbon based product used as water repellant in the fabric industry.

In the experimental program**,** the commercially available fluorocarbon based product AsahiGuard E-series (AG-E400) synonym fluoropolymer emulsion was procured and the performance of a fluoropolymer emulsion modified cement mortar was compared with the performance with the unmodified cement mortar. Fluoropolymer emulsion is Milky white emulsion in colour as shown in fig. 3.1. The composition/information on ingredients of AsahiGuard E-series (AG-E400) synonym fluoropolymer emulsion is given in the table 3.4. The Physical/Chemical properties of AsahiGuard E-series (AG-E400) synonym fluoropolymer emulsion used in the experiments are given in the table 3.5.

**Table 3.4: Composition/Information on Ingredients of Fluoropolymer Emulsion [AsahiGuard E-series (AG-E400)]**

| Sr. No. | Name | %weight |
|---|---|---|
| 1 | Fluoropolymer | - |
| 2 | Emulsifier | - |
| 3 | Dipropylene glycol | 5.4 |
| 4 | Acetic acid | > 0.1 |
| 5 | Water | 74.5 |

**Table 3.5: Physical and Chemical Properties of Fluoropolymer Emulsion [AsahiGuard E-series (AG-E400)]**

| Sr. No. | Properties | Value |
|---|---|---|
| 1 | Appearance | Milky white emulsion |
| 2 | Odour | Glycol odour |
| 3 | pH | Acidity |
| 4 | Flash Point (method) | > 100deg.C (Extimate) |
| 5 | Specific gravity | 1.00-1.10 |
| 6 | Solid content | 20% |
| 7 | Ionic charge | Weakly cationic |
| 8 | Solubility | Easily diluted in water (Dispersible) |
| 9 | Solvent Content | Dipropylene glycol 5.4% |

**Fig. 3.1: Fluoropolymer Emulsion [AsahiGuard E-series (AG-E400)]**

## 3.3 MIX PROPORTION, CURING REGIME

| | | |
|---|---|---|
| a) | Mix Proportion | Cement : Sand ( 1 : 2 ) |
| b) | Polymers Percentage | 0%, 5%, 10%, 15%, 20% by weight of Cement |
| c) | Strength Development | 7days and 28days |
| d) | Curing Regime | i. Dry curing refers to sample remains dry at room temperature after demoulding the sample up to age of testing.<br>ii. Wet curing refers to sample cured in water after de-moulding the sample up to age of testing. |

## 3.4 TEST METHODS

To obtain the different parameters like compressive strength, flexure strength and permeability, first of all the flow table test is necessary to be conducted to find out the water-content for maintaining the constant flow value 110±5 mm for varying percentage of polymer contents from 0 to 20%. Detail descriptions of tests are given below:-

### 3.4.1 Flow Test

The flow test is conducted first to find the flow value at constant and varied water cement ratio. The cement sand ratio was used as 1: 2. The constant flow value 110±5 was fixed at 0 % polymer. The effect of polymer was studied and the fluoropolymer emulsion was used in liquid form in this experimental study. It was find that flow of mortar increases by adding polymer at constant w/c ratio. The amount of polymer added was 5%, 10%, 15% and 20%. Hence a fixed value of w/c ratio is found out at each particular addition of polymer. The detail of flow test is given below:-

**3.4.1.1 Procedure for Flow Test:-** The flow is defined as the resulting increase in the base diameter of a mortar mass expressed as a percentage of the original base diameter after being vibrated on a flow table. First of all the constituents were mixed thoroughly to achieve uniform mix. The standard mould of 100 mm base diameter 70 mm top diameter and 50 mm height is used to conduct the test as shown in diagram. Wet and clean the table top and inside of the mould. Then center the mould on the table and fill the thoroughly mixed Cement mortar 1:2 (1cement : sand ) in 2 layers compacting each layer with 20 number of blow of 25 mm dia. mild steel bar. After filling, the mould removes by applying a steady upward pull. Then table shall be raised and dropped from standard height of 12.5mm at the rate of 25 drops in 15 seconds. Measure the diameter of spread mortar. Flow value is calculated as:

$$\text{Flow value} = \frac{(\text{Final diameter} - \text{Initial diameter})}{\text{Initial diameter}} \text{ X } 100$$

**Fig.3.2 Measurement of flow value by Flow Test**

### 3.4.2 Compressive Strength

Determination of compressive strength of the fluoropolymer emulsion modified cement mortar with varying contents of polymer from 0 to 20%. Mortar cubes of size 70.6 x 70.6 x 70.6 mm were casted for determination of compressive strength under different curing regime i.e. dried/wet up to age at testing. Detail regarding number of specimen given below.

For **Dry** Curing:-

| Percentage of Fluoropolymer Emulsion | 0% | 5% | 10% | 15% | 20% |
|---|---|---|---|---|---|
| No. of Specimens | 6 | 6 | 6 | 6 | 6 |

Total specimens = 30

For **Wet** Curing:-

| Percentage of Fluoropolymer Emulsion | 0% | 5% | 10% | 15% | 20% |
|---|---|---|---|---|---|
| No. of Specimens | 6 | 6 | 6 | 6 | 6 |

Total specimens = 30

The quantities of cement, fine aggregate, fluoropolymer emulsion and water for each batch i.e. for different percentage of fluoropolymer emulsion replacement was weighed separately. The cement and fine aggregate were mixed dry to a uniform colour separately. Similarly fluoropolymer emulsion and water of different percentage were mixed separately and after mixing the diluted liquid were added to the dry mix. Firstly, 50 to 70% of mix solution was added to the dry mix and then mixed thoroughly for 3 to 4 minutes. Then the remaining solution was added in mixture and again mixes thoroughly. After properly mixing the cement mortar was filled into the cube moulds of size 70.6 x 70.6 x 70.6mm and then gets vibrated to ensure proper compaction as shown in fig. 3.3 and fig. 3.4 respectively. The surface of the mortar was finished level with the top of the mould using trowel. 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 to dry at room temperature in the laboratory.

**Fig. 3.3: Cube Specimens of Size 70.6 mm x 70.6 mm x 70.6 mm**

**Fig.3.4: Vibrating Machine each Sample to be Vibrated at 12000 Cycles per Minute**

The dried cube specimens of size 70.6 mm x 70.6 mm x 70.6 mm were tested at the ages of 7 & 28 days as shown in fig. 3.5**.** The position of cube when tested was at right angle to that as cast. The tests were performed on Universal Testing Machine (UTM). During testing loading is applied gradually at the rate of 70 KN/min. without shock till the failure of the specimen occurs.

**Fig. 3.5: Compressive Strength Testing of Cube under UTM**

Thus the compressive strength was found by following formula:

$$f = \frac{F}{A}$$

Where: f = Compressive Strength (MPa),

F = Ultimate Load (N)

A = Cross-Sectional Area perpendicular to loading direction ($mm^2$)

Similarly for wet conditions same number of specimens casted as described above. The cube specimens were removed from the moulds after 24 hours of casting and were placed in the water tank, filled with potable water in the laboratory. These cube specimens were taken out from the curing tank at the ages of 7 & 28 days and surface water was wiped off. Then these wet cube specimens were similarly tested as described above for dry specimens, and then compressive strength was calculated by the above given formula.

### 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 mortar in tension. To determine the flexural strength of fluoropolymer emulsion modified cement mortar with varying contents of polymer from 0 to 20%, the specimens of size 40 X 40 X 160 mm were casted under different curing regime i.e. dried/wet up to age at testing. Detail regarding number of specimen given below.

For **Dry** Curing:-

| Percentage of Fluoropolymer Emulsion | 0% | 5% | 10% | 15% | 20% |
|---|---|---|---|---|---|
| No. of Specimens | 6 | 6 | 6 | 6 | 6 |

Total specimens = 30

For **Wet** Curing:-

| Percentage of Fluoropolymer Emulsion | 0% | 5% | 10% | 15% | 20% |
|---|---|---|---|---|---|
| No. of Specimens | 6 | 6 | 6 | 6 | 6 |

Total specimens = 30

The quantities of cement, fine aggregate, fluoropolymer emulsion and water for each batch i.e. for different percentage of fluoropolymer emulsion replacement was weighed separately. The cement and fine aggregate were mixed dry to a uniform colour separately. Similarly fluoropolymer emulsion and water of different percentage were mixed separately and after mixing the diluted liquid were added to the dry mix. Firstly, 50 to 70% of mix solution was added to the dry mix and then mixed thoroughly for 3 to 4 minutes. Then the remaining solution was added in mixture and again mixes thoroughly. After properly mixing the cement mortar was filled into the moulds of size Specimens of size 40 X 40 X 160mm as shown in fig. 3.6 and then gets vibrated to ensure proper compaction. The surface of the mortar was finished level with the top of the mould using trowel. 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 to dry at room temperature in the laboratory.

**Fig. 3.6: Mould Specimens of Size 40 mm x 40 mm x 160 mm**

The dried specimens of size 40 mm x 40 mm x 160 mm were tested at the ages of 7 & 28 days. The position of specimen during flexural testing by three points loading was shown in fig. 3.7 and in schematic diagram fig. no 3.8. The tests were performed on Universal Testing Machine (UTM). During testing loading is applied gradually at the rate of 2.65 KN/min. and the effective length of beam is taken as 120 mm without shock till the failure of the specimen occurs.

**Fig. 3.7: Flexural Strength Testing of Specimen under UTM by Three Point Loading**

The flexural strength under three point loading can be finding out by the formula given below:

$$\sigma = \frac{3FL}{2BD^2}$$

Where $\sigma$ = Stress at outer fiber (N/mm$^2$),

F = Load at fracture point (N),

L = is Length of supported span (mm),

B = width (mm),

D = Thickness (mm).

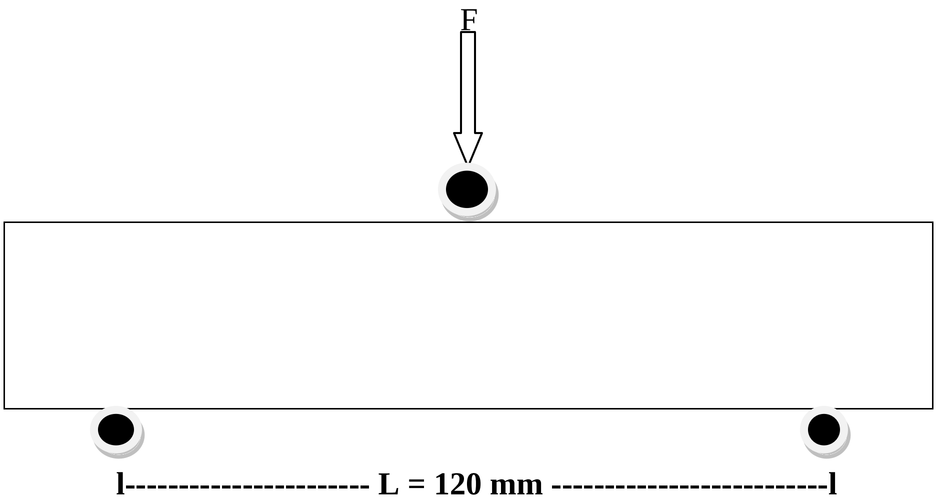

**Fig.3.8: Schematic Diagram for Three Point Loading**

Similarly for wet conditions same number of specimens casted as described above. The specimens were removed from the moulds after 24 hours of casting and were placed in the water tank, filled with potable water in the laboratory. These specimens were taken out from the curing tank at the ages of 7 & 28 days and surface water was wiped off. Then these wet specimens were similarly tested as described above for dry specimens, and then flexural strength was calculated by the above given formula.

### 3.4.4 Rapid Chloride Permeability Test

The durability of cement mortar is also influenced by its permeability to the access of chloride. The chloride ion present in the cement mortar can have harmful affect on mortar. Swelling of mortar due to chloride ion penetration is larger than that observed with water penetration. So this test covers the experimental evaluation of electrical conductance of polymer modified cement mortar to provide rapid indication of polymer modified cement mortar resistance against chloride ion penetration.

To determine the permeability of fluoropolymer emulsion modified cement mortar with varying contents of polymer from 0 to 20%, cylindrical specimens of 100mm (diameter) X 200 mm (long) were casted under different curing regime i.e. dry/wet up to age at testing i.e. 28 days. Detail regarding number of specimen given below.

For **Dry** Curing:-

| Percentage of Fluoropolymer Emulsion | 0% | 5% | 10% | 15% | 20% |
|---|---|---|---|---|---|
| No. of Specimens | 3 | 3 | 3 | 3 | 3 |

Total specimens = 15

For **Wet** Curing:-

| Percentage of Fluoropolymer Emulsion | 0% | 5% | 10% | 15% | 20% |
|---|---|---|---|---|---|
| No. of Specimens | 3 | 3 | 3 | 3 | 3 |

Total specimens = 15

The quantities of cement, fine aggregate, fluoropolymer emulsion and water for each batch i.e. for different percentage of fluoropolymer emulsion replacement was weighed separately. The cement and fine aggregate were mixed dry to a uniform colour separately. Similarly fluoropolymer emulsion and water of different percentage were mixed separately and after mixing the diluted liquid were added to the dry mix. Firstly, 50 to 70% of mix solution was added to the dry mix and then mixed thoroughly for 3 to 4 minutes. Then the remaining solution was added in mixture and again mixes thoroughly. After properly mixing the cement mortar was filled into the cylindrical moulds of size Specimens of cylindrical size 100mm X 200mm as shown in fig. 3.9 (a) and then gets vibrated to ensure proper compaction. The surface of the mortar was finished level with the top of the mould using trowel. 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 to dry at room temperature in the laboratory as shown in fig. 3.9(b).

**Fig. 3.9 (a) Cylindrical Mould for Specimens of Size 100 mm x 200 mm**

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

For rapid chloride permeability test (RCPT) when the casted cylindrical specimens of 100 X 200 mm attained the age of testing i.e. 28 days, then specimen cutter machine as shown in fig. 3.10 the cylindrical specimen of 51 mm (long) x 100 mm (diameter) size were cut from cores as shown in fig. 3.11.

**Fig. 3.10: Cylindrical Specimens Cutter Machine**

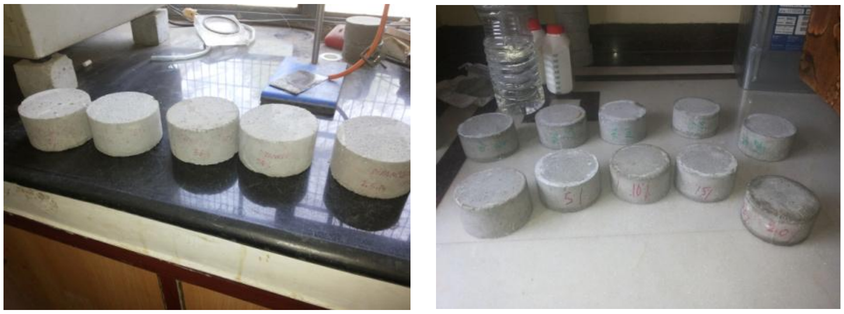

**Fig. 3.11: Cylindrical Specimens of Size 51 mm x 100 mm**

The dried 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. The de-aerated water was allowed to flow into the desiccators, so that it completely covers the specimens and no air was allowed to enter. Again the vacuum was maintained for another one hour. Then the specimens were left to soak in the container water for another 18 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 20 V potential were applied across the specimens. The current across the specimens were measured after the 6-hour test.

**Fig.3.13: Rapid Chloride Permeability Test Setup**

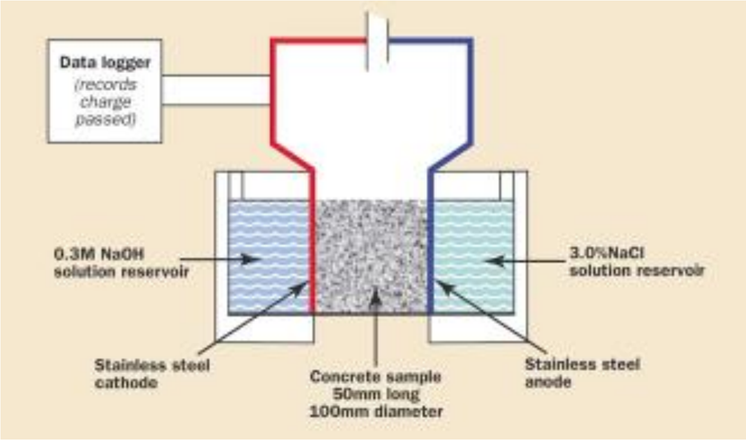

**Fig.3.14: Schematic of Rapid Chloride Permeability Test Setup**

Similarly for wet curing conditions same number of specimens casted as described above. The specimens were removed from the cylindrical moulds after 24 hours of casting and were placed in the water tank, filled with potable water in the laboratory. These specimens were taken out from the curing tank at the ages of 28 days and surface water was wiped off. Then these wet specimens were similarly tested as described above for dry specimens, and then permeability was evaluated.

## 3.5 Summary

In this chapter various properties like specific gravity, moisture content, etc. were evaluated for the components of cement mortar. Ingredients of mix were evaluated, by conducting the flow test for constant flow value and according to mix proportion, materials were weighed. According to the mix prepared, specimens were casted to evaluate mechanical properties (compressive strength and flexural strength) and durability property (rapid chloride permeability test) for the fluoropolymer emulsion modified cement mortar mixes.

# CHAPTER - 4

# RESULTS AND DISCUSSION

## 4.1 GENERAL

In this chapter results obtained from various tests conducted on fluoropolymer emulsion modified cement mortar as detailed in chapter 3 are presented and discussed. In order to discuss the results of different parameters like compressive strength, flexure strength and permeability, first of all the flow table test was conducted to find out the water-content for maintaining the constant workability for varying percentage of polymer contents from 0 to 20%. Then as per calculated total liquid contents (water & polymer) by flow test, six cubes each for varying percentage of polymer for different curing conditions (dry & wet) at 7 days & 28 days were prepared with the specimens as designed were shown in the table 4.1, for investigation of compressive strength, flexural strength and three cubes each for varying percentage of polymer for different curing conditions (dry & wet) at 28 days were prepared for investigation of water permeability.

**Table 4.1: Designation of Specimens for Percentage Addition of Fluoropolymer by weight of Cement in Mortar**

| Sr. No. | Percentage Addition of Fluoropolymer by weight of Cement in Mortar | Specimen Designation |
|---|---|---|
| **1** | **0%** | F-0 |
| **2** | **5%** | F-5 |
| **3** | **10%** | F-10 |
| **4** | **15%** | F-15 |
| **5** | **20%** | F-20 |

## 4.2 WORKABILITY

The term workability is broadly defined as the property of freshly mixed concrete or mortar which determines the ease and homogeneity with which it can be mixed, placed, consolidated, and finished. Also it may define as the amount of useful internal work necessary to produce full compaction.

In present study, first of all the constant flow value 110±5 was fixed for 0% polymer addition then the flow test were conducted for addition of varying percentage (5%, 10%, 15% & 20%) of polymer with constant water-cement ratio as fixed for 0% polymer. Experimental results show in table 4.2 and fig. 4.1 that the flow value increase about 20% with the addition of 5% polymer contents, increase about 51% with the addition of 10% polymer contents, increase about 72% with the addition of 15% polymer contents and with addition of 20% polymer contents the flow value was too much increases beyond the limits of apparatus surface.

**Table 4.2: Workability at Constant w/c Ratio with varying Percentage of Fluoropolymer Emulsion**

| Sr. No. | Specimen | w/c Ratio | Flow Value |
|---|---|---|---|
| **1** | F-0 | **0.58** | **107** |
| **2** | F-5 | **0.58** | **128** |
| **3** | F-10 | **0.58** | **162** |
| **4** | F-15 | **0.58** | **184** |
| **5** | F-20 | **0.58** | **-** |

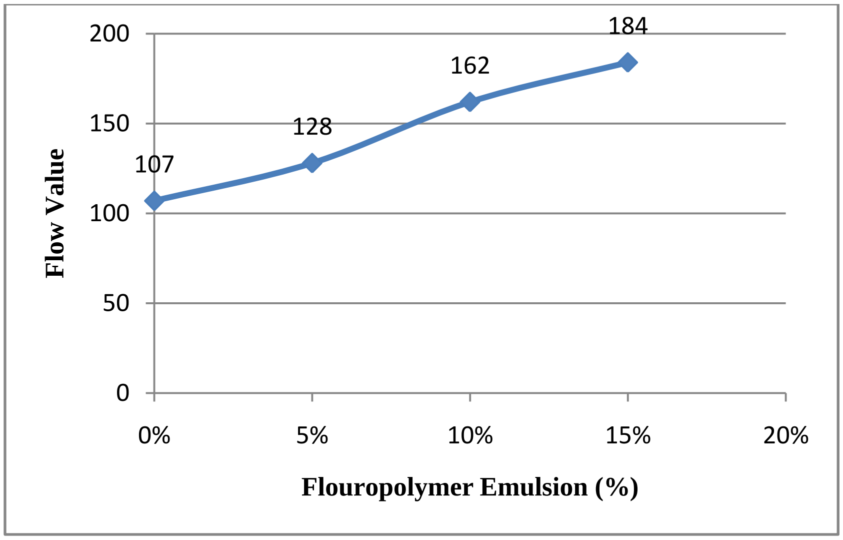

**Fig. 4.1: Workability at Constant W/C Ratio with varying Percentage of Fluoropolymer Emulsion**

Experimentally it was find out that fluoropolymer emulsion modified cement mortar provides better workability over conventional cement mortar. This increase in flow value may be due to fact that polymer particle act as ball bearing among the cement particle to increase workability and entrained air in Polymer modified mortar may be another reason to increase workability.

For further investigation the workability of the mortar was kept constant and in order to achieve the constant workability (flow value 110±5) the amount of the water content in the mortar was adjusted and the details of same are presented in table 4.3.

**Table 4.3: Constant Workability at varying w/c Ratio & Fluoropolymer Emulsion**

| Sr. No. | Specimen | Cement (Kg) | Sand (Kg) | Water Content (Kg) | Fluoropolymer Emulsion Content (Kg) | Total Liquid Content (Kg) | Flow value (mm) |
|---|---|---|---|---|---|---|---|
| 1 | F-0 | 1 | 2 | 0.58 | 0.00 | 0.58 | 107 |
| 2 | F-5 | 1 | 2 | 0.56 | 0.05 | 0.61 | 107 |
| 3 | F-10 | 1 | 2 | 0.53 | 0.10 | 0.63 | 111 |
| 4 | F-15 | 1 | 2 | 0.46 | 0.15 | 0.61 | 112 |
| `5 | F-20 | 1 | 2 | 0.37 | 0.20 | 0.57 | 109 |

From the above table 4.3 it can be observed that for the constant workability, the total liquid contents in mortar increase with addition of fluoropolymer emulsion upto 10 percent and thereafter it decreases.

## 4.3 COMPRESSIVE STRENGTH

To study the effect on compressive strength, six cubes (size 70.6 x 70.6 x 70.6 mm) each for varying percentage (0%, 5%, 10%, 15% & 20%) of polymer contents for both dry & wet curing conditions at 7 days & 28 days were cast keeping workability constant as described in section 3.4.2 of chapter 3.

**Table 4.4: Comparison between Dry and Wet Curing Conditions for Compressive Strength Tested at 7 days**

| Sr. No. | Specimen | Compressive Strength after 7 days ($N/mm^2$) | |
|---|---|---|---|
| | | Dry Curing | Wet Curing |
| 1 | F-0 | 15.72 | 21.64 |
| 2 | F-5 | 12.87 | 15.88 |
| 3 | F-10 | 9.37 | 13.23 |
| 4 | F-15 | 9.41 | 13.62 |
| `5 | F-20 | 10.17 | 14.84 |

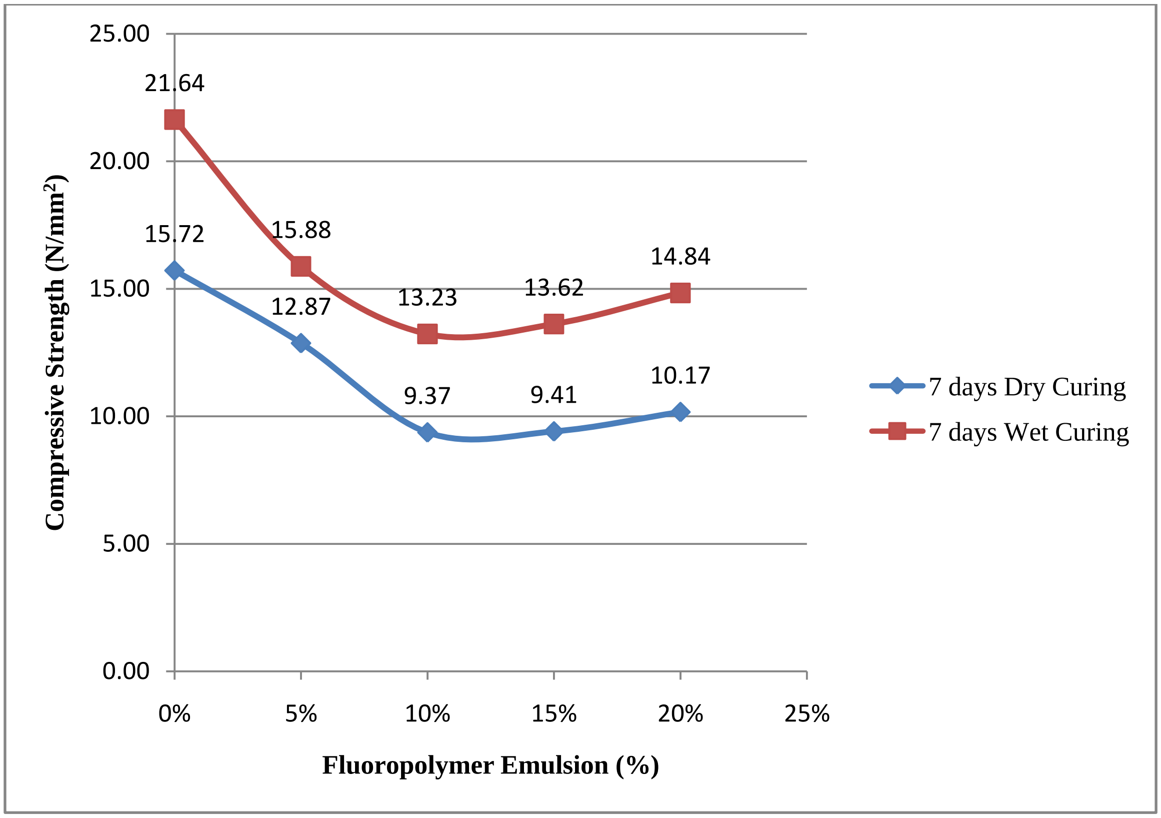

**Fig. 4.2: Comparison between Dry and Wet Curing Conditions for Compressive Strength of Fluoropolymer Emulsion Modified Cement Mortar after 7 days**

**Table 4.5: Comparison between Dry and Wet Curing Conditions for Compressive Strength Tested at 28 days**

| Sr. No. | Specimen | Compressive strength after 28 days (N/mm$^2$) | |
|---|---|---|---|
| | | Dry Curing | Wet Curing |
| 1 | F-0 | 20.67 | 30.08 |
| 2 | F-5 | 15.78 | 21.01 |
| 3 | F-10 | 12.85 | 19.41 |
| 4 | F-15 | 13.46 | 19.73 |
| `5 | F-20 | 14.28 | 21.46 |

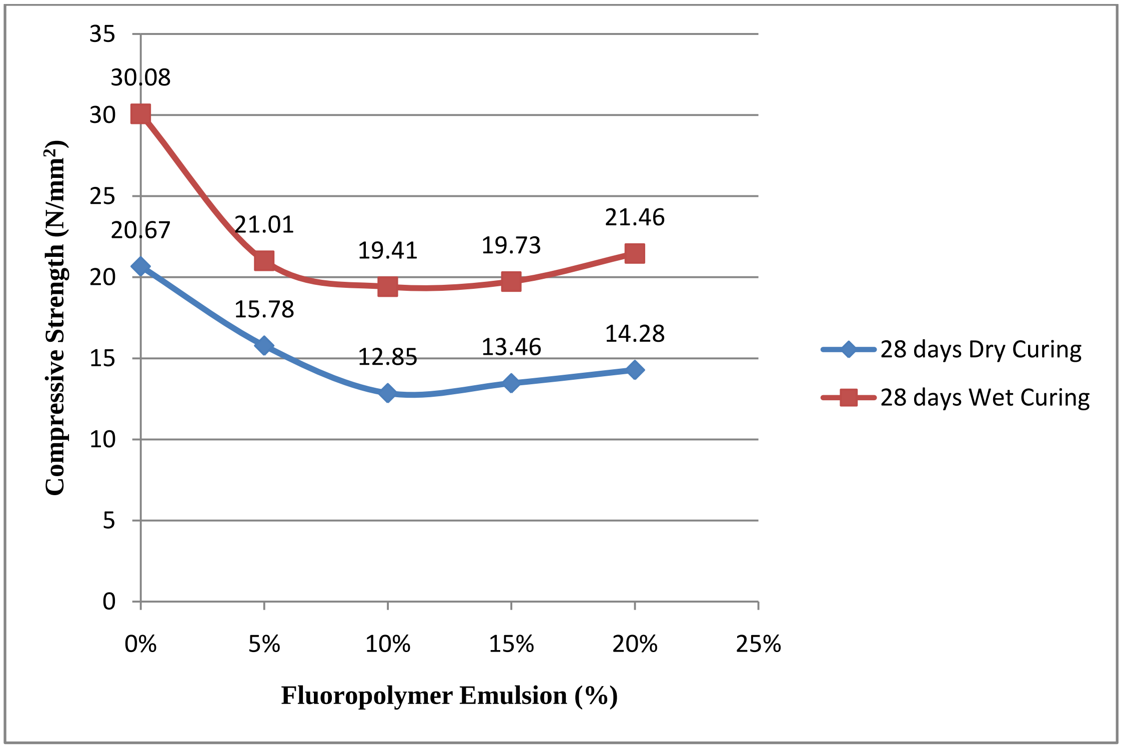

**Fig. 4.3: Comparison between Dry and Wet Curing Conditions for Compressive Strength of Fluoropolymer Emulsion Modified Cement Mortar after 28 days**

Average results of three specimens of the compressive strength test on fluoropolymer emulsion modified cement mortar of all five mix at the age of 7 days are given in the table 4.4 and shown graphically in fig. 4.2 whereas for 28 days are given in the table 4.5 and shown graphically in fig. 4.3.

The variation of 7 & 28 days compressive strength of both dry & wet curing conditions for all mixes under examination are evaluated and from the graphs it is observed that the compressive strength decreases as compared to control mix as the percentage of fluoropolymer emulsion is increased in the mix upto 10% and after that compressive strength slightly increases at 10% to 20% of polymer addition for both dry as well as wet curing conditions. This may be due to the increase in total liquid content in the mix, the compressive strength decreases and vice versa.

It is also observed that after addition of 10% of fluoropolymer emulsion there is a decrease of 40.39% strength in 7 days for dry curing, 38.86% strength in 7 days for wet curing, whereas, the reduction at 28 days is comparatively less and is of the range of 37.83% reduction in strength at 28 days for dry curing, 35.47% reduction in strength at 28 days for wet curing as compared to the control mix. This indicates that early strength gain is lesser as compared with slightly later strength gain for all the mixes containing fluoropolymer emulsion.

Further it is observed that after addition of 20% of fluoropolymer emulsion there is a decrease of 35.30% strength in 7 days for dry curing, 31.42% strength in 7 days for wet curing, whereas, the reduction at 28 days is comparatively less and is of the range of 30.91% reduction in strength at 28 days for dry curing, 28.65% reduction in strength at 28 days for wet curing as compared to the control mix. This indicates that early strength gain is lesser as compared with slightly later strength gain for all the mixes containing fluoropolymer emulsion.

## 4.4 Flexural Strength

To study the effect of flexural strength, six prisms (size 40 x 40 x 160 mm) each for varying percentage (0%, 5%, 10%, 15% & 20%) of polymer contents for both dry & wet curing conditions at 7 days & 28 days were casted at constant workability as described in section 3.4.3 of chapter 3.

**Table 4.6: Comparison between Dry and Wet Curing Conditions for Flexural Strength Tested at 7 days**

| Sr. No. | Specimen | Flexural strength after 7 days (N/mm$^2$) | |
|---|---|---|---|
| | | Dry Curing | Wet Curing |
| 1 | F-0 | 3.57 | 4.54 |
| 2 | F-5 | 2.87 | 3.90 |
| 3 | F-10 | 2.70 | 3.33 |
| 4 | F-15 | 2.89 | 3.42 |
| `5 | F-20 | 2.96 | 3.55 |

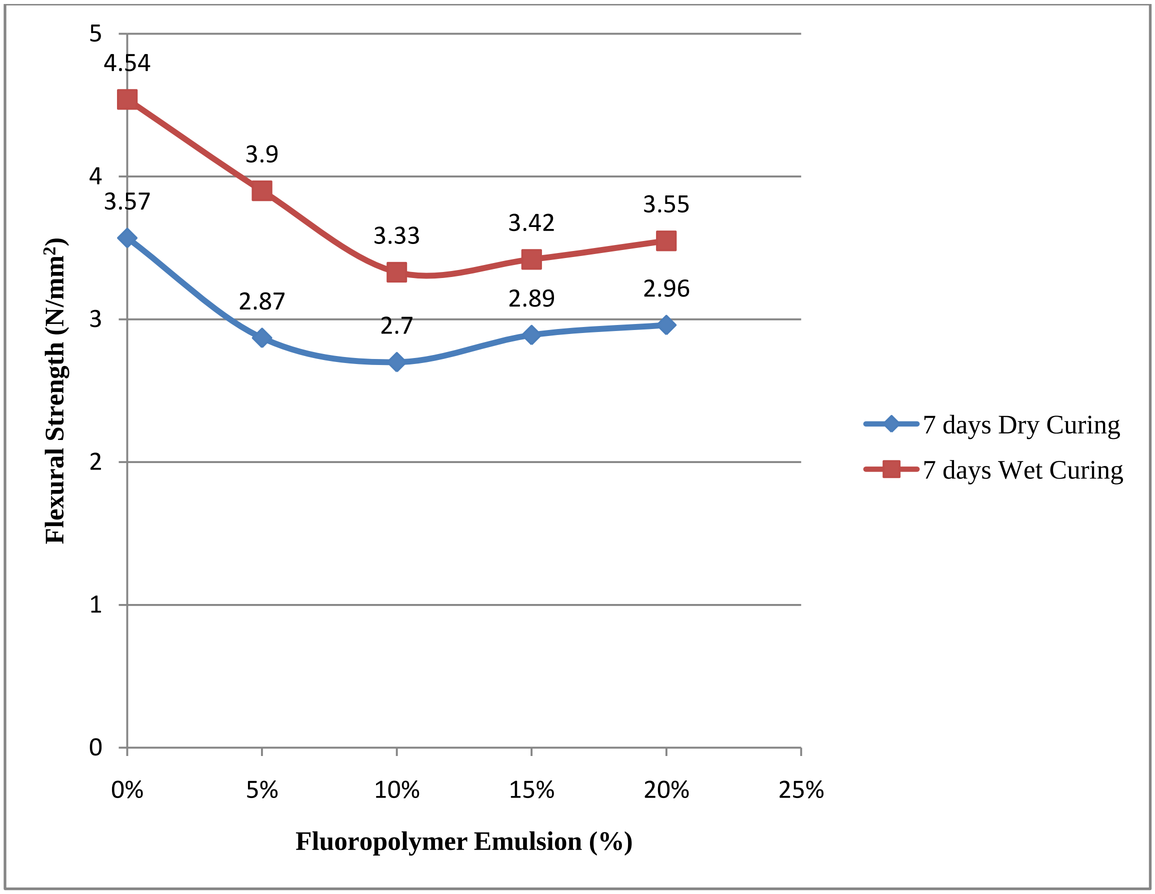

Fig. 4.4: Comparison between Dry and Wet Curing Conditions for Flexural Strength of Fluoropolymer Emulsion Modified Cement Mortar after 7 days

## Table 4.7: Comparison between Dry and Wet Curing Conditions for Flexural Strength Tested at 28 days

| Sr. No. | Specimen | Flexural strength after 28 days (N/mm$^2$) | |
|---|---|---|---|
| | | Dry Curing | Wet Curing |
| 1 | F-0 | 4.66 | 6.19 |
| 2 | F-5 | 3.91 | 5.42 |
| 3 | F-10 | 3.58 | 4.63 |
| 4 | F-15 | 3.88 | 4.85 |
| `5 | F-20 | 4.01 | 4.97 |

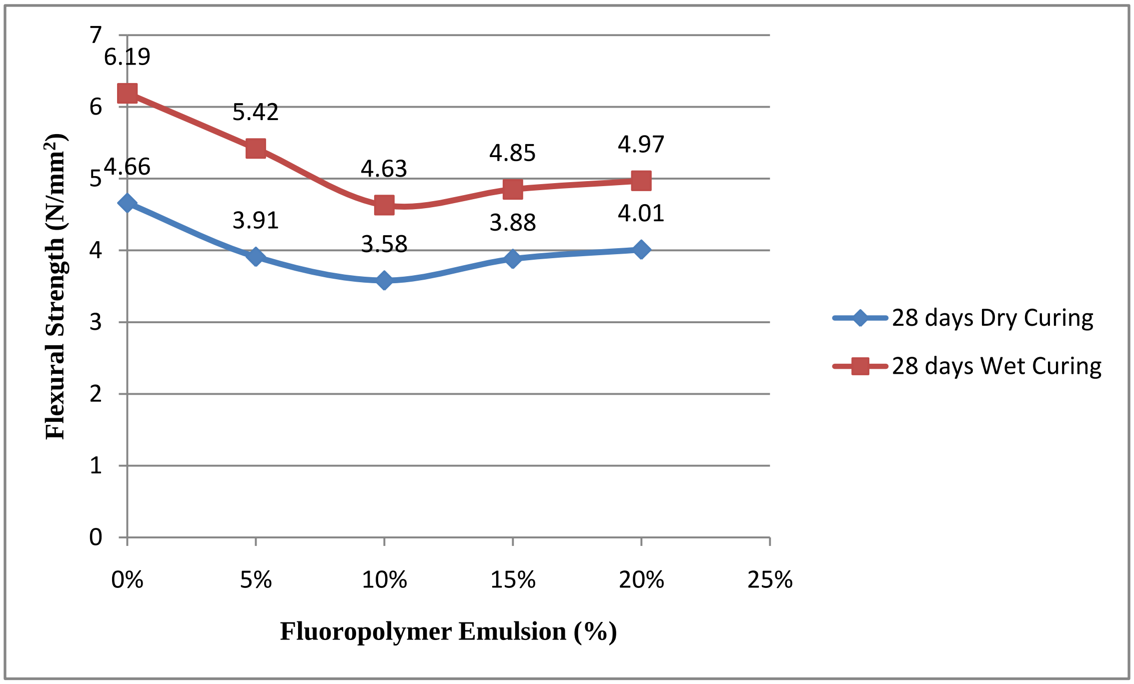

**Fig. 4.5: Comparison between Dry and Wet Curing Conditions for Flexural Strength of Fluoropolymer Emulsion Modified Cement Mortar after 28 days**

Average results of three specimens of the flexural strength test on fluoropolymer emulsion modified cement mortar of all five mix at the age of 7 days are given in the table 4.6 and shown graphically in fig. 4.4 whereas for 28 days are given in the table 4.7 and shown graphically in fig. 4.5.

The variation of 7 & 28 days flexural strength of both dry & wet curing conditions for all mixes under examination are evaluated and from the graphs it is observed that the flexural strength also decreases as compared to control mix as the percentage of fluoropolymer emulsion is increased in the mix upto 10% and after that flexural strength slightly increases at 10% to 20%of polymer addition for both dry as well as wet curing conditions. This may be due to the increase in total liquid content in the mix, the flexural strength decreases and vice versa.

It is also observed that after addition of 10% of fluoropolymer emulsion there is a decrease of 24.36% strength in 7 days for dry curing, 26.65% strength in 7 days for wet curing, whereas, the reduction at 28 days is comparatively less and is of the range of 23.17% reduction in strength at 28 days for dry curing, 25.20% reduction in strength at 28 days for wet curing as compared to the control mix. This indicates that early strength gain is lesser as compared with slightly later strength gain for all the mixes containing fluoropolymer emulsion.

Further it is observed that after addition of 20% of fluoropolymer emulsion there is a decrease of 17.08% strength in 7 days for dry curing, 21.80% strength in 7 days for wet curing, whereas, the reduction at 28 days is comparatively less and is of the range of 13.94% reduction in strength at 28 days for dry curing, 19.70% reduction in strength at 28 days for wet curing as compared to the control mix. This indicates that early strength gain is lesser as compared with slightly later strength gain for all the mixes containing fluoropolymer emulsion.

## 4.5 Rapid Chloride Permeability Test

To study the effect of permeability, three cylindrical specimen (size 100mm diameter x 200 mm long) each for varying percentage (0%, 5%, 10%, 15% & 20%) of polymer contents for both dry & wet curing conditions at 28 days were casted at constant workability. To calculate the permeability by rapid chloride permeability test (RCPT) when the casted cylindrical specimens of 100 X 200 mm attained the age of testing i.e. 28 days, then specimen cutter machine as shown in fig. 3.10 the cylindrical specimen of 51 mm (long) x 100 mm (diameter) size were cut from cores as described in section 3.4.4 of chapter 3. The results of permeability for the specimens under different curing conditions i.e. dry and wet at the age of 28-days are shown in table 4.8 and fig.4.6.

**Table 4.8 Results for Rapid Chloride Permeability Test of Fluoropolymer Emulsion Modified Cement Mortar Specimens after 28 days**

| Sr. No. | Specimen | Total charge passed after 6 hours (Coulombs) | |
|---|---|---|---|
| | | Dry condition | Curing condition |
| 1 | F-0 | 2613 | 532 |
| 2 | F-5 | 2172 | 321 |
| 3 | F-10 | 2107 | 319 |
| 4 | F-15 | 2051 | 308 |
| `5 | F-20 | 1998 | 299 |

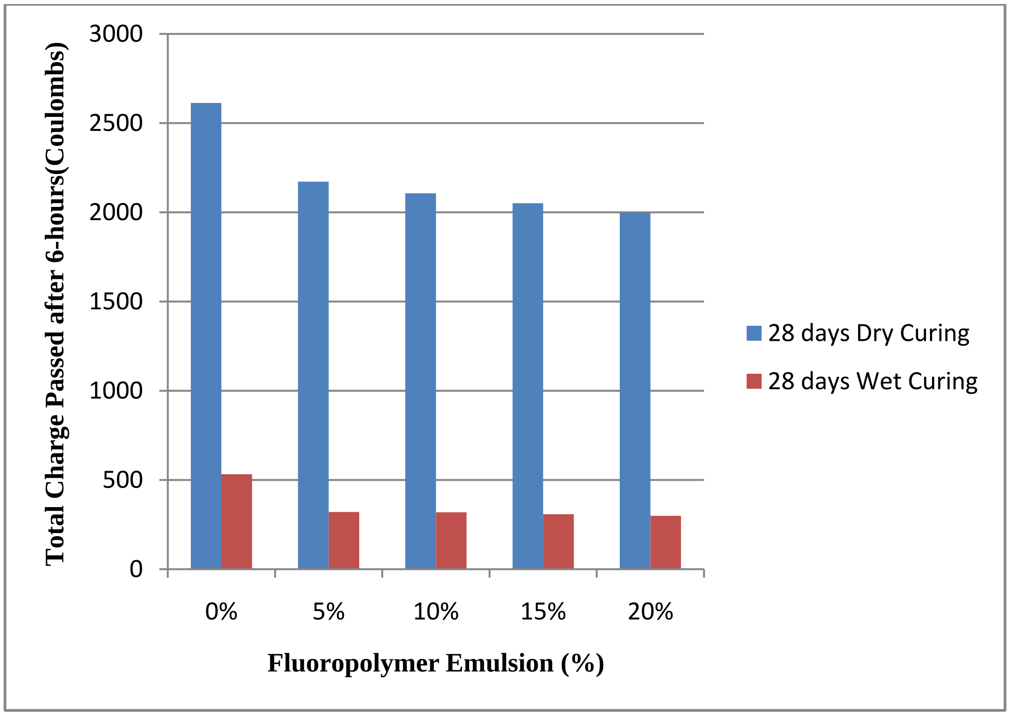

**Fig. 4.6: Chart for Rapid Chloride Permeability Test of Fluoropolymer Emulsion Modified Cement Mortar Specimens after 28 days**

From the above table 4.8 and fig. 4.6 it is observed that in control mixture, chloride ions passed were more as compared to fluoropolymer modified cement mortar for both dry as well as wet curing conditions.

It is also observed that with wet curing the water permeability is 6-7 times less in comparison with dry curing. Further it is observed that permeability can be reduces by increasing the percentage addition of fluoropolymer emulsion in the mix.

# CHAPTER-5
# CONCLUSIONS

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## 5.1 GENERAL

The strength and durability characteristics of polymer modified cement mortar such as compressive strength, flexural strength and permeability of mortar mixtures have been studied in the present work by addition of varying 0%, 5%, 10%, 15% & 20% polymer contents in the following five proportion of fluoropolymer emulsion in all mixes with constant flow value 110±5.

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

1. The addition of fluoropolymer emulsion in cement mortar improves the workability.
2. On addition of fluoropolymer in mortar the compressive strength decreases as compared to control mix with the percentage increase in fluoropolymer emulsion upto 10% and thereafter the compressive strength increases slightly with further addition of fluoropolymer in mortar from 10% to 20% for both dry as well as wet conditions.
3. Percentage decrease in compressive strength under both dry and wet curing conditions is almost same. However, the compressive strength of fluoropolymer modified mortar under wet curing conditions is higher than dry curing conditions.
4. On addition of fluoropolymer in mortar the flexural strength decreases as compared to control mix with the percentage increase in fluoropolymer emulsion upto 10% and thereafter the flexural strength increases slightly with further addition of fluoropolymer in mortar from 10% to 20% for both dry as well as wet conditions.
5. Percentage decrease in flexural strength under both dry and wet curing conditions is almost same. However, the flexural strength of fluoropolymer modified mortar under wet curing conditions is higher than dry curing conditions.
6. Under both dry and wet curing conditions the permeability of fluoropolymer modified mortar decreases with increase in percentage of fluoropolymers.
7. However, the decrease in permeability under wet conditions is 6 to 7 times higher than that for dry curing conditions.

8. Due to lower permeability of fluoropolymer modified mortar, it can be used as good waterproofing material without much loss in mechanical properties by selecting suitable quantity of fluoropolymer in mortar.

## 5.2 SCOPE FOR FUTURE WORK

i. As in present study we concluded that the compressive and flexural strength is inversely proportional to the total liquid contents added in the mix, so further study is needed to investigate the micro structure and chemical reaction of mix conducting XRD and SEM for different mix compositions.

ii. In the present study addition of varying 0%, 5%, 10%, 15% & 20% fluoropolymer contents has been considered for dry and wet conditions. The other one day curing plus 27 days dry and 7 days curing plus 21 days dry are need to be study.

iii. Also further research is needed for determining the optimum fluoropolymer emulsion dosage and cost effectiveness.

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