MECHANICAL PROPERTIES

OF

FLUOROPOLYMER MODIFIED MORTAR

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CERTIFICATE

I hereby certify that the dissertation on **"Mechanical Properties of Fluoropolymer Modified Mortar"** is submitted in partial fulfillment of the requirement for the award of the degree of **Masters of Engineering** in **Structural Engineering** in the **Department of Civil Engineering (CED), Thapar University, Patiala**, is a record of my independent and original research work carried out under supervision and guidance of **Dr. Prem Pal Bansal** and **Dr. Rafat Siddique.** The matter embodied in this dissertation has not been submitted in part or full to any other University or Institute for the award of any degree.

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ABSTRACT

In past lot of experimental studies were carried out on polymer modified cement (PMC) mortar and concrete using polymers such as SBR, acrylic, VAE and integral water proofing 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, Split tensile strength at the age of 28 days and permeability & sorptivity at the age of 28 days under different curing conditions i.e.1 day wet 27 day dry & 7 day wet 21 day dry has been studied. The SEM and XRD analysis has been carried out to inestigate the results.The fluoropolymer was added in different quantities viz. 10, 20 and 30 percent by weight of cement in cement mortar.

On addition of fluoropolymer in the mortar it has been observed that for a constant flow value the water cement ratio decreases as the addition of flouropolymer in the mortar is increased from 10-30 percent by weight of cement. 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 split tensile strength of the fluoropolymer modified mortar, for both 1 day wet 27 day dry & 7 day wet 21 day dry curing conditions, decreases with addition of fluoropolymers upto 10 percent thereafter an increasing trend was observed. However, with the addition of the fluoropolymer both the permeability and sorptivity of the mortar decreases and this decrease in much more under 7 day wet 21 day 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

Mortar and concrete made with Portland cement has been a popular construction material in the world for the past 170 years or more. However, cement mortar and concrete have some disadvantages such as delayed hardening, low tensile strength, large drying shrinkage, and low chemical resistance. To overcome these disadvantages, many attempts to use polymers have been made. One such attempt is polymer-modified (or polymer cement) mortar or concrete, which is made by the modifying ordinary cement mortar or concrete with polymer additives such as latexes, redispersible polymer powders, water-soluble polymers, liquid resins, and monomers. Polymer-modified mortars and concretes have a monolithic co-matrix in which the organic polymer matrix and the cement gel matrix are homogenized. The properties of polymer-modified mortar and concrete are characterized by such a co-matrix. In the systems modified with the latexes, redispersible polymer powders, and water-soluble polymers, the drainage of water from the systems along with the cement hydration leads to film or membrane formation. In the systems modified with the liquid resins and monomers, the addition of water induces the hydration of the cement and the polymerization of the liquid resins or monomers.

1.2 Polymer concrete

Concrete is a porous. The porosity is due to air voids , water voids or due to inherent property of gel structures. On account of porosity strength of concrete is reduced , reduction of porosity result in increase in strength of concrete. The impregnation of monomer and subsequent polymerization is the latest technique adopted to reduce inherent porosity of concrete and increase strength and other properties of concrete.

1.3 Classification of Polymer concrete

There are mainly four types of polymer concrete:

1. Polymer impregnated concrete (PIC)
2. Polymer cement concrete
3. Polymer concrete
4. Partially impregnated and surface coated polymer concrete.

1.3.1 *Polymer impregnated concrete*

The concept underlying PIC is that if voids are responsible for low strength as well as poor durability of concrete in severe environments,then eliminating them by filling with a polymer should improve the characteristics of the material.

It is a 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 a low viscosity monomer is diffused through the open cell and polymerized by using radiation, application of heat or by chemical initiation.It is difficult for a liquid to penetrate if the viscosity of the liquid is high and the voids in concrete are not empty (they contain water and air). Therefore, for producing PIC, it is essential not only to select a low-viscosity liquid for penetration but also to dry and evacuate the concrete before subjecting it to the penetration process.

Mainly the following type of monomers are used:

1. Methyl methacrlylate(MMA)
2. Acrylonitrile
3. t- butyl styrene
4. Other thermoplastic monomer

The amount of monomer that can be loaded into a concrete specimen is limited by the amount of water and air that has occupied the total void space.PIC require cast in situ structures Monomers 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.

After penetration, the monomer has to be polymerized insitu. This can be accomplished in one of three ways.

1. 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.
2. Gamma radiation can also induce polymerization at room temperature, but the health hazard associated with it discourages the wide acceptance of this process in field practice.
3. 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.

A. Casting conventional concrete elements

Since the quality of concrete before penetration is not important from the standpoint of properties of the end product, no special care is needed in the selection of materials and proportioning of concrete mixtures.Section thickness is generally limited to a maximum of about 150 mm, since it is difficult to fully penetrate thick sections.

B. Curing the elements

1. Following the removal of elements from forms, at ambient temperatures conventional moist curing for 28 days or even 7 days is adequate because the ultimate properties of PIC do not depend on the prepenetration concrete quality.
2. For fast production schedules, thermal curing techniques may be adopted.

C. *Drying and evacuation*

1. The time and temperature needed for removal of free water from the capillary pores of moist-cured products depend on the thickness of the elements.
2. At the drying temperatures ordinarily used (i.e.,105 C), it may require 3 to 7 days before free water has been completely removed from a 150- by 300-mm concrete cylinder.
3. Temperatures on the order of 150 C can accelerate the drying process so that it is complete in 1 to 2 days.

D. Soaking the dried concrete in a monomer

1. The in situ penetration of concrete in the field may be achieved by surface ponding, but precast elements are directly immersed in the monomercatalyst mixture.
2. Commercial monomers contain inhibitors that prevent premature polymerization during storage; the catalyst serves to overcome the effect of the inhibitor.

E. Sealing the monomer

To prevent loss of monomer by evaporation during handling and polymerization, the impregnated elements must be effectively sealed in steel containers or several layers of aluminium foil.In the rehabilitation of bridge decks this has been achieved by covering the surface with sand.

F. Polymerizing the monomer

1. Thermal-catalytical polymerization is the preferred technique.
2. The time for complete polymerization of the monomer in the sealed elements exposed to steam, hot water or air, or infrared heat at 70 to C may vary from a few to several hours.

3. In the case of a MMA-benzoyl peroxide mixture,no differences in strength were found between specimens polymerized at C with hot air for 16 hr or with hot water for 4 hr.

G. Significance

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

1.3.2 ***Polymer cement concrete***

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

1. Polyster- 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 material are in compatable 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. The materials and the production technology for concrete in LMC are the same as those used in normal portland cement concrete except that latex, which is a colloidal suspension of polymer in water, is used as an admixture.Earlier latexes were based on polyvinyl acetate or polyvinylidene chloride, but these are seldom used now because of the risk of corrosion of steel in concrete in the latter case, and low wet strengths in the former.Elastomeric or rubberlike polymers based on styrenebutadiene and polyacrylate copolymers are more commonly used now.

A. Latex

1. A latex generally contains about 50 % by weight of spherical and very small (0.01 to 1 m in diameter) polymer particles held in suspension in water by surface-active agents.

2. The presence of surface-active agents in the latex tends to incorporate large amounts of entrained air in concrete; therefore, air detraining agents are usually added to commercial latexes.
3. 10 to 25 percent polymer (solid basis) by weight of cement is used in typical LMC formulations.
4. The addition of latex provides a large quantity of the needed mixing water in concrete.
5. The application of LMC is limited to overlays where durability to severe environmental conditions is of primary concern.
6. LMC is made with as low an addition of extra mixing water as possible; the spherical polymer molecules and the entrained air associated with the latex usually provide excellent workability.

B. Concrete mix

Typically, water-cement ratios are in the range 0.40 to 0.45, and cement contents are on the order of 650 to 700 lb/yd3 (390 to 420 kg/m3).

C. Curing

1. The hardening of a latex takes place by drying or loss of water.
2. Dry curing is mandatory for LMC; the material cured in air is believed to form a continuous and coherent polymer film which coats the cement hydration products, aggregate particles, and even the capillary pores.

D. Properties

1. The most impressive characteristics of LMC are its ability to bond strongly with old concrete, and to resist the entry of water and aggressive solutions.
2. It is believed that the polymer film lining the capillary pores and microcracks does an excellent job in impeding the fluid flow in LMC.
3. These characteristics have made the LMC a popular material for rehabilitation of deteriorated floors, pavements, and bridge decks.

E. Significance

LMC possess excellent bonding ability to old concrete, and high durability to aggressive solutions; it has therefore been used mainly for overlays in industrial floors, and for rehabilitation of deteriorated bridge decks.

1.3.3 ***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 properly grading and mixing the aggregate to attain maximum density and minimum voids.Commercial products are available with a variety of formulations, some capable of hardening to 105 MPa (15,000 psi) within a few minutes without thermal treatment.

1. Epoxy resins are higher in cost but offer advantages such as adhesion to wet surfaces.
2. Styrene monomer, and methyl methacrylate (MMA) with benzoyl peroxide catalyst and an amine promoter are often used.
3. Products with increased strength have been obtained by adding to the PC monomer system a silane coupling agent,which increases the interfacial bond between the polymer and aggregate.
4. The properties of PC are largely dependent on the amount and properties of polymer in the concrete.
5. PC made with MMA is a brittle material that shows a nearly linear stress-strain relationship with high ultimate strength, but the addition of butyl acrylate produces a more ductile material.

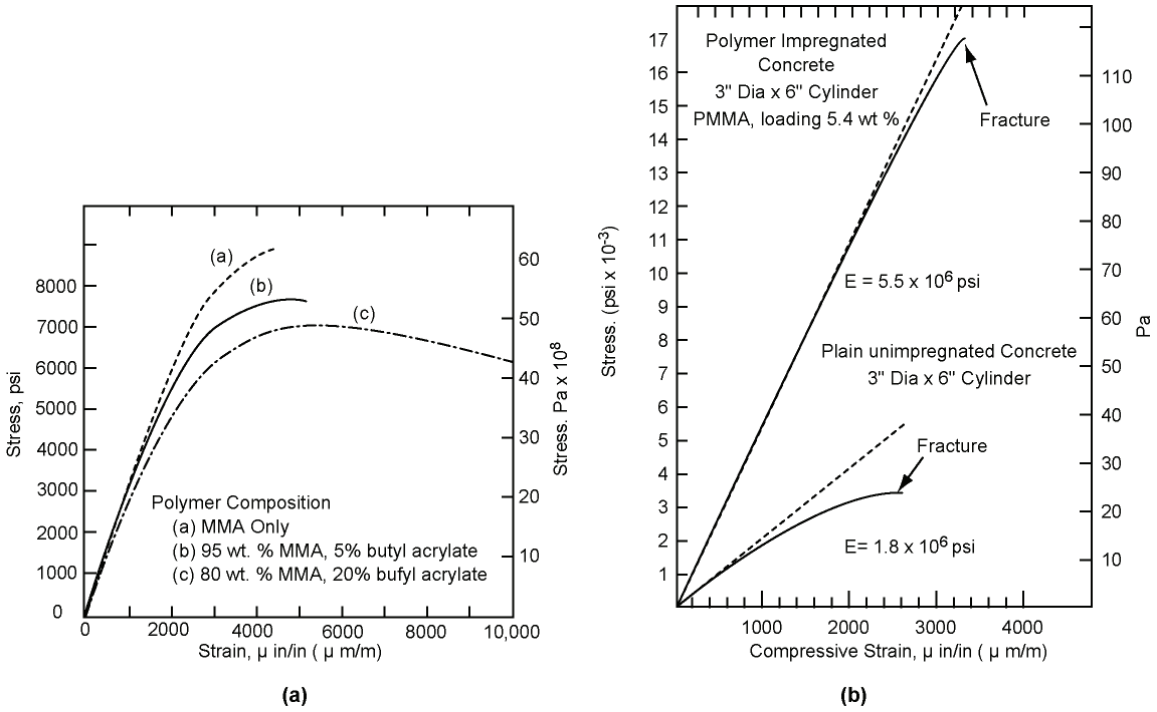


Fig.-1.1 Stress-Strain diagram

A. Properties

1. Due to good chemical resistance and high initial strength and modulus of elasticity, industrial use of PC has been mainly in overlays and repair jobs.
2. Thermal and creep characterstics of the material are usually not favorable for structural applications of PC.
3. Polyester concretes are viscoelastic and will fail under a sustained compressive loading at stress levels greater than 50 percent of the ultimate strength. Sustained loadings at a stress level of 25 percent did not reduce ultimate strength capacity for a loading period of 1000 hr.

B. Significance

Both PC and LMC have been in commercial use since the 1950s; PIC was developed and has been in use since the1970s. Depending on the materials employed, PC can develop compressive strengths of the order of 140 MPa (20,000 psi) within hours or even minutes and is therefore suitable for emergency concreting jobs in mines, tunnels, and highways.

1.4 FlouroPolymer

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 et al. (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.

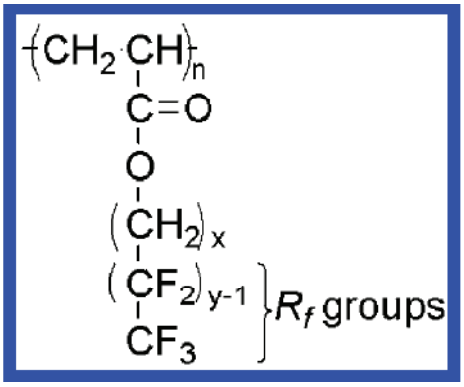


Fig. 1.2: Chemical structure of poly (perfluoroalkyl acrylate)s

[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)

Fluoropolymer is usually olefinic polymer which consists of partially or fully fluorinated olefinic monomers such as vinylidene fluoride (CH2¼CF2) and tetrafluoroethylene (TFE) (CF2¼CF2). More speciality fluorinated polymers include perfluoroethers, fluoroacrylates, and fluorosilicones which are used in significantly smaller volume than olefinic fluoropolymers.

1.4.1 *Fundamental propeties of FlouroPolymer*

- High melting Point,342 ˚C
- High Thermal Stability
- Usefull Mechanical properties at extremely Low and High Temperature
- Insolubility
- Chemical inertness
- Low coefficient of Friction
- Low Dielectric constant/Dissipation Factor
- Low water absorptivity/adsorptivity
- Excelent weatherability
- Flame Resistance
- Purity

1.5 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 by adding different quantities viz. 0%, 10%, 20%, and 30% of fluoropolymer by weight of cement in cement mortar are as under:-

1) To study the effect of fluoropolymer modified mortar on workability.
2) To study the effect of fluoropolymer modified mortar on Compressive Strength,Split tensile strength at the age of 28 days under different curing conditions i.e.(1 day wet 27 day dry & 7 day wet 21 day dry).

3) To study the effect of fluoropolymer modified mortar on Permeability at the age of 28 days under different curing conditions i.e.(1 day wet 27 day dry & 7 day wet 21 day dry).
4) To study the effect of fluoropolymer modified mortar on capillary suction i.e. Sorptivity at the age of 28 days under different curing conditions i.e.(1 day wet 27 day dry & 7 day wet 21 day dry).
5) To study the surface morphology (SEM) & X ray diffraction of various fluoropolymer modified mortars at the age of 28 days under different curing conditions i.e.(1 day wet 27 day dry & 7 day wet 21 days).

CHAPTER – 2

REVIEW OF LITERATURE

2.1 GENERAL

The concept of polymer modification for cement mortar and concrete was put forward before 80 years. Since then, considerable research and development of polymer modification for cement mortar and concrete have been conducted in various countries. As a result, many effective polymer modification systems for cement mortar have been developed and are already used in various applications in the construction industry. Polymer-modified mortar is a good repair material for its many excellent properties, such as the same production progress with cement mortar, good mechanical properties, especially bond strength and toughness, and good durability. In this field, polymer latexes have been widely used and prove to be very good. Although the properties of cement mortars can be improved by adding polymer latex,the polymer modification mechanism is not clear and still much research should be done.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

Zahrani et al. (2003) conducted a study to evaluate the mechanical properties and durability characteristics of nine polymer- and cement-based repair mortars. Mechanical properties, such as compressive, tensile and flexural strength, elastic modulus, shrinkage and thermal expansion were studied.

Seven proprietary repair materials were selected to represent the generic type of repair mortars that are presently utilized in the repair of deteriorated concrete.Three of the selected proprietary repair mortars were cement-based while the other four were polymer-based.In addition to proprietary repair mortars two cement based repair mortars (CB1 and CB2) prepared in the laboratory were also evaluated. Table2.1 summarizes the composition of the repair mortars evaluated in this study.

Table-2.1 Selected cement and polymer based repair mortars (Zahrani et al. (2003))

Repair mortar	Description
CB1	Portland cement mortar (w/c: 0.38, sand/cement 2.5)
CB2	Portland cement silica fume mortar (w/c: 0.38, sand/ cement 2.5, silica fume 5% of total cement)
CB3	Pre-packed blend of Portland cement, fine aggregate, fillers and additives
CB4	Pre-packed blend of Portland cement, fine aggregate and additives
CB5	One component cement-based repair mortar
PB1	Consists of Portland cement, sand and acrylic latex admixture
PB2	Consists of Portland cement, silica fume, fibers and polymer
PB3	Pre-packed blend of cement, silica fume and polymer
PB4	Single component polymer based-repair material. Based on Portland cement, graded aggregate, special fillers and chemical additives

Table-2.2 Compressive strength cement and polymer based repair mortar (Zahrani et al. (2003)).

Repair mortar	Compressive strength (MPa)		
	3 days	7 days	28 days
CB1	39.3	45.4	45.8
CB2	39.4	40.3	44.2
CB3	36.5	44.4	71.9
CB4	34.9	42.9	50.1
CB5	28.5	36.3	44.7
PB1	7.0	9.5	19.3
PB2	26.8	34.7	45.8
PB3	14.4	16.6	24.1
PB4	42.9	43.2	60.4

Table 2.2 shows the compressive strength development in the selected polymer- and cement-based repair mortars. As expected, the compressive strength of specimens prepared with the selected polymer- and cement-based repair mortars increased with the age of curing. After 28 days of curing, the highest compressive strength was measured in the specimens prepared with CB3. The compressive strength of CB3, CB4 and PB4 repair mortars was more than 50 MPa, while the compressive strength of the specimens prepared with PB3 and PB1 was in the

range of 19–24 MPa. The compressive strength of specimens prepared with other proprietary repair mortars, Portland cement mortar and silica fume cement mortar, was around 45 MPa.

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.

Wang et al. (2004) Polymer-modified cement mortars were prepared by varying polymer/cement mass ratio (P/C) with a constant water/cement mass ratio of 0.4. The effect of styrene–butadiene rubber (SBR) emulsion on the physical and mechanical properties of cement mortars is studied. With P/C below 10%, the toughness of the modified mortars enhances with the increase of P/C. A relationship between the physical and mechanical properties of the modified cement mortars at P/C below 10% is found; that is, the compressive strength and flexural strength of the modified mortars are directly proportional to the apparent bulk density. But when P/C is above 10%, the mechanical properties are not highly dependent on the apparent bulk density, and the flexural and compressive strength of the mortars are not improved further with more polymer.Two curing methods [wet cure: 2, 6 or 27 days immersed in 20 8C water; mixed cure: 6 days immersed in 20 8C water followed by 21 days at 20 8C and 70% relative humidity (RH)] were also evaluated in this paper. The results have shown that the mixed cure is more beneficial to the improvement of the mortar properties. The compressive strength of polymer-modified mortars with different P/C is illustrated in Fig. 2.1. It is seen that the compressive strength of the wet-cured modified mortars declines with the increase of P/C between 1% and 8%, and then hardly changes. The longer the cured ages, the higher the compressive strength of the wet-cured modified mortars. This may be attributed to that the long cured time is helpful for the cement hydration and the formation of the polymer film in mortars. The compressive strength of the mixed cured modified mortars sharply increases at the P/C of 1–2%, and then the variation of the compressive strength with P/C is similar to that of wet-cured mortars. However, the compressive strength of the mixed-cured mortars is higher at a same P/C.

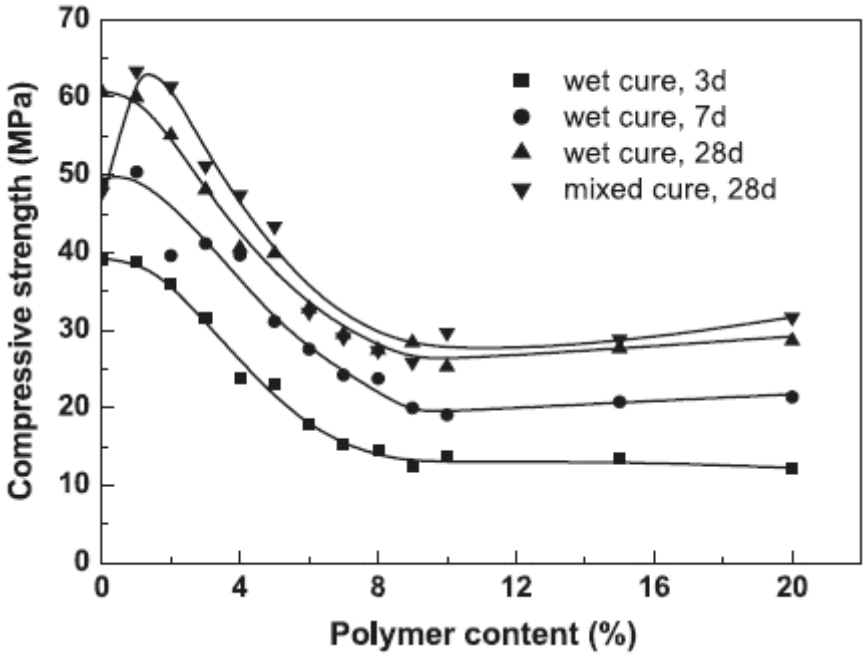


Fig.-2.1 Compressive strength of polymer-modified mortar with different polymer/cement mass ratio (P/C) (Wang et al. (2004))

Materials

Portland cement type P II 52.5R, according to Chinese standard GB 175, and standard sand, according to ISO 679,were used for preparing the specimens. The chemical composition and physical properties of the cement are listed in Tables-2.3 and 2.4, respectively. The Styrofan SD622S styrene–butadiene rubber (SBR) emulsion (viscosity: 30 mPad s; Tg: 11 8C; pH: 9.5; solid content: 47%) and deionized water were used in the experiment

Table-2.3 Chemical composition of P 52.5R portland cement (Wang et al. (2004))

Component	SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	TiO_2	BaO
Content (%)	21.3	65.1	5.1	2.9	1.1	1.8	0.7	0.2	0.3

Table-2.4 Physical properties of P 52.5R portland cement (Wang et al. (2004))

Specific gravity (20 °C), ($g \cdot cm^{-3}$)	Fineness		Setting time		Flexural strength of mortar (MPa)			Compressive strength of mortar (MPa)		
	Residue on sieve of 80 μm (%)	Blaine's specific area ($m^2 \cdot kg^{-1}$)	Initial set (h)	Final set (h)	3 days	7 days	28 days	3 days	7 days	28 days
3.20	0.5	385.50	2.05	3.17	6.94	7.77	8.43	39.04	48.98	60.62

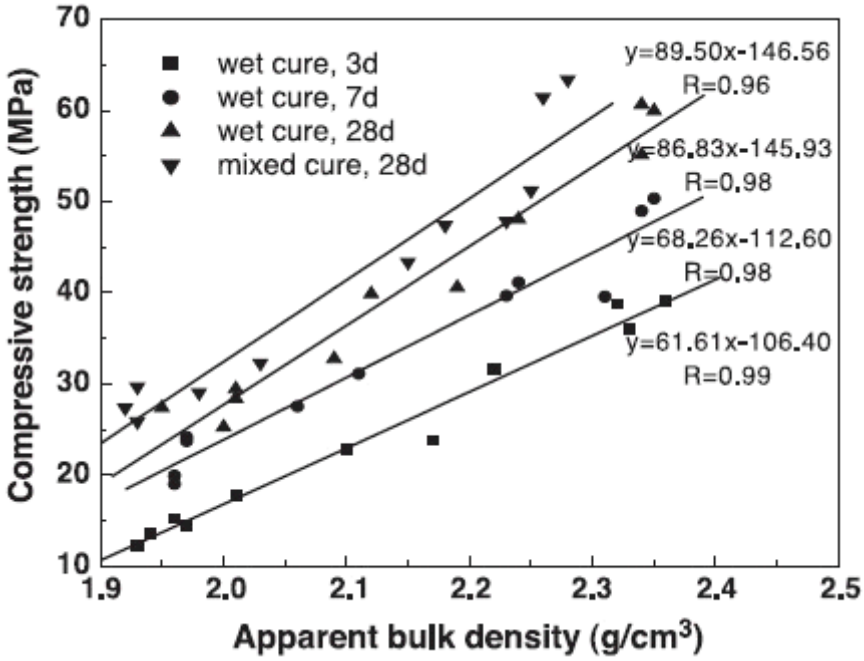


Fig.-2.2 Relationship between the compressive strength and apparent bulk density of polymer-modified mortars (P/C<10%) (Wang et al. (2004))

With the same water/cement mass ratio, the apparent bulk density and compressive and flexural strengths of the polymer-modified mortars rise slightly when a little SBR emulsion is added, and then all of them decline with increasing P/C. But when P/C is above 10%, the apparent bulk density grows with increasing P/C and the strength hardly changes. The toughness of the modified mortars can be improved markedly and the higher the P/C, the higher the toughness at P/C below 10%. The compressive and flexural strengths of the modified mortars have good relations with the apparent bulk density at P/C below 10%; that is, they are directly proportional to the apparent bulk density. With P/C above 10%, the polymer films in the mortars become thicker and the flexural and compressive strengths are not improved further. The relationship between the strength and apparent bulk density of the modified mortars at P/C above 10% is no longer coincident with the linearity at P/C below 10% as shown in Fig.2.2. The interpenetrating structure between the polymer and cement hydrates forms at a P/C of 8%, and fully develops at a P/C of 10%. The properties of the polymer-modified mortars are influenced by the polymer film, cement hydrates, and the associative structure between the organic and inorganic phases. The mixed cure is more beneficial to the improvement of the mortar properties.

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.

2.2.2 *Flexure strength*

Wang et al. (2004) The mortar specimens were prepared with polymer/cement mass ratio (P/C) of 1–20%, water/cement mass ratio of 0.40 and sand/cement mass ratio of 3. The polymer emulsion was added to water firstly, then specimens with the dimension of 40_40_160 mm were prepared according to GB 17671 (ISO 679). The specimens were demolded after 1 day. Two curing methods [wet cure: 2, 6 or 27 days immersed in 20 8C water; mixed cure: 6 days immersed in 20 8C water followed by 21 days at 20 8C and 70% relative humidity (RH)] were used. The flexural strength of the wet-cured modified mortars with different cured ages rises slightly at the P/C of 1–2%, then declines with growing P/C until it reaches 7% as shown in Fig. 2.3. The flexural strength is hardly dependent upon the P/C range of 8–10%. However, the change of the flexural strength with increasing P/C is different for the mortars with different cured ages at P/C above 10%: it decreases for 3 days, hardly changes for 7 days and goes up for 28 days. The longer cured age makes the flexural strength higher at the same P/C. For the mixed-cured modified mortars, the flexural strength rises remarkably when a small amount of polymer is added, and then slightly declines. When the P/C is higher than 8%, the flexural strength goes up again. All the flexural strengths of the mixed-cured modified mortars are higher than that of the control mortar, indicating that the mixed cure is more helpful for the development of the flexural strength. This must be due to the easier polymer film formation and to the higher degree of cement hydration under this curing condition.

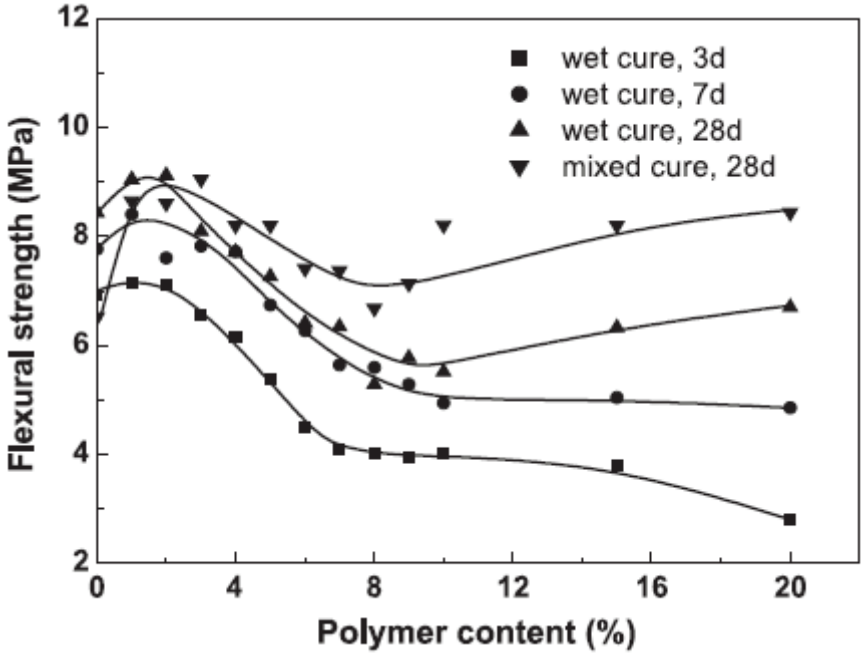


Fig.-2.3 Flexure strength of polymer-modified mortars with different polymer/cement ratio (Wang et al. (2004))

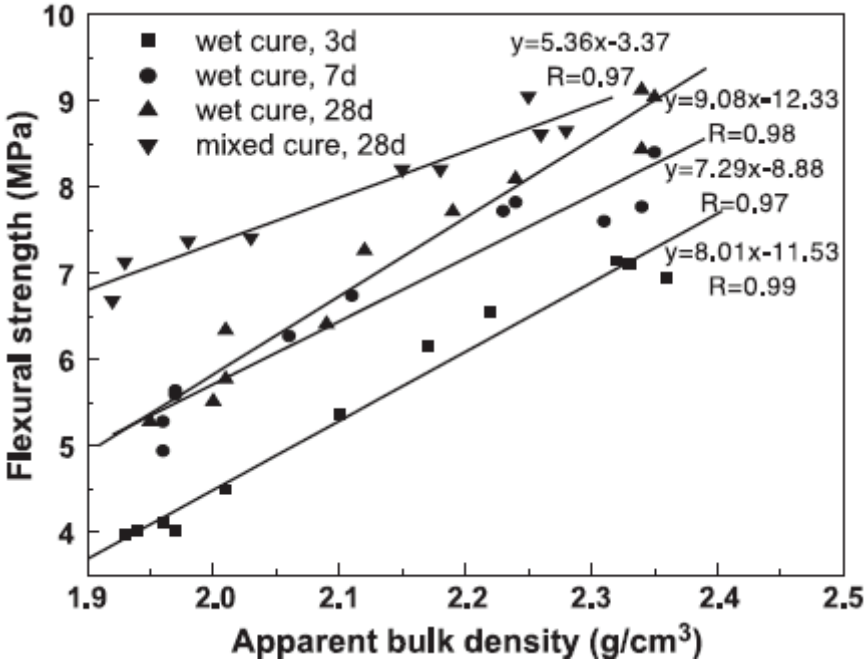


Fig.-2.4 Relationship between the flexure strength and apparent bulk density of polymer-modified mortars (P/C<10%) (Wang et al. (2004))

The relationships between the flexural strength and the apparent bulk density of polymer modified mortars at P/C below 10% are illustrated in Fig 2.4, respectively. It is clear from these figures that the flexural strengths of the modified mortars are directly proportional to the apparent bulk density no matter what curing age and method are used; that is, the strength

rises linearly with the apparent bulk density. From the slope of the line, it is seen that the rise of the compressive and flexural strengths with increasing apparent bulk density is faster for 28-day than for 3- or 7-day wet-cured mortars. The flexural strengths of the modified mortars increase with prolongation cured ages at the same apparent bulk density. The growing rate of the compressive strength with the apparent bulk density of the mixed-cured modified mortars is close to that of 28 days wet-cured, but that of its flexural strength is slower. Nevertheless, both the compressive and flexural strengths of the mixed-cured modified mortars are higher at the same apparent bulk density. It implies that the cement hydration and polymer film are also important factors for the compressive and flexural strengths of the modified mortars, except for the apparent bulk density. In our experiment, it is found that the strength of the modified mortars is not highly dependent on the apparent bulk density at P/C above 10% and the relationship between them is no longer coincident with the linearity at P/C below 10%.

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.

Zulkarnain et al. (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.

2.2.3 *Workability*

Aggarwal et al. (2007) studied the properties of the cement mortar modified with the newly developed epoxy emulsion & compared with those of the acrylic-modified mortar. The results showed that the mortars with the newly developed system have superior strength properties and better resistance to the penetration of chloride ions and carbon dioxide. Epoxy emulsion was prepared by emulsifying epoxy resin, based on diglycidyl ether of bisphenol-A, and amino-amide based hardener in water by using a non-ionic surfactant. Additives like defoaming, wetting and anticatering agents, and fillers were also used. For both, epoxy emulsion and acrylic emulsion, similar dosages of additives were used. The prepared epoxy emulsion had density of 1.00–1.05 g/cm3, epoxide equivalent value of 200–300 g eq and total solids of 60 ± 2%; while acrylic emulsion had density of 1.05–1.10 g/cm3 and total solids 38 ± 2%.Ordinary Portland cement, grade 43, and quartz sand No. 10 were used for making the PMM test specimens.To study the effect of polymer–cement ratio on various properties specimens were prepared by varying the polymer–cement ratio from 0% to 30% by mass of cement. A cement–sand ratio of 1:3 by mass was kept constant for all the specimens. For all the mixes the water–cement ratio (w/c) was adjusted to maintain a constant flow between 110 and 120 mm.The effect of polymer addition on water–cement ratio required to maintain the desired flow (110–120 mm) is shown in Fig. 2.5. The required quantity of water decreases with the addition of both polymers. However, the decrease is relatively more in case of acrylic emulsion. A reduction in water requirement

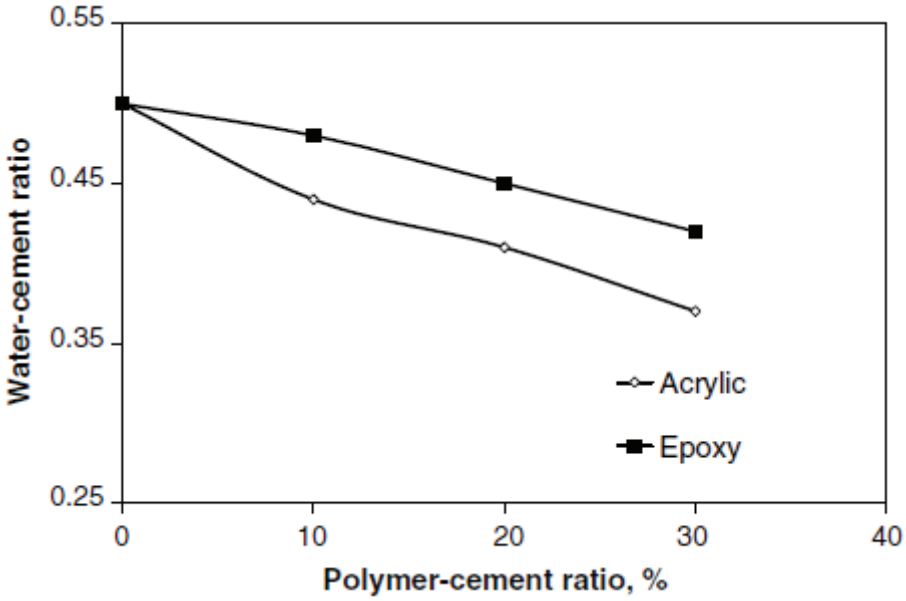


Fig.-2.5 Effect of polymer addition on w/c ratio required to maintain flow (Aggarwal et al. (2007))

was expected not only due to the presence of surfactants in the polymers but also due to the lower surface tension of polymer molecules, which facilitates better flow of the mix at the same water content.

2.3 Durability properties

2.3.1 *Permeability*

Ramli et al. (2012) studied the oxygen permeability of unmodified controls and polymer-modified specimens was determined from a 50 mm diameter mortar sample using a Leeds cell permeameter developed by Cabrera and Lynsdale. The test was carried out in a laboratory controlled temperature at 20 ± 2 _C, RH 65 ± 5% and free from draughts.The effects of polymer addition on the permeability characteristics of cement mortars are presented in Figs.2.6-2.8. According to the figures, the permeability of all mixes decreased with the increasing age of curing. Furthermore, the permeability of PMMs was found to be much lower than that of the unmodified controls. This was due to the partial filling micro-pores and voids by polymer particles as the cement hydration process continued. The intrinsic permeabilities of SBR3 and PAE were about 0.2×10^{-16} m^2 at the age of 28 days and 0.1×10^{-16} m^2 at 18 months compared to those of the unmodified control, CON, which were about 1.05 and $0.4\times10^{-16}m^2$, respectively.However, the VAE-modified mortar, which comprised of polymer powder, did not seem to perform as good as the SBR latex or the PAE emulsion, although their polymer loadings were the same. The results also revealed that a polymer modification greatly enhanced the permeability of cement mortar. Low permeability

properties in the PMMs were attributed to the fact that polymer particles, being much smaller than the sand and cement particles, filled the smaller voids and eventually coalesced into a monolithic film that surrounded the aggregate and coated the cement particles. The resulting matrix also prevented the formation of micro-cracks, thereby improved the impermeability characteristics of the mortar.

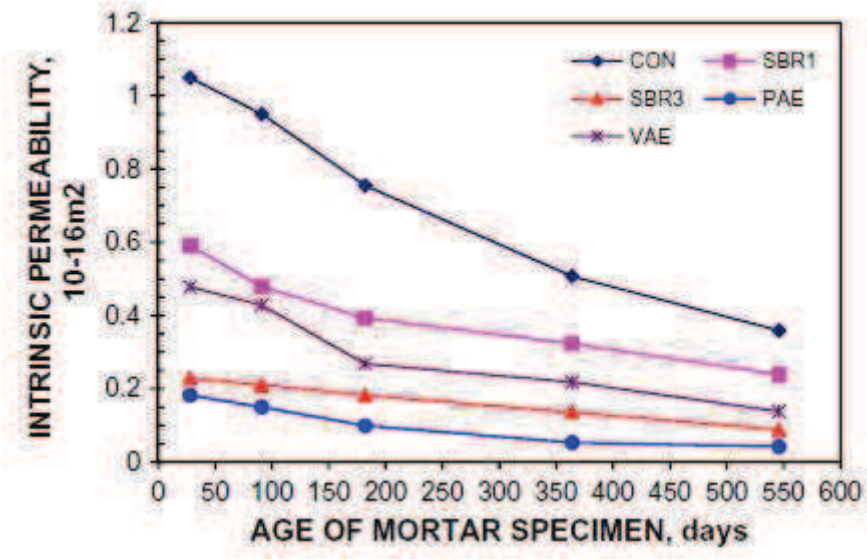


Fig.-2.6 Intrinsic permeability of mortar specimen under prolonged air curing (Ramli et al. (2012))

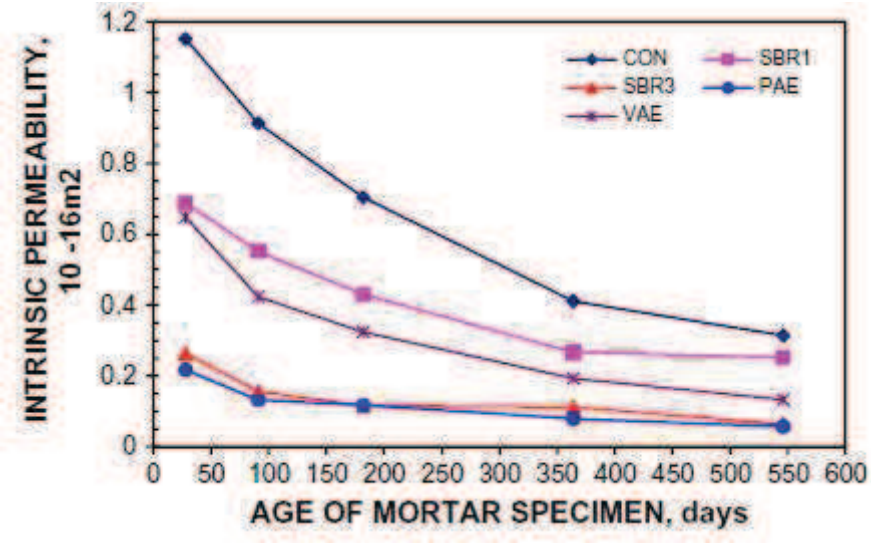


Fig.-2.7 Intrinsic permeability of mortar specimen under prolonged water curing (Ramli et al. (2012))

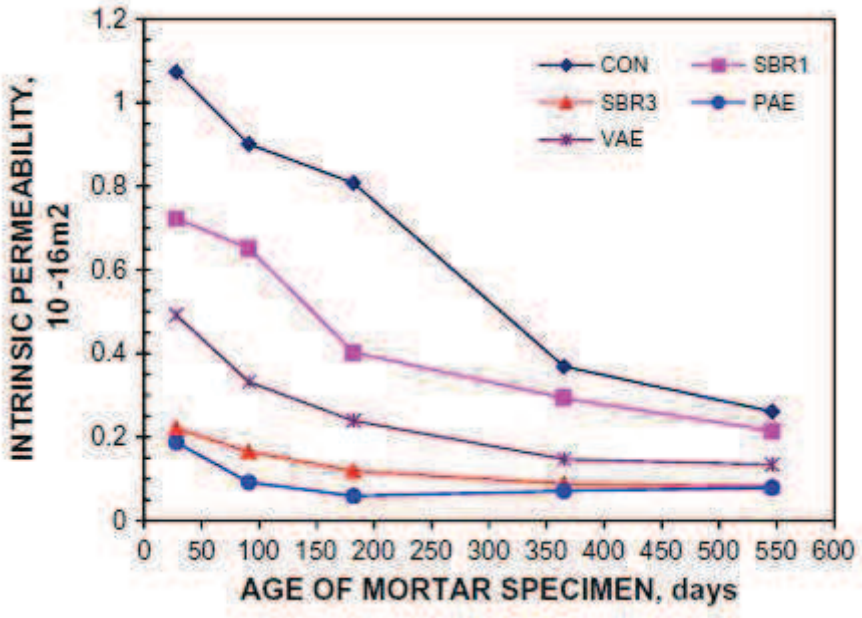


Fig.-2.8 Intrinsic permeability of mortar specimen under prolonged air and water curing (Ramli et al. (2012))

Zahrani et al. (2003) conducted a study to evaluate the durability characteristics of nine polymer- and cement-based repair mortars. The durability characteristics of the repair materials were evaluated by measuring: chloride permeability.

The chloride permeability of the selected polymer- and cement-based repair materials is summarized in Table 2.5.This table also provides the chloride permeability classification according to ASTM C 1202. Chloride permeability of the selected polymer- and cement-based repair materials was in the range of 158–1368 C and is therefore classified as very low-to-low, as per ASTM C 1202 criterion. The results show that there is no clear difference between the cement- and polymer-based repair mortars with regard to the chloride permeability. Since the chloride permeability indirectly provides an indication of the electrical resistivity of concrete, these data indicate that both the cement- and polymer-based repair materials would be effective in reducing reinforcement corrosion.

Table-2.5 Chloride permeability of cement and polymer-based repair mortar specimen (Zahrani et al. (2003))

Repair material	Chloride permeability (C)	ASTM C 1202 chloride classification
CB1	1043	Low
CB2	608	Very low
CB3	377	Very low
CB4	1368	Low
CB5	744	Very low
PB1	1002	Low
PB2	613	Very low
PB3	158	Very low
PB4	334	Very low

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 addition of fluoropolymer emulsion on compressive strength, split tensile 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.

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)	35.5	-
2.	Fineness of cement as retained on 90μ Sieve (percent)	2	2 – 5
3.	Specific gravity	2.98	-
4.	Soundness of cement (mm) by Le-chatelier apparatus	2	10
5.	Initial setting time (minutes)	110	30 (minimum)
6.	Final setting time (minutes)	400	600 (maximum)
7.	Compressivestrength (N/mm^2) 7 days 28 days	 23.82 44.24	 22 (minimum) 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 as shown in Table 3.2

Table 3.2 Grading of fine aggregate as per IS:383:1970

Sr No.	IS seive designation	Percentage passing for			
		Grade 1	Grade 2	Grade 3	Grade 4
1	10mm	100	100	100	100
2	4.75mm	90-100	90-100	90-100	95-100
3	2.36mm	60-95	75-100	85-100	95-100
4	1.18mm	30-70	55-90	75-100	90-100
5	600µ	15-34	35-59	60-79	85-100
6	300µ	5-20	8-30	12-40	15-50
7	150µ	0-10	0-10	0-10	0-15

Table 3.3: 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 3.3 and Table 3.4 respectively.

Table: 3.4 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. 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 3.5. The Physical/Chemical properties of AsahiGuard E-series (AG-E400) synonym fluoropolymer emulsion used in the experiments are given in the Table 3.6.

Table 3.5: 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 3.6: 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%, 10%, 20%, 30%, by weight of Cement

c) Strength development — 28 days

d) Curing regime

i. 1 day Wet 27 day Dry curing :refers to sample cured in water for 1 day at room temperature after demoulding the sample& kept dry for 27 days up to age of testing.

ii. 7 day Wet & 21 day dry 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, split tensile 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 of 110±5 mm for varying percentage of polymer contents from 0 to 30%. Detail descriptions of tests are given below:-

3.4.1 *Flow test*

The flow test is conducted at a constant flow value and varied water cement ratio for each addition of flouropolymer content. The cement sand ratio was used as 1: 2. The constant flow value 110±5 was fixed at for every flouro polymer addition. The effect of polymer was studied and the fluoropolymer emulsion was used in liquid form in this experimental study. It was find that For a constant flow value both the water cement ratio and the total liquid content decreases as we go on adding the flouropolymer. The amount of polymer added was 10%, 20% and 30%. Hence everytime a new value of w/c ratio is found out at each particular addition of polymer for constant flow. 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 Fig. 3.2. 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:

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

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 30% were studied. 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. 1 day wet 27 day dry & 7 day wet 21 day dry. Detail regarding number of specimen given below.

For 1 day wet 27 day dry curing:-

Percentage of fluoropolymer emulsion	0%	10%	20%	30%
No. of specimens	3	3	3	3

Total specimens = 12

For 7 day wet 21 day dry curing:-

Percentage of fluoropolymer emulsion	0%	10%	20%	30%
No. of specimens	3	3	3	3

Total specimens = 12

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 × 70.6 × 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.

Fig. 3.3: Cube specimens of size 70.6 mm x 70.6 mm x 70.6 mm each sample to be vibrated at 12000 cycles per minute

Fig.3.4: Vibrating machine

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 age of 1 day and surface water was wiped off and they were left for dry curing for 27 days. The dried cube specimens of size 70.6 mm x 70.6 mm x 70.6 mm were tested at the age of 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

Similarly for 7 day wet 21 day dry 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 days and surface water was wiped off and they were left for dry curing for 21 days. Then these cube specimens were similarly tested as described above, and then compressive strength was calculated by the above given formula.

3.4.3 *Split tensile strength*

To determine the tensile strength of concrete/mortar the indirect method of split tensile strength is generally employed as it is practically not possible to measure directly the tensile strength. This method consist of applying the load along the diameter of the cylindrical specimen. Determination of split tensile strength of the fluoropolymer emulsion modified cement mortar with varying contents of polymer from 0 to 30% were studied. Cylindrical specimens of 100mm (diameter) × 200 mm (long) were casted & were cured under different curing regimes i.e. (1 day wet 27 day dry & 7 day wet 21 day dry) tested at 28 days. Detail regarding number of specimen given below

For 1 day wet 27 day dry curing:-

Percentage of fluoropolymer emulsion	0%	10%	20%	30%
No. of specimens	3	3	3	3

Total specimens = 12

For 7 day wet 21 day dry curing:-

Percentage of fluoropolymer emulsion	0%	10%	20%	30%
No. of specimens	3	3	3	3

Total specimens = 12

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 color 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 100mm × 200mm as and then gets vibrated to ensure proper compaction as shown in Fig. 3.6(a) and Fig. 3.6(b) 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 cured under different curing regimes i.e.(1 day wet 27 day dry & 7 day wet 21 day dry) tested at 28 days.

Fig. 3.6(a) Cylindrical mould for specimen of Size 100 mm x 200 mm

Fig.3.6(b) Casted cylinders

The cylinders were placed with their longitudinal axis perpendicular to the load application. The compressive load is applied along the diameter of cylinder as shown in Fig 3.7 and split tensile strength is calculated as:

$SPT=2P/\Pi dl$

Where

P=Compressive Load along the Diameter

D=Dia. Of Cylinder (100mm)

L=Length of Cylinder (200mm)

Fig3.7 Cylinderical test specimen tested under UTM

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 30%, cylindrical specimens of 100mm (diameter) × 200 mm (long) were casted under different curing regime i.e. I day wet 27 day dry & 7 day wet 21 day dry tested at 28 days. Detail regarding number of specimen given below.

For 1 day wet 27 day dry curing:-

Percentage of fluoropolymer emulsion	0%	10%	20%	30%
No. of specimens	3	3	3	3

Total specimens = 12

For 7 day wet 21 day dry curing:-

Percentage of fluoropolymer emulsion	0%	10%	20%	30%
No. of specimens	3	3	3	3

Total specimens = 12

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 color 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 × 200mm as shown in Fig. 3.8 (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 for curing under different curing conditions i.e. (I day wet 27 day dry & 7 day wet 21 day) at room temperature in the laboratory as shown in Fig. 3.8(b).

Fig. 3.8(a) Cylindrical mould for specimens

Fig. 3.8 (b) Casted cylinders

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. 3.9 the cylindrical specimen of 51 mm (long) x 100 mm (diameter) size were cut from cores as shown in Fig. 3.10.

Fig. 3.9: Cylindrical specimens cutting machine

Fig. 3.10: 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 3.11 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 3.11: Vacuum desiccators' bowl

The specimens were removed from the desiccator, dried and placed in gasket. The specimen is then placed in the testing apparatus as shown in Fig. 3.12 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. 3.13. 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.3.12: Rapid chloride permeability test setup

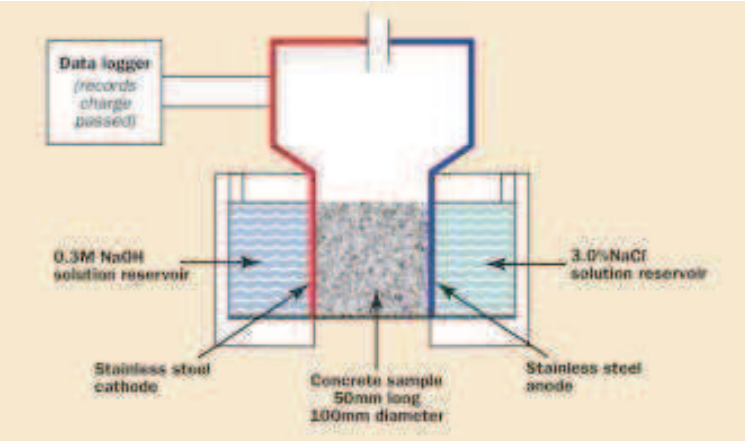


Fig.3.13: Schematic of rapid chloride permeability test setup

3.4.5 *Sorptivity test*

The sorptivity can be determined by the measurement of the capillary rise absorption rate on reasonably homogenous material. To determine the sorptivity of fluoropolymer emulsion modified cement mortar with varying contents of polymer from 0 to 30%, cylindrical specimens of 100mm (diameter) X 200 mm (long) were casted & were cured under different curing regime i.e(I day wet 27 day dry & 7 day wet 21 day dry) tested at 28 days. Detail regarding number of specimen given below.

For 1 day wet 21 day dry curing:-

Percentage of fluoropolymer emulsion	0%	10%	20%	30%
No. of specimens	3	3	3	3

Total specimens = 12

For 7 day wet21 day dry curing:-

Percentage of fluoropolymer emulsion	0%	10%	20%	30%
No. of specimens	3	3	3	3

Total specimens = 12

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 × 200mm as shown in Fig 3.8(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 for curing under different curing conditions i.e. (1 day wet 27 day dry & 7 day wet 21 day) at room temperature in the laboratory as shown in Fig. 3.8(b). For sorptivity testing when the casted cylindrical specimens of 100 × 200 mm attained the age of testing i.e. 28 days, then specimen cutter machine as shown in Fig. 3.9 the cylindrical specimen of 51 mm (long) x 100 mm (diameter) size were cut from cores as shown in Fig. 3.10.Water was used as the test fluid.The cylinrical specimens of size 100mm dia×50mm height after curing under respective conditions were dried in oven at temperature of 100+10℃ and weight was measured .Then the samples were drowned with water level not more than 5mm above the base of specimen and the flow from the peripheral surface is prevented by sealing it properly with non-absorbent coating.The quantity of water absorbed in time period of 30 minutes was measured by weighting the specimen on a top pan balance weighting upto 0.1mg.surface water on the specimen was wiped off with a dampened tissue and each weighting operation was completed within 30 second. Sorpitivity is a tendency of a porous material property which characterizes the tendency of a porous material to absorb and transmit water by capillarity.The cumulative water absorption (per unit area of the inflow surface) increases as the square root of elapsed time (T).

Note-: $S=I/\sqrt{t}$

A=Surface area of specimen through which water penetrated

d=Density of water

S=Sorptivity in cm/√sec

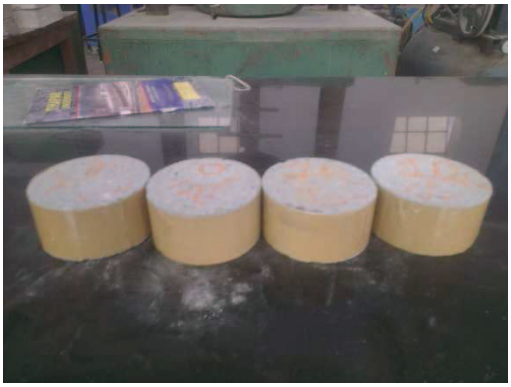
$I=\Delta W/Ad$

ΔW=Change in weight=W_2-W_1

Where t=Elapsed time in minute

W_1=Oven dry weight of cylinder in grams

W_2=Weight of cylinder after 30 minutes capillary suction of water in grams



(a)

(b)

(c)

Fig. 3.14 Sorptivity test

3.4.6 *X-ray diffraction*

X-ray powder diffraction (XRD) is a rapid analytical technique primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. The analyzed material is finely ground, homogenized, and average bulk composition is determined .X-ray diffractometers consist of three basic elements: an X-ray tube, a sample holder, and an X-ray detector.

X-rays are generated in a cathode ray tube by heating a filament to produce electrons, accelerating the electrons toward a target by applying a voltage, and bombarding the target material with electrons. When electrons have sufficient energy to dislodge inner shell electrons of the target material, characteristic X-ray spectra are produced**.**To determine the chemical compounds formed in different specimens cured under both the conditions i.e (1

day wet 27 day dry & 7 day wet 21 day dry),the samples were extracted from the casted specimens from the very cores of them and they were analysed in x rayon machine.The sample for x ray analysis was pulverized to a powder form and subjected to x rays as shown in Fig. 3.15 and 3.16.

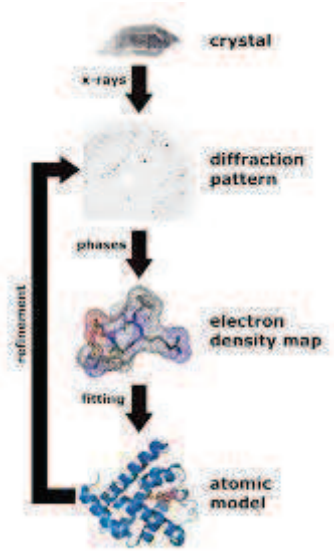


Fig 3.15 X-ray diffraction technique

Fig 3.16 X-ray diffraction test

3.4.7 *Scanning electron microscopy*

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometer. Specimens can be observed in high vacuum, in low vacuum, in wet conditions (in environmental SEM), and at a wide range of cryogenic or elevated temperatures. To determine the surface morphology in different specimens cured under both the conditions i.e (1 day wet 27 day dry & 7 day wet 21 day dry),the samples were extracted from the casted specimens from the very cores of them and they were analysed under electrons.The sample were prepared in small granular form and were tested at the age of 28 ays.

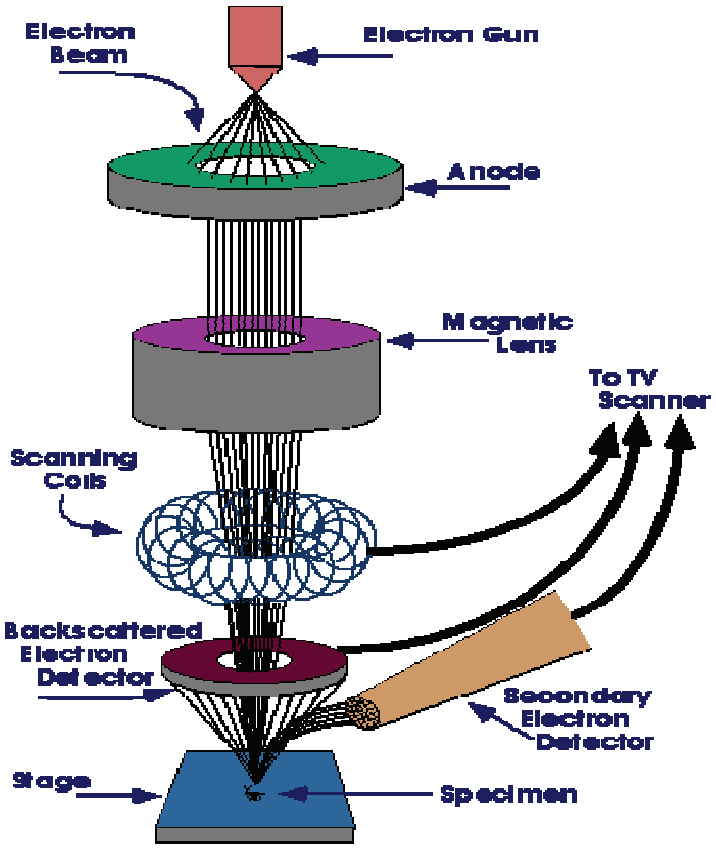


Fig. 3.17 Scanning electron microscopy

Fig.3.18 Scanning electron microscopy test

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 detailed. In order to discuss the results of different parameters like compressive strength, split tensile 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 30 percent. Then as per calculated total liquid contents (water and polymer) by flow test, three cubes each for varying percentage of polymer for different curing conditions (1 day wet 27 day dry & 7 day wet 21 day dry) were prepared with the specimens as designated in the Table 4.1, for investigation of compressive strength, and three cylinders each for varying percentage of polymer for different curing conditions(1 day wet 27 day dry & 7 day wet 21 day dry) were prepared for investigation of split tensile strength, sorptivity, water permeability.

Table 4.1: Designation of specimens for addition of different percentage of fluoropolymer emulsion contents in mortar mix w.r.t. cement content

Sr. No.	Addition of fluoropolymer emulsion contents in mix w. r. t. cement contents	Specimen designation
1	0%	F-0
2	10%	F-10
3	20%	F-20
4	30%	F-30

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 be defined as the amount of useful internal work necessary to produce full compaction.

In present study, the constant flow value of 110±5 mm was fixed for zero percent polymer addition, then the flow test were conducted for addition of varying percentage i.e. 10, 20 &

30 percent of polymer with reducing water-cement ratio as fixed for zero percent polymer. Experimental results shown in Table 4.2 depict that for the constant flow value the amount of water decreases to 78 percent to (that of water which was added in control mortar) with the addition of 10 percent polymer contents, decrease to 54 percent with the addition of 20 percent polymer contents and decrease to 30 percent with addition of 30 percent polymer contents. Experimentally it was found that fluoropolymer emulsion modified cement mortar provides better workability over conventional cement mortar. This increase in flow value may be due to fact that the flouropolymer particles are smaller than both the cement & sand particles and thus act as ball bearings providing hinge type action and increasing the workability and entrained air in Polymer modified mortar may be another reason to increase the workability.

Table 4.2 Constant workability at varying w/c ratio & fluoropolymer emulsion

Sr. No.	Specimen	Cement (Kg)	Sand (Kg)	Water Content (Kg)	Fluoropolymer emulsion Content (Kg)	Water added from floroplymer emulsion (Kg)	Total liquid content (Kg)	Flow value (mm)
1	F-0	1	2	0.56	0.00	0.0000	0.56	115
2	F-10	1	2	0.44	0.05	0.0745	0.52	115
3	F-20	1	2	0.30	0.10	0.1490	0.45	112
4	F-30	1	2	0.17	0.15	0.2235	0.40	111

NOTE: Water content of flouropolymer is 74.5 percent

4.3 Compressive strength

To study the effect on compressive strength, three cubes (size 70.6 x 70.6 x 70.6 mm) each for varying percentage 0, 10, 20 and 30 percent of polymer contents for both curing conditions i.e.(1 day wet 27 day dry & 7 day wet 21 day dry) were cast keeping workability constant as described in section 3.4.2 of chapter 3. The results of compressive strength for the specimens under different curing conditions are shown in Table 4.3 & and Fig.4.1

Table 4.3: Comparison between 1 day wet 27 day dry curing and 7 day wet 21 day dry curing conditions for compressive strength tested at 28 days

Sr. No.	Specimen	Compressive strength after 28 days (N/mm^2)	
		1 day curing 27 dry	7 day curing 21 dry
1	F-0	21.23	24.02
2	F-10	15.97	17.05
3	F-20	17.97	19.62
4	F-30	21.90	24.35

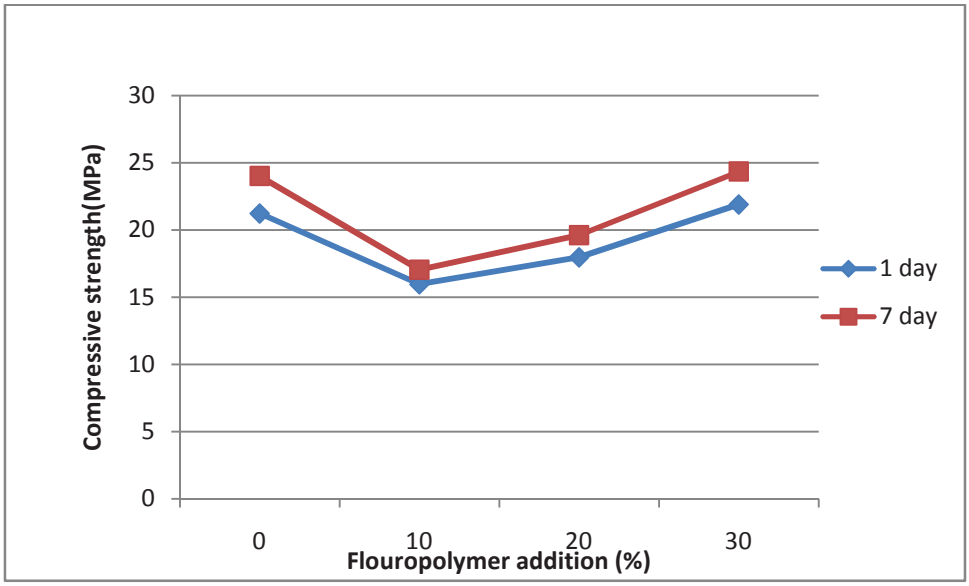


Fig 4.1 : Comparison between 1 day wet 27 day dry curing and 7 day wet 21 day dry curing conditions for compressive strength tested at 28 days

Average results of three specimens of the compressive strength test on fluoropolymer emulsion modified cement mortar of all four mix at the age of 28 days are given in the Table 4.3 and shown graphically in Fig. 4.1.

The variation of 28 days compressive strength of both (1 day wet 27 day dry & 7 day wet 21 day dry) 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 addition of fluoropolymer emulsion is increased in the mix up to 10 percent and after that compressive strength slightly increases at 10 percent to 20 percent flouropolymer

addition and on further increasing the flouropolymer content from 20 percent to 30 percent strength increases and becomes equal to the strength at control for both curing conditions.

- The compressive strength for same proportions of cement and flouropolymer is more for mixes cured at 7 day wet 21 day dry & 1 day wet 27 day dry .This increase is approximately 7-13 percent. The higher increase is in the case of 30 percent flouropolymer addition.
- This change in compressive strength has been analyzed through SEM test discussed in section 4.8 and detailed in section 4.8.1 and 4.8.2:
    a) It is observed from the SEM results that with zero percent flouropolymer addition a uniformly distributed C-S-H gel is formed.
    b) Further the results show that with increase in floropolymer content to 10 percent in the mortar the percentage of C-S-H gel starts reducing and Ettringite starts forming which is a weak structure but as we go on increasing the percentage of flouropolymer further the C-S-H gel percentage increases and that of Ettringite reduces with 20 percent flouropolymer addition & still further at 30 percent flouropolymer addition the C-S-H forms uniformly over the entire surface area making a dense proportion which is responsible for the higher strength.
- Moreover, the change in compressive strength of different flouropolymer modified mortar specimen can be analyzed through XRD results as shown in Tables-4.8 & 4.9.

    a) It is observed from the Tables 4.8 & 4.9 that percentage of C-S-H gel with zero percent flouropolymer addition is 28 percent, which reduces to 23 percent at 10 percent flouropolymer addition and as we increase the addition of flouropolymer emulsion from 10-20 percent and 20-30 percent the percentage of C-S-H gel increases to 25 percent & 29 percent respectively (for 1 day wet 27 day dry cured specimens).

    b) For 7 day wet 21 day dry cured specimens the percentage of C-S-H gel improves slightly for each specimen. At zero percent flouropolymer addition the percentage C-S-H gel is 31 percent, which reduces to 25 percent with 10 percent flouropolymer addition, and on further increasing the flouropolymer

content up to 20 percent and 30 percent the percentage C-S-H gel is 29 percent and 31 percent respectively which validates the above results.

4.4 Split tensile strength

To study the effect on split tensile strength, three cylinders (size100mmdia.x 200 mm height) each for varying percentage i.e.0, 10, 20, 30 percent of polymer contents for both curing conditions i.e.(1 day wet 27 day dry & 7 day wet 21 day dry) were cast keeping workability constant as described in section 3.4.3 of chapter 3. The results of split tensile strength for the specimens under different curing conditions are shown in Table 4.4 & and Fig.4.2.

Table 4.4 Comparison between 1 day curing 27 day dry and 7 day curing 21 day dry curing conditions for split tensile tested at 28 days

Sr. No.	Specimen	Split tensile test after 28 days (N/mm^2)	
		1 day curing 27 dry	7 day curing 21 dry
1	F-0	1.38	1.59
2	F-10	1.31	1.47
3	F-20	1.76	1.92
4	F-30	2.06	2.31

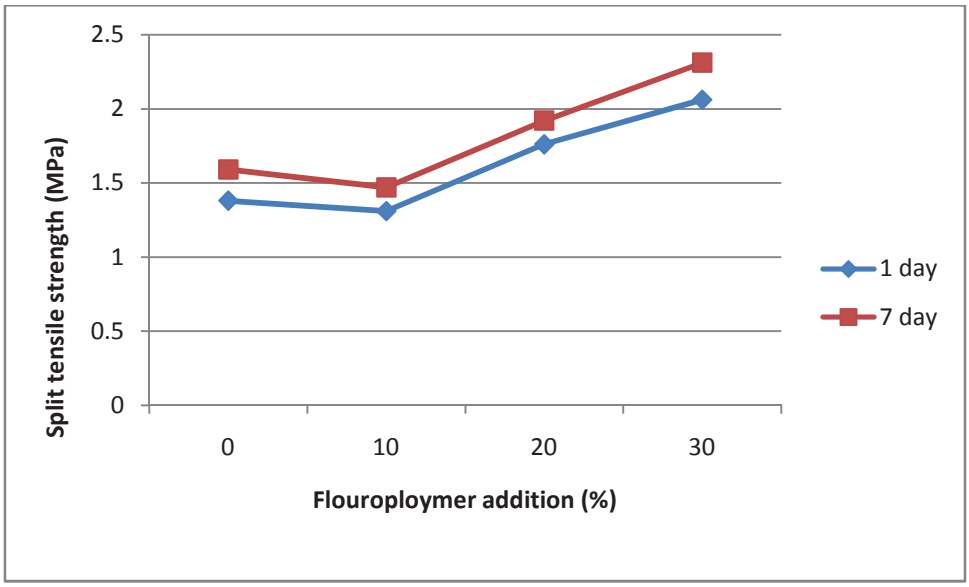


Fig 4.2 Comparison between 1 day curing 27 day dry and 7 day curing 21 day dry curing conditions for split tensile tested at 28 days

Average results of three specimens of the split tensile strength test on fluoropolymer emulsion modified cement mortar of all four mix at the age of 28 days are given in the Table 4.4 and represented graphically in Fig. 4.2

The variation of 28 days split tensile strength of both (1 day wet 27 day dry & 7 day wet 21 day dry)curing conditions for all mixes under examination are evaluated and from the graphs it is observed that:-

- The split tensile strength decreases as compared to control mix as the percentage of fluoropolymer emulsion is increased in the mix up to 10 percent and after that split tensile strength slightly increases at 10 to 20 percent & on further increasing the flouropolymer content from 20 to 30 percent strength increases and becomes equal to the strength at control for both curing conditions
- The split tensile strength increases for mixes cured at 7 days wet & 21 dry as compared to that for mixes cured at 1 day wet 21 day dry .the increase is approximately 12-15 percent.
- This change in split tensile strength has been analyzed through SEM test discussed in section 4.8 and detailed in section 4.8.1 and 4.8.2:
    c) It is observed from the SEM results that with zero percent flouropolymer addition a uniformly distributed C-S-H gel is formed.
    d) Further the results show that with increase in flouropolymer content to 10 percent in the mortar the percentage of C-S-H gel starts reducing and Ettringite starts forming which is a weak structure but as we go on increasing the percentage of flouropolymer further the C-S-H gel percentage increases and that of Ettringite reduces with 20 percent flouropolymer addition & still further at 30 percent flouropolymer addition the C-S-H forms uniformly over the entire surface area making a dense proportion which is responsible for the higher strength.
- Moreover, the change in split tensile strength of different flouropolymer modified mortar specimen can be analyzed through XRD results as shown in Table-4.8 & 4.9.

    c) It is observed from the Tables 4.8 & 4.9 that percentage of C-S-H gel with zero percent flouropolymer addition is 28 percent, which reduces to 23 percent at 10 percent flouropolymer addition and as we increase the addition of flouropolymer emulsion from 10-20 percent and 20-30 percent the percentage

of C-S-H gel increases to 25 percent & 29 percent respectively (for 1 day wet 27 day dry cured specimens).

d) For 7 day wet 21 day dry cured specimens the percentage of C-S-H gel improves slightly for each specimen. At zero percent flouropolymer addition the percentage C-S-H gel is 31 percent, which reduces to 25 percent with 10 percent flouropolymer addition, and on further increasing the flouropolymer content up to 20 percent and 30 percent the percentage C-S-H is 29 percent and 31 percent respectively which validates the above results.

4.5 Sorptivity result

To determine the sorptivity three cylinders (size 100mm dia. x 200 mm height) each for varying percentage of polymer contents i.e.0, 10, 20, 30 percent for both curing conditions i.e.(1 day wet 27 day dry & 7 day wet 21 day dry) were cast keeping workability constant as described in section 3.4.5 of chapter 3. The casted cylinders were cut longitudinally and samples of (size 100 mm dia. x 50 mm height) were immersed in water for 30 minutes. The results are shown in Tables 4.5 ,4.6 & Fig 4.3 .

Table4.5 Results for sorptivity test of fluoropolymer emulsion modified cement mortar specimens 1 day curing 27 day dry

Sr. No.	Specimen	Dry weight (W_1)gm	Wet weight (W_2)gm	$\Delta W = W_2 - W_1$ (gm)	Sorptivity Value(cm/√sec)
1	F-0	806	824	18	.402
2	F-10	763	772	9	.2096
3	F-20	814	818	4	.093
4	F-30	803	805	2	.0465

The Sorptivity test results reveal that-

- The amount of water absorbed in capillary suction goes on decreasing as we go on increasing the flouropolymer content from 0 to 30 percent in the mortar.

- The sorptivity value was further less in sample's cured at (7 day wet 21 day dry curing condition) as compared to those cured at (1 day wet 27 day dry cured sample's).This behavior can be attributed from SEM results as discussed below.
- The decrease in the sorptivity value and improvement in the porous structure of the flouropolymer modified mortar can be due to the partial filling of micro-pores and voids by polymer particles as the cement hydration process continued. Low permeability properties in the Polymer modified mortars were attributed to the fact that polymer particles, being much smaller than the sand and cement particles, filled the smaller voids and eventually coalesced into a monolithic film that surrounded the aggregate and coated the cement particles . The resulting matrix also prevented the formation of micro-cracks, thereby improved the impermeability characteristics of the mortar.

Table4.6 Results for sorptivity test of fluoropolymer emulsion modified cement mortar specimens 7day curing 21 day dry

Sr. No.	Specimen	Dry weight (W_1)gm	Wet weight (W_2)gm	$\Delta W = W_2 - W_1$ (gm)	Sorptivity value(cm/√sec)
1	F-0	815	826	11	.256
2	F-10	780	786	6	.139
3	F-20	775	778	3	.0698
4	F-30	758	759	1	.023

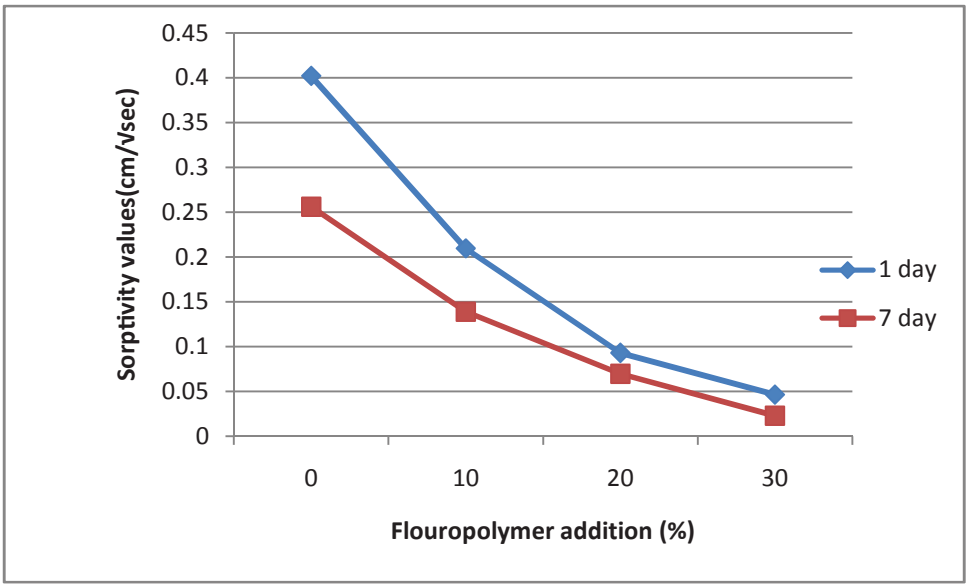


Fig 4.3 Results for sorptivity test of fluoropolymer emulsion modified cement mortar specimens 7day curing 21 day dry

4.6 Rapid chloride permeability test

To study the effect of permeability, three cylindrical specimen (size 100mm diameter x 200 mm height) each for varying percentage of polymer contents i.e. 0, 10, 20, 30 percent for both (1 day wet 27 day dry &7 day wet 21 day dry) 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 × 200 mm attained the age of testing i.e. 28 days, then specimen cutter machine as shown in Fig. 3.9 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 are shown in Table 4.7 and Fig.4.4.

Table 4.7 Results for rapid chloride permeability test of fluoropolymer emulsion modified cement mortar specimens 1 day curing 27 day dry & 7 day curing 21 day dry

Sr. No.	Specimen	Total charge passed after 6 hours (Coulombs)	
		1 Day curing 27 day dry	7 Day curing 21 day dry
1	F-0	5678	3348
2	F-10	2383	1459
3	F-20	1127	519
4	F-30	978	429

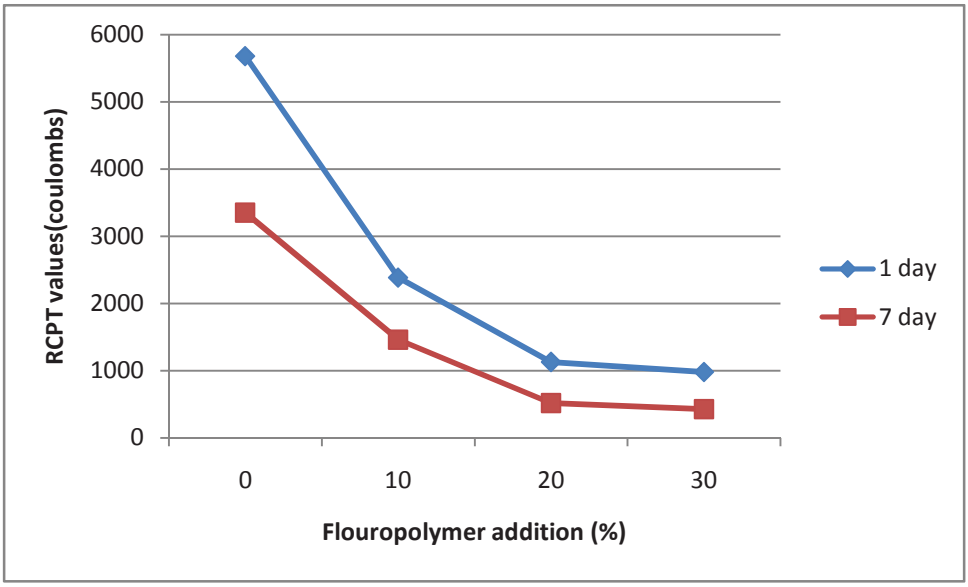


Fig4.4 Results for rapid chloride permeability test (RCPT) of fluoropolymer emulsion modified cement mortar specimens 1 Day curing 27 day dry & 7 day curing 21 day dry.

From the above Table 4.7 and Fig. 4.4 it is observed that:-

- In control mixture, chloride ions passed were more in number as compared to fluoropolymer modified cement mortar for both 1 day wet & 27 day dry & 7 day wet 21 day dry curing conditions.
- With 7 day wet 21 day dry the water permeability is almost half times in comparison with 1 day wet 27 day dry curing.
- The permeability reduces by increasing the percentage addition of fluoropolymer emulsion in the mix.
- This behavior of the mixes can be due to due to the partial filling of micro-pores and voids by polymer particles as the cement hydration process continued. Low permeability properties in the Polymer modified mortars were attributed to the fact that polymer particles, being much smaller than the sand and cement particles, filled the smaller voids and eventually coalesced into a monolithic film that surrounded the aggregate and coated the cement particles . The resulting matrix also prevented the formation of micro-cracks, thereby improved the impermeability characteristics of the mortar

4.7 X-ray diffraction test

To analyze the chemical compounds formed in different samples at both the curing conditions, the samples were extracted from the casted specimens from the very cores of them and they were analyzed in X rayon machine.

The samples for X ray analysis were pulverized to a powder form and were subjected to X rays the results obtained are shown in Fig 4.5-4.12

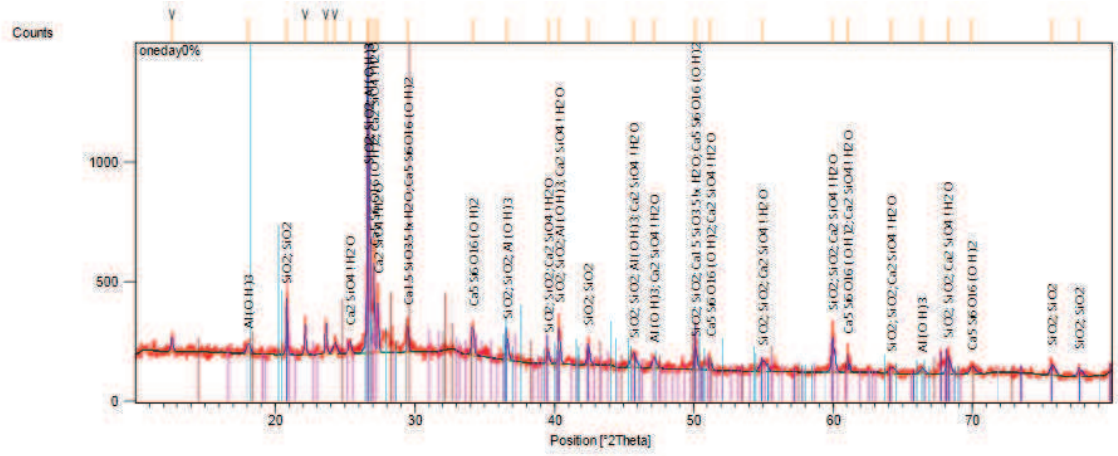


Fig.-4.5 (a) XRD image of 1 day wet 27 day dry and zero percent flouropolymer specimen

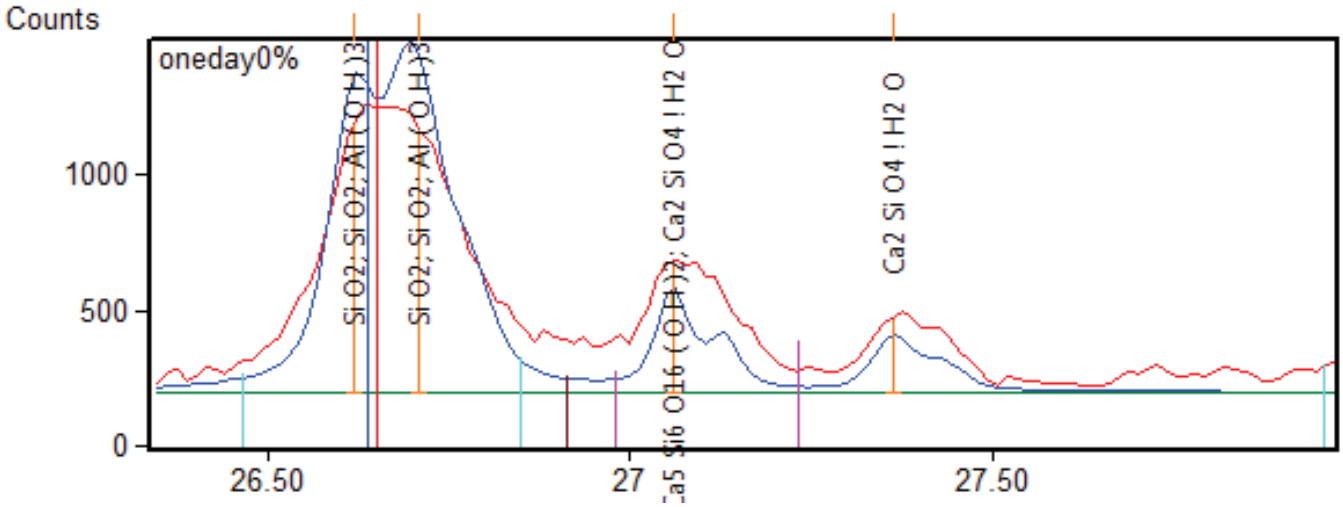


Fig.-4.5 (b) XRD image of 1 day wet 27 day dry and zero percent flouropolymer specimen – maginified view

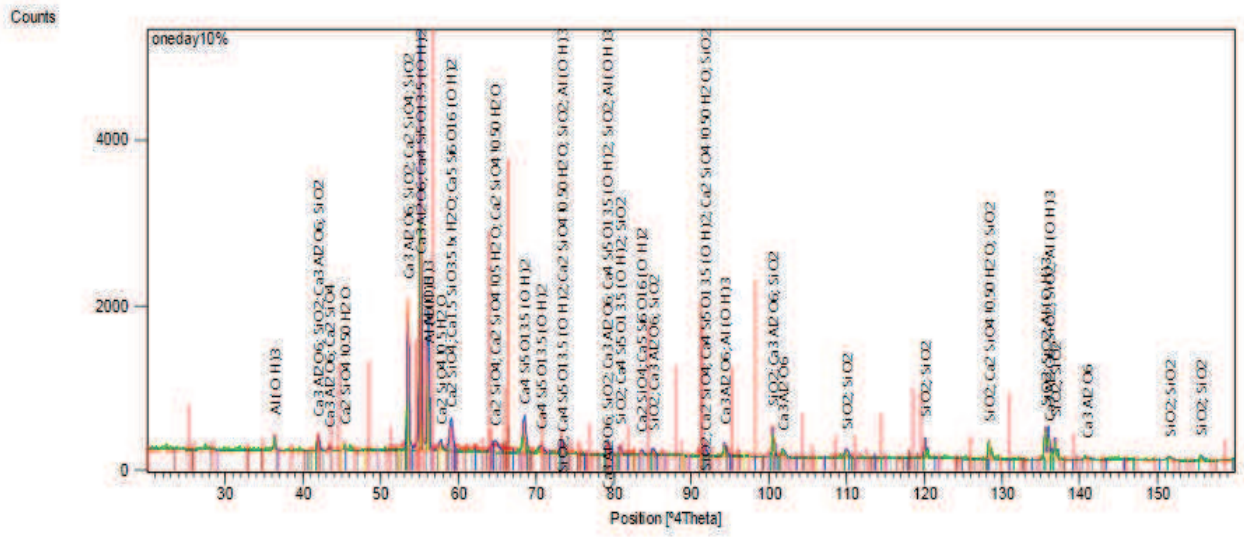


Fig.-4.6 (a) XRD image of 1 day wet 27 day dry and 10 percent polymer specimen

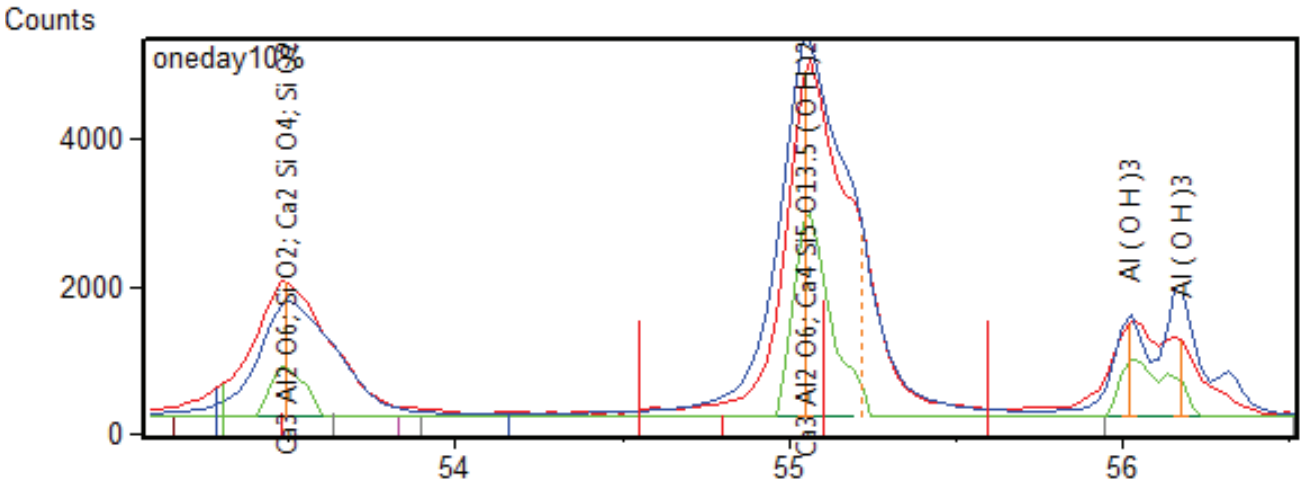


Fig.-4.6 (b) XRD image of 1 day wet 27 day dry and 10 percent polymer specimen – magnified view

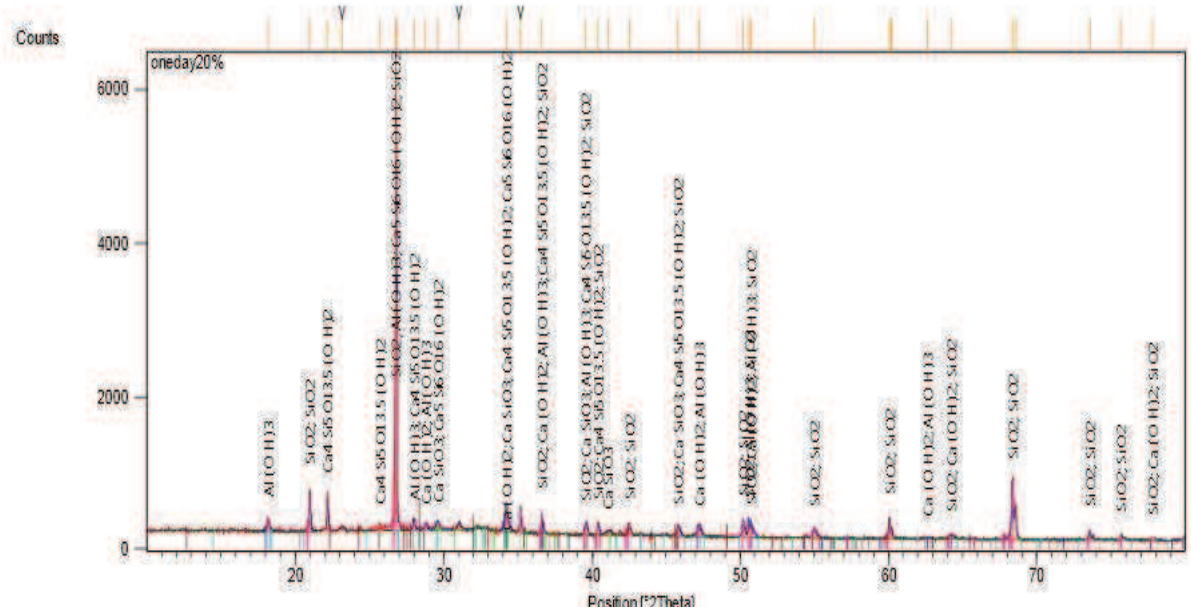


Fig.-4.7 (a) XRD image of 1 day wet 27 day dry and 20 percent flouropolymer specimen

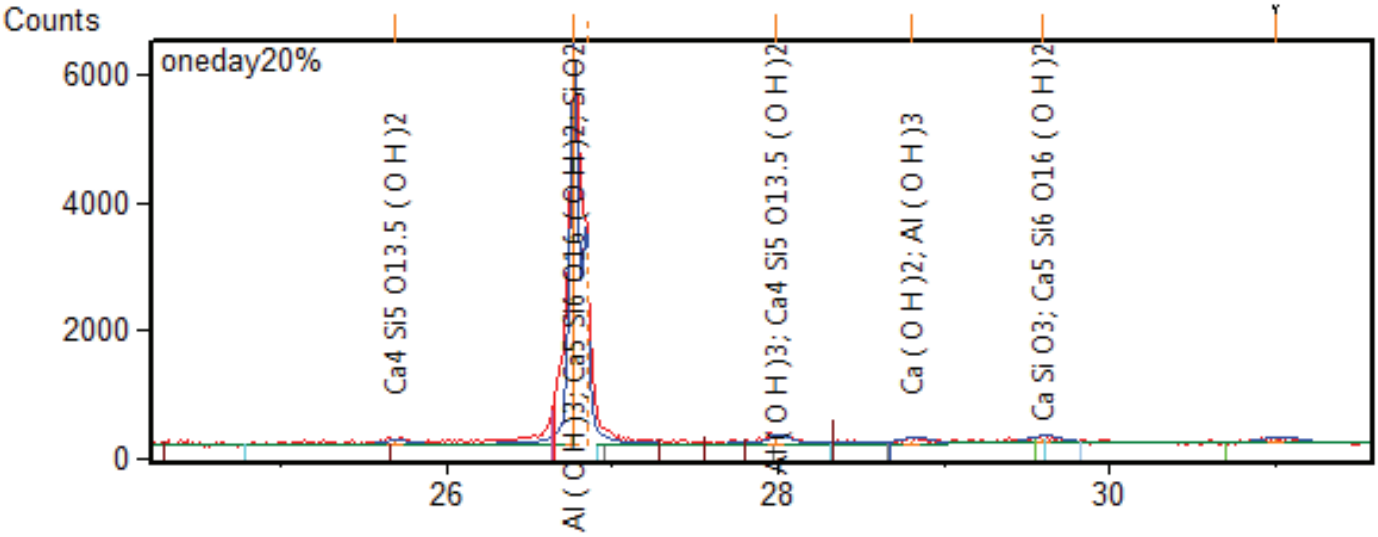


Fig.-4.7 (b) XRD image of 1 day wet 27 day dry and 20 percent flouropolymer specimen.

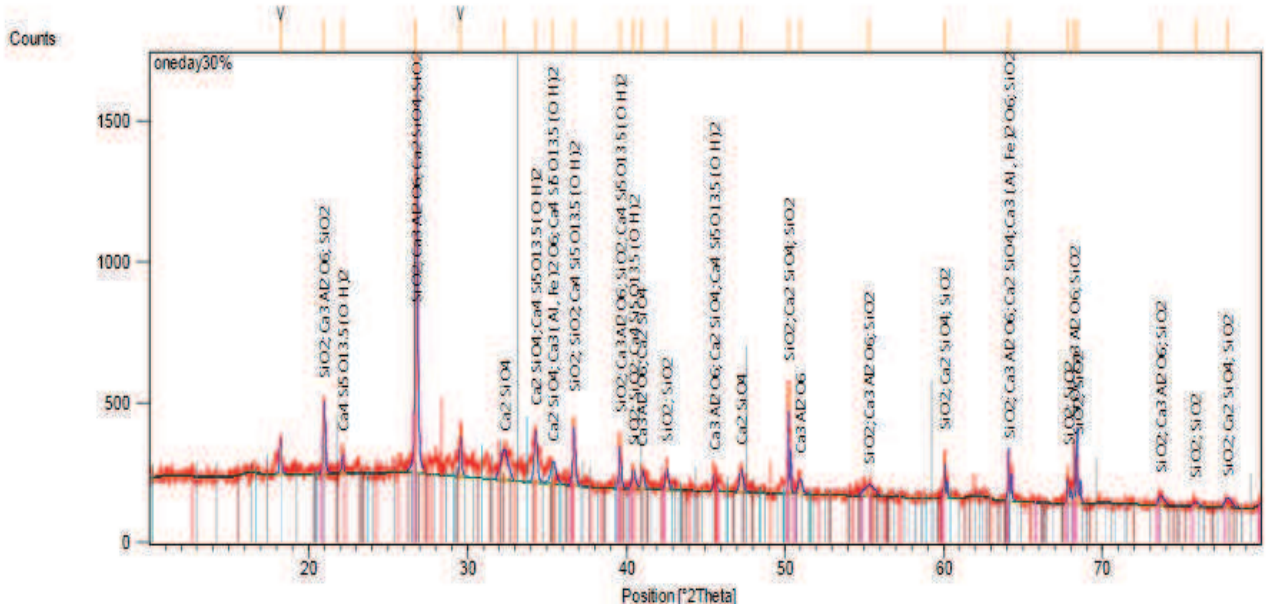


Fig.-4.8 (a) XRD image of 1 day wet 27 day dry and 30 percent flouropolymer specimen

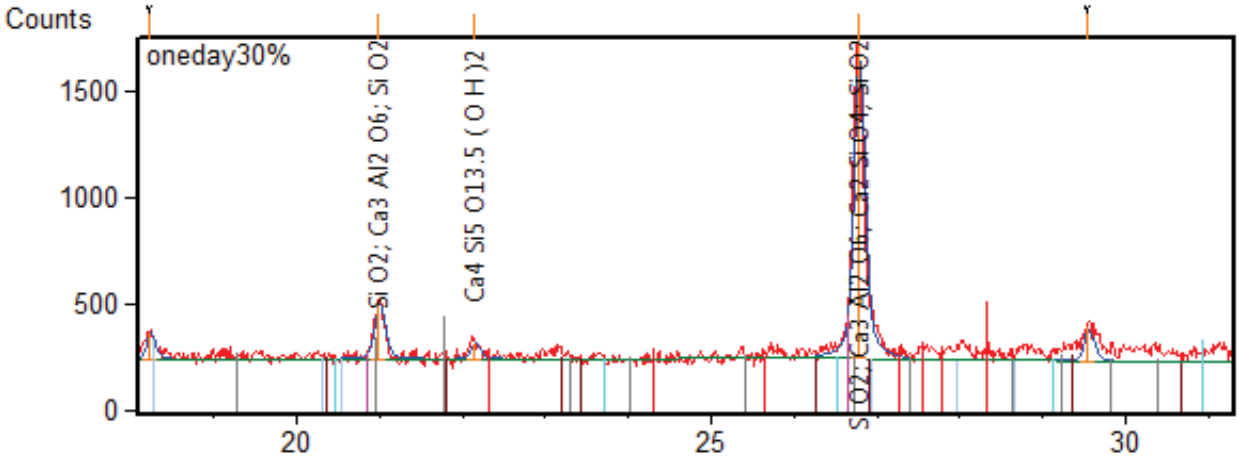


Fig.-4.8 (b) XRD image of 1 day wet 27 day dry and 30 percent flouropolymer specimen-magnified view

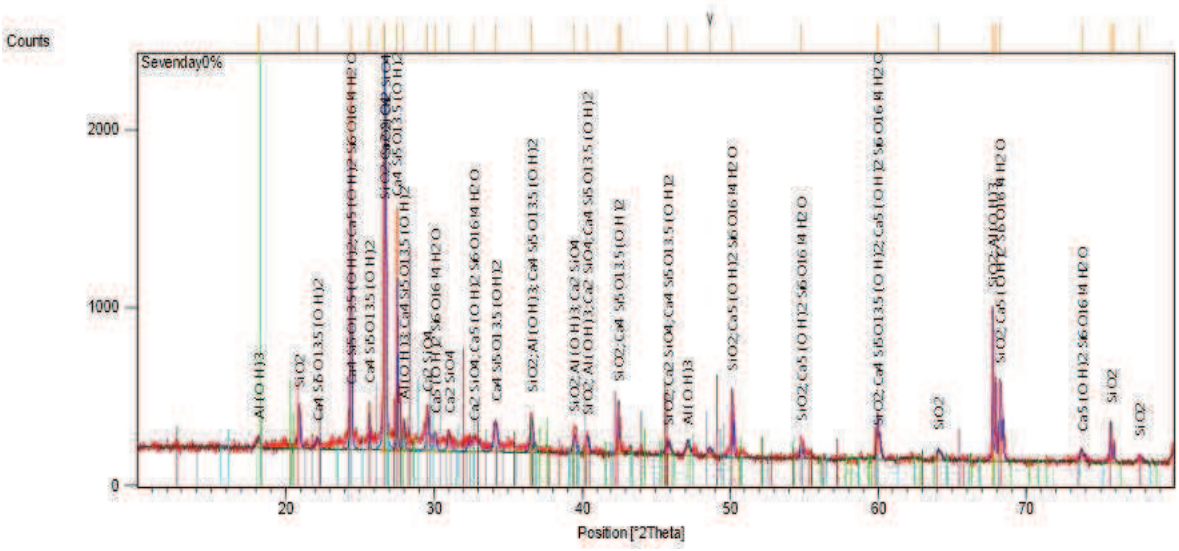


Fig.-4.9 (a) XRD image of 7 day wet 21 day dry and zero percent flouropolymer specimen

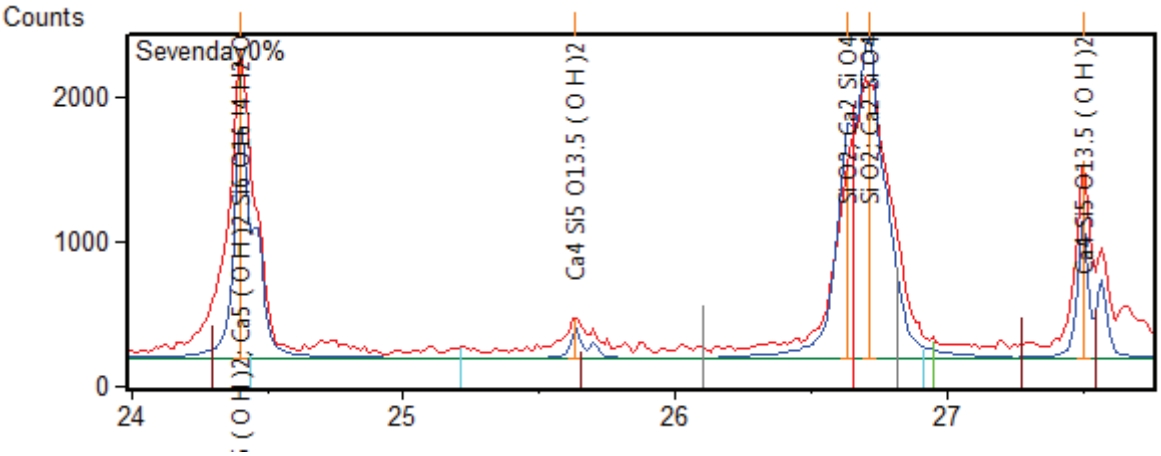


Fig.-4.9 (b) XRD image of 7 day wet 21 day dry and zero percent flouropolymer specimen-magnified view

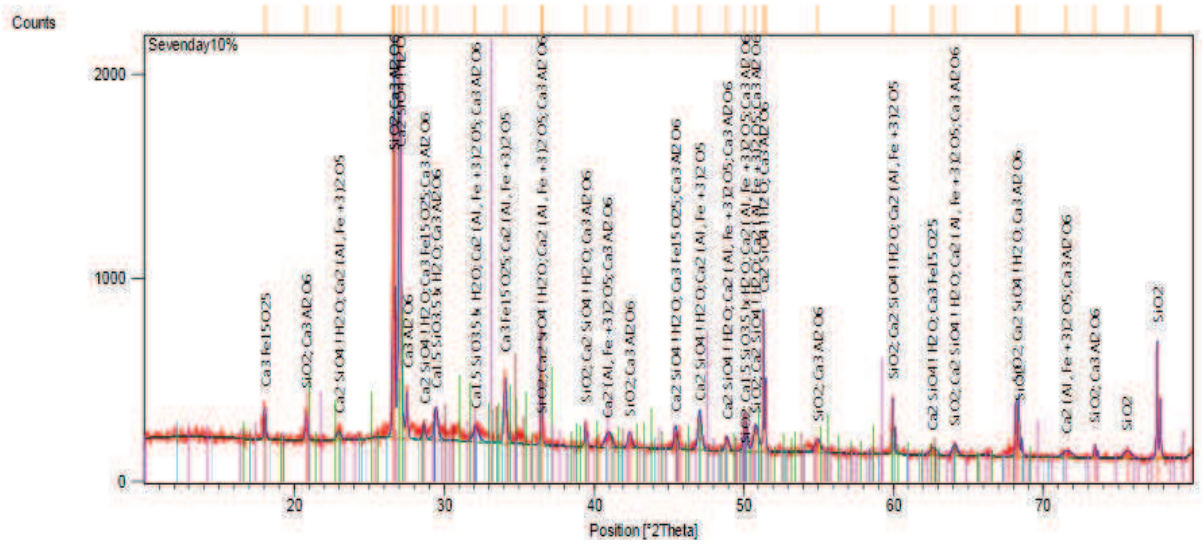


Fig.-4.10 (a) XRD image of 7 day wet 21 day dry and 10 percent flouropolymer specimen

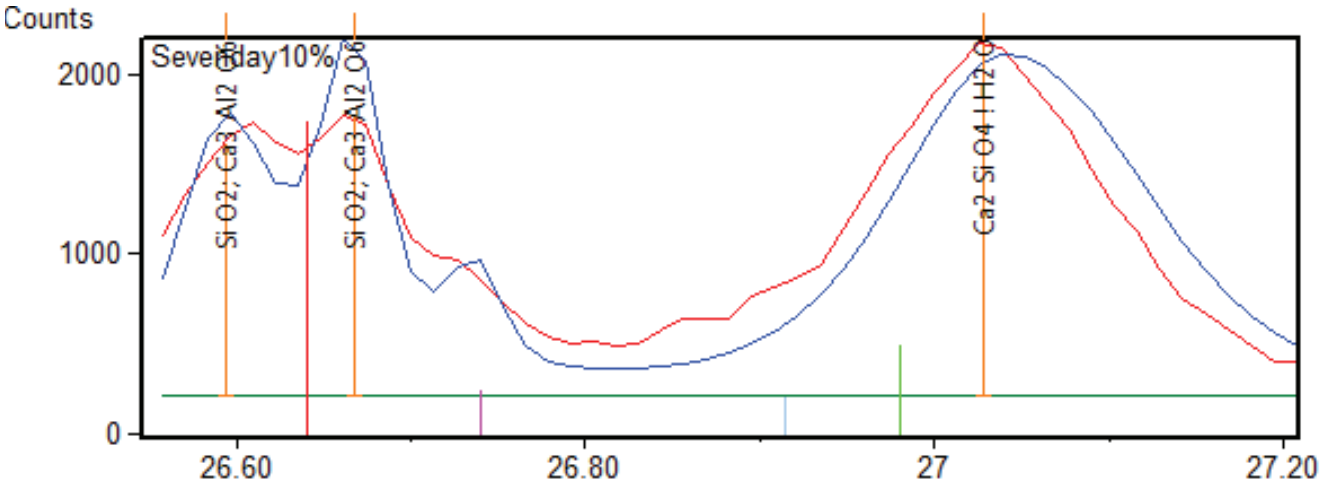


Fig.-4.10 (b) XRD image of 7 day wet 21 day dry and 10 percent flouropolymer specimen-magnified image

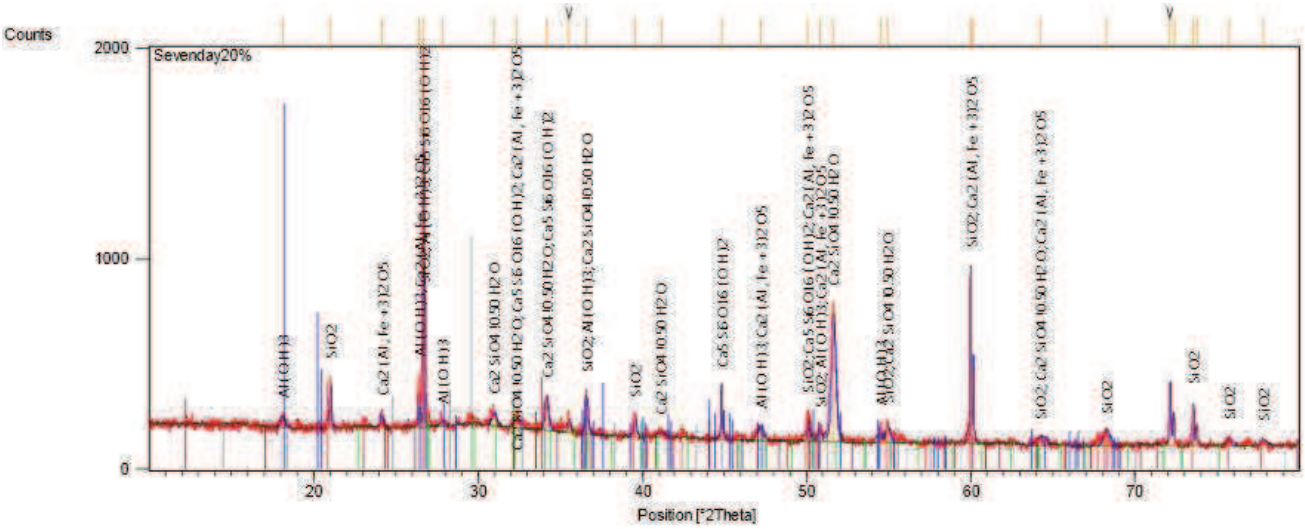


Fig.-4.11 (a) XRD image of 7 day wet 21 day dry and 20 percent flouropolymer specimen

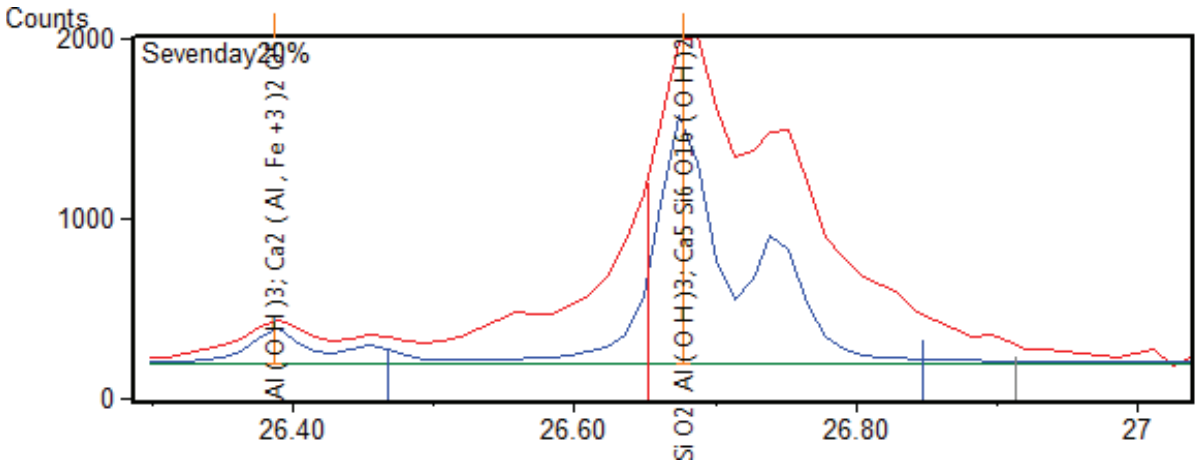


Fig.-4.11 (b) XRD image of 7 day wet 21 day dry and 20 percent flouropolymer specimen-magnified view

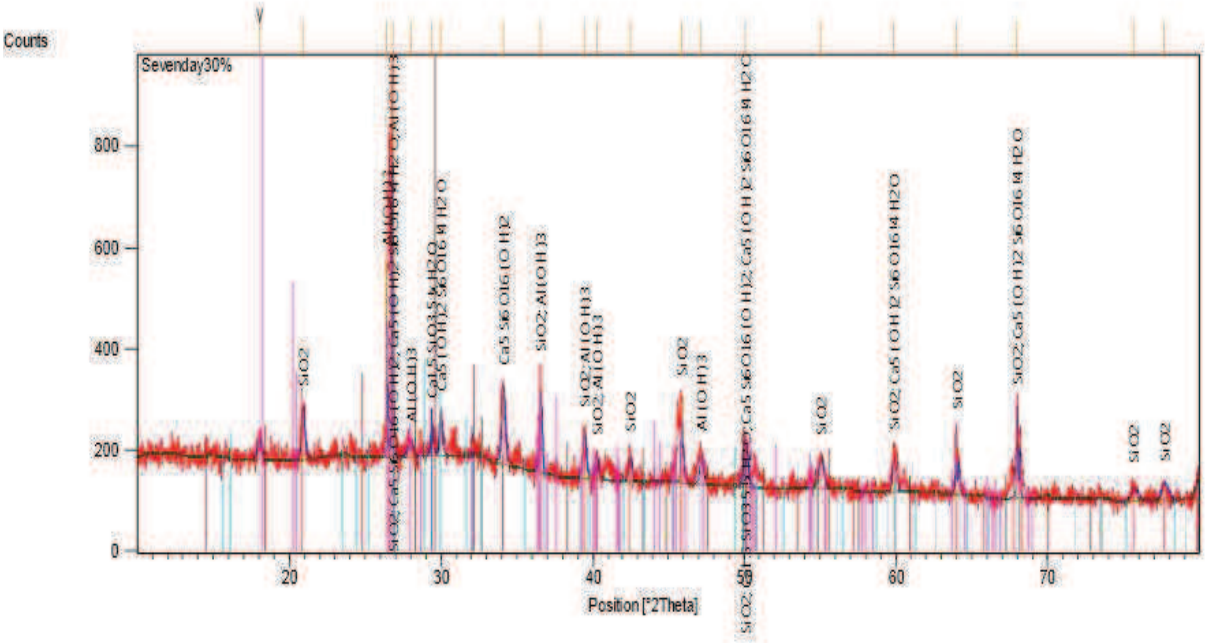


Fig.-4.12 (a) XRD image of 7 day wet 21 day dry and 30 percent flouropolymer specimen

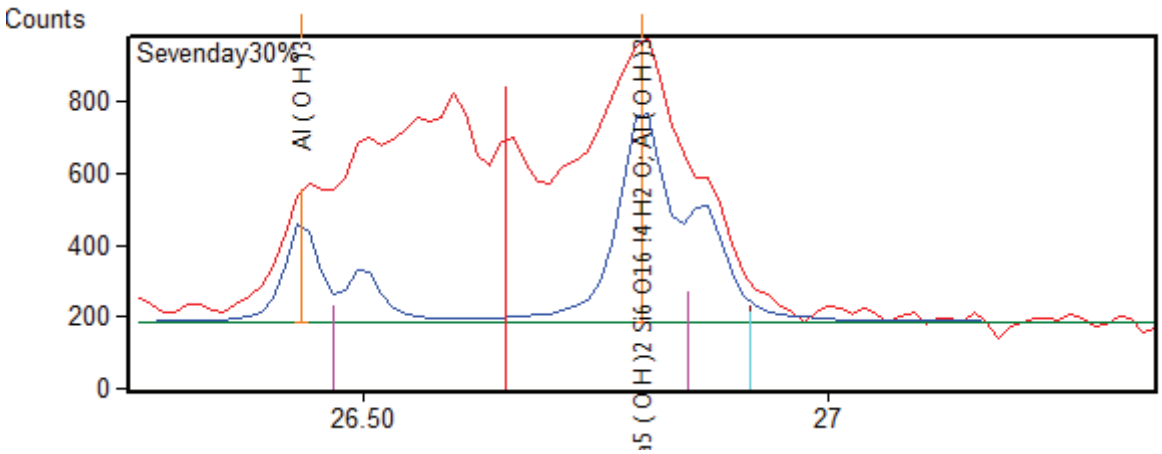


Fig.-4.12 (b) XRD image of 7 day wet 21 day dry and 30 percent flouropolymer specimen-magnified view

The above graphs show that qualitatively the compounds formed are same i.e tobermerite, C-S-H gel ,quartz, silica, etc but they change quantitatively with a phase change for every different proportion of flouropolymer addition .Thus contributes to change in the mechanical properties.

Table No. 4.8 X-ray diffraction test for 1 day wet 27 day dry curing

Sr No.	Compound Name	Chemical Formula	Score			
			0%	10%	20%	30%
1	Silica	$Si\ O_2$	59	24	33	21
2	Quartz,Syn	$Si\ O_2$	63	25	30	20
3	Calcium Silicate Hydrate	$Ca1.5\ Si\ O_3.5\ !x\ H_2\ O$	18	9	11	13
4	Tobermorite,9A	$Ca_5\ Si_6\ O_{16}\ (\ O\ H\ )_2$	2	7	7	11
5	Gibbsite	$Al\ (\ O\ H\ )_3$	3	-	5	9
6	Calcium Silicate Hydrate	$Ca_2\ Si\ O_4\ !\ H_2\ O$	4	7		-
7	Tricalcium Aluminate	$Ca_3\ Al_2\ O_6$	-	1	-	2
8	Calcium Silicate Hydroxide	$Ca_4\ Si_5\ O_{13}.5\ (\ O\ H\ )_2$	-	2	0	1
9	Portlandite, syn	$Ca\ (\ O\ H\ )_2$	-	-	18	-
10	Calcium Silicate	$Ca\ Si\ O_3$	4	-	7	4
11	Calcium Aluminum Iron Oxide	$Ca_3\ (\ Al\ ,\ Fe\ )_2\ O_6$	-	-	-	1

Table No. 4.9 X-ray diffraction test for 7 day wet 21 day dry curing

Sr No.	Compound Name	Chemical Formula	Score			
			0%	10%	20%	30%
1	Silica	$Si O_2$	61	54	46	43
2	Quartz,Syn	$Si O_2$	65	54	46	39
3	Calcium Silicate Hydrate	$Ca1.5 Si O_3.5 !x H_2 O$	3	12	18	21
4	Tobermorite,9A	$Ca_5 Si_6 O_{16} (O H)_2$	12	3	1	2
5	Gibbsite	$Al (O H)_3$	5	4	5	2
6	Calcium Silicate Hydrate	$Ca_2 Si O_4 ! H_2 O$	4	5	3	
7	Calcium Silicate Hydroxide	$Ca_4 Si_5 O_{13}.5 (O H)_2$	7	-	1	3
8	Calcium Silicate	$Ca Si O_3$	5	5	6	6

4.8 Scanning electron microscopy

This test was performed to study the surface morphology of the specimen cured under the different curing condition i.e.(1 day wet 27 day dry & 7 day wet 21 day dry).The samples were taken from the core of the specimen casted i.e. Cubes and Cylinders. The samples were prepared in small granular form and were tested at the age of 28 days. The result of Scanning Electron Microscopy are presented below in Fig 4.13 to 4.20

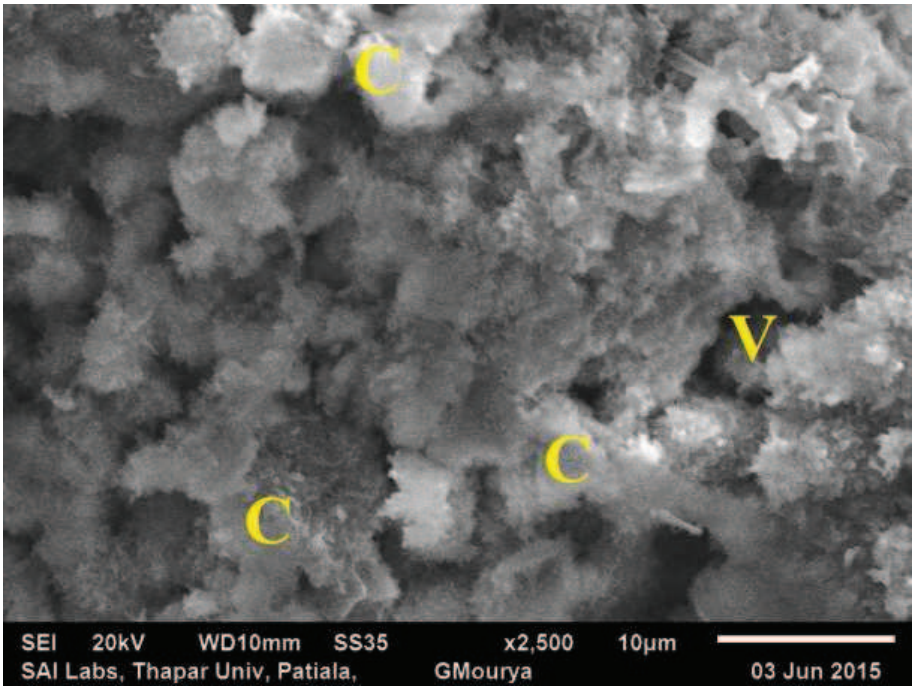


Fig.-4.13 SEM image of 1 day wet 27 day dry and zero percent flouropolymer

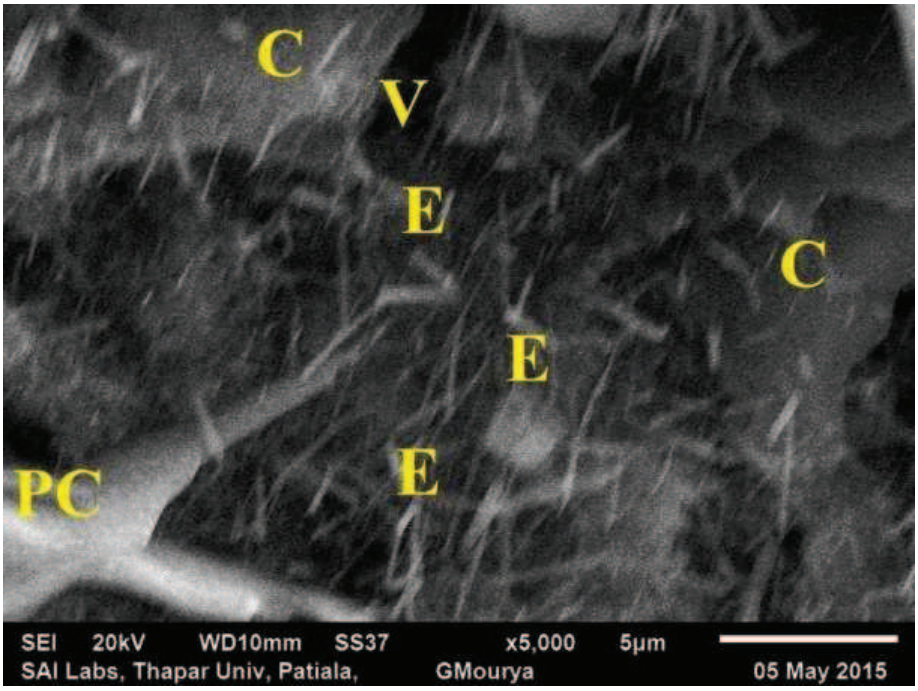


Fig.-4.14 SEM image of 1 day wet 27 day dry and 10 percent flouropolymer specimen

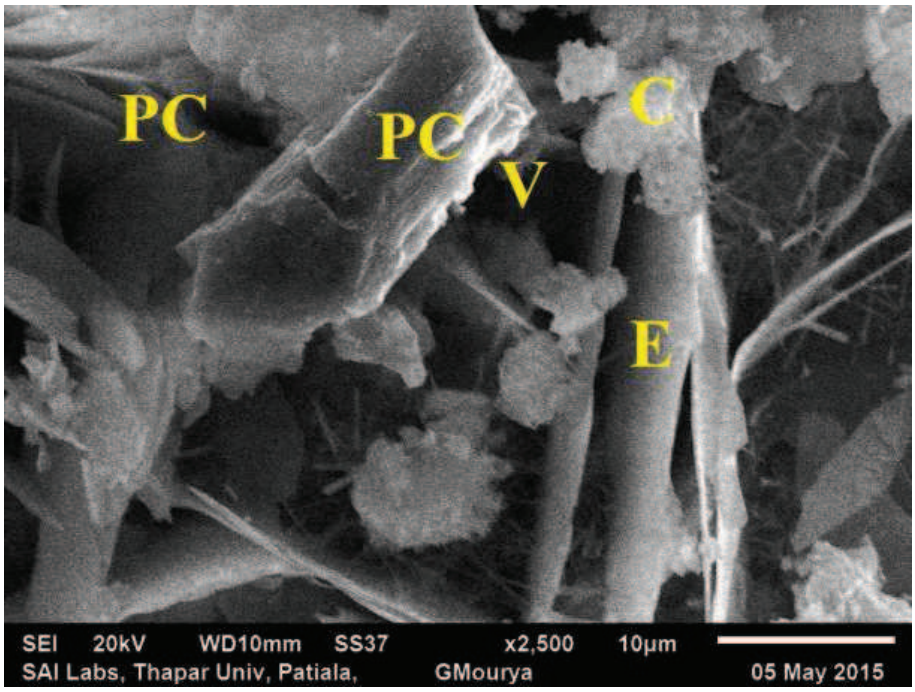


Fig.-4.15 SEM image of 1 day wet 27 day dry and 20 percent flouropolymer specimen

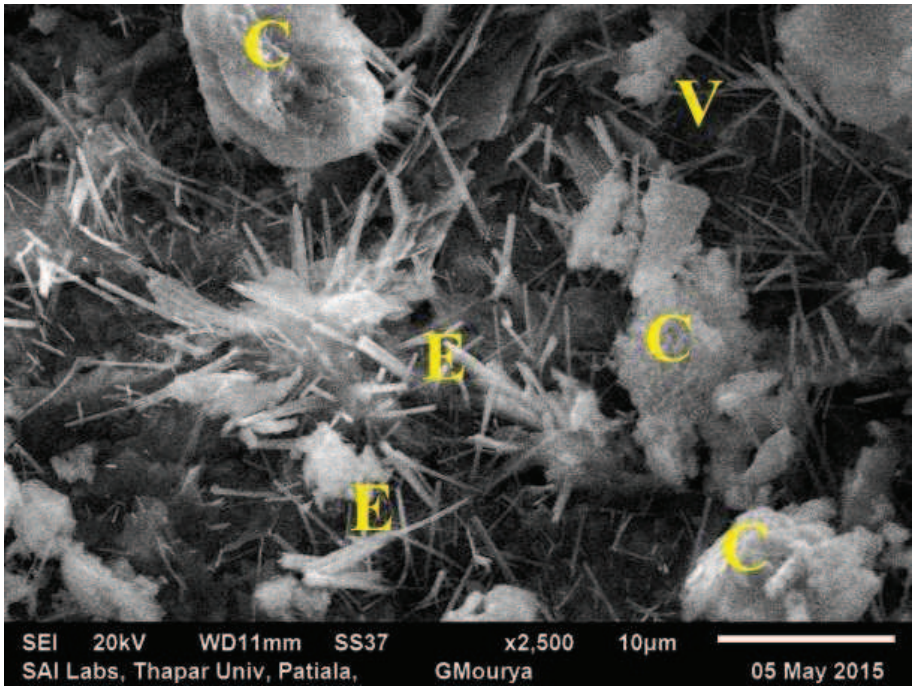


Fig.-4.16 SEM image of 1 day wet 27 day dry and 30 percent flouropolymer specimen

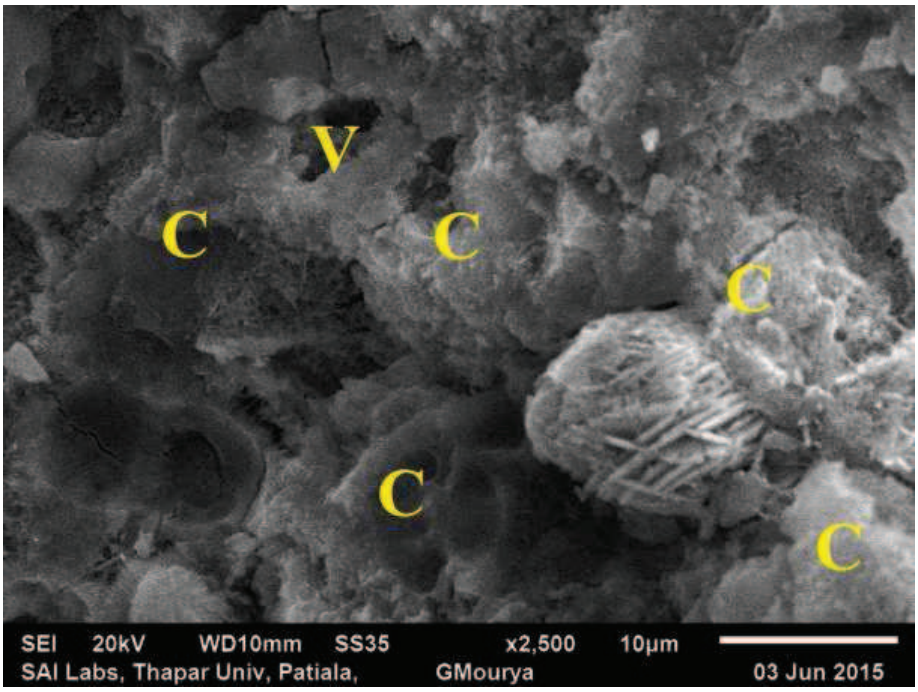


Fig.-4.17 SEM image of 7 day wet 21 day dry and zero percent flouropolymer specimen

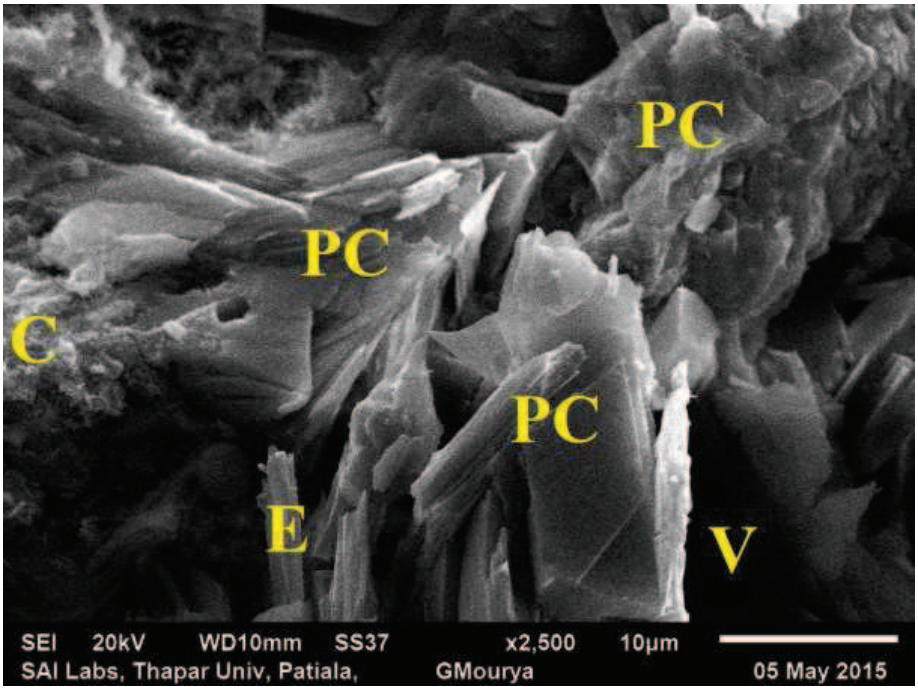


Fig.-4.18 SEM image of 7 day wet 21 day dry and 10 percent flouropolymer specimen

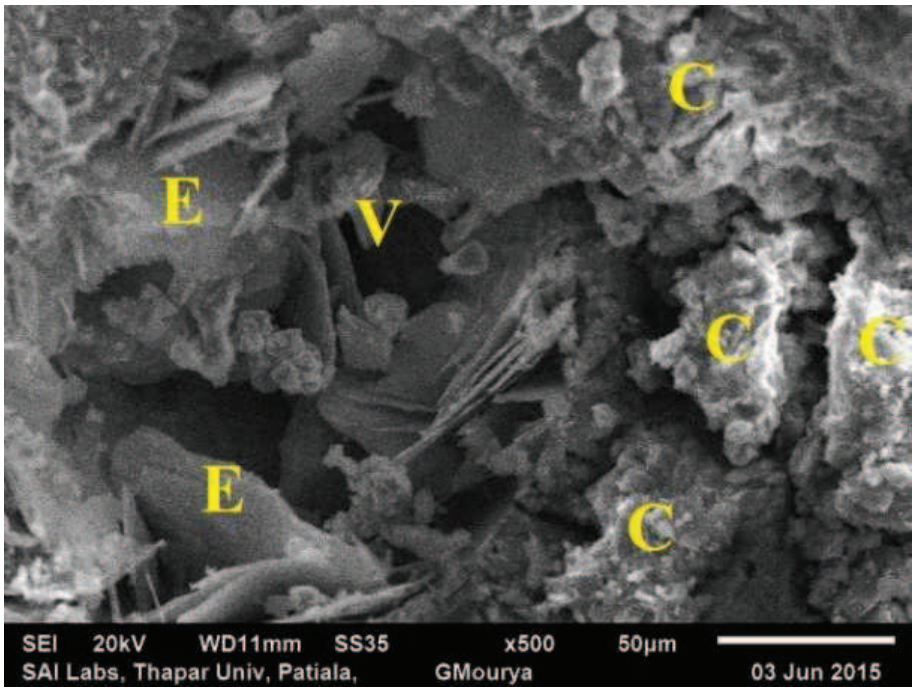


Fig.-4.19 SEM image of 7 day wet 21 day dry and 20 percent flouropolymer specimen

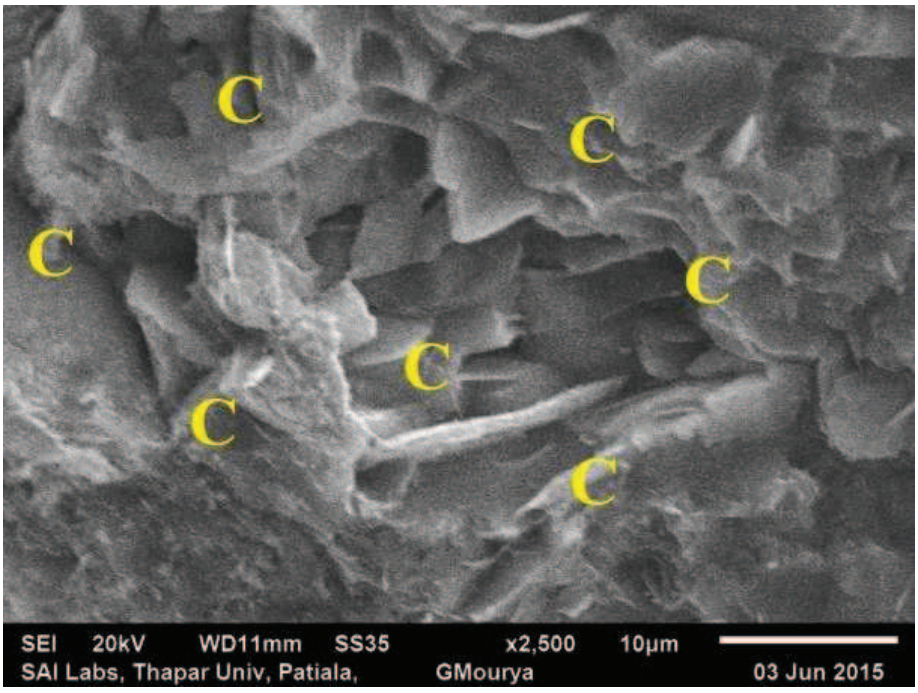


Fig.-4.20 SEM image of 7 day wet 21 day dry and 30 percent flouropolymer specimen

The SEM results of the samples are shown above in the Figure and the appropriate structures are marked over the pictures and their designation as follow:

C: C-S-H GEL

E: ETTRINGITE

V: VOID SPACE

PC: PLATED CRYSTALS ($Ca(OH)_2$)

From the above Figures it can be Visualized that

- The SEM result of the specimen @ zero percent flouropolymer addition consists of a uniformly distributed C-S-H gel over the whole image surface. The structure is compact and the particles are more or less spherical and the void space is minimum. Thus this structural composition attributes to a maximum compressive strength as observed in Table 4.3.
- At 10 percent flouropolymer addition needle like structures were formed i.e. Ettringite. Ettringite is weak in strength and therefore it leads to lower compressive as well as split tensile strength as observed Table 4.3 and Table 4.4.
- At 20 percent flouropolymer addition percentage of C-S-H gel increases and that of Ettringite decreases. This increase in the percentage of C-S-H gel is responsible for increase in both compressive and split tensile strength.
- At 30 percent flouropolymer addition the surface refine itself with an evenly distributed C-S-H gel which contributes to the maximum compressive and split tensile strength equal to that at control.

CHAPTER-5
CONCLUSIONS

5.1 GENERAL

The strength and durability characteristics of polymer modified cement mortar such as Compressive strength, Split tensile Strength, Permeability & Sorptivity of mortar mixtures have been studied in the present work by addition of varying percentage i.e. 0, 10, 20 and 30 percent of polymer contents with constant flow value 110±5 mm.

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

- The addition of fluoropolymer emulsion in cement mortar improves the workability.
- For same flow value at different additions of flouropolymer viz.10, 20, 30 percent the w/c ratio decreases which results in decrease in total liquid content also.
- The compressive strength decreases as compared to control mix as the percentage of fluoropolymer emulsion is increased in the mix up to 10 percent and after that compressive strength slightly increases at 10 to 20 percent of polymer addition and when the floropolymer content is increased to 30 percent the strength increases and is equal or more than that at control for both (1 day wet 27 day dry & 7 day wet 21 day dry) curing conditions.
- The compressive strength increases for the samples cured at 7 day wet 21 day dry as compared to 1 day wet 27 day dry and the percentage increase in the strength is approximately 7-13 percent.
- The split tensile strength also decreases as compared to control mix as the percentage of fluoropolymer emulsion is increased in the mix up to 10 percent and after that split tensile strength slightly increases at 10 to 20 percent of polymer addition & when the floropolymer content is increased up to 30 percent the strength increases and is equal or more than that at control for both (1 day wet 27 day dry & 7 day wet 21 day dry) curing conditions.
- The split tensile strength increases for mixes cured at 7 days wet & 21 dry as compared to that for mixes cured at 1 day wet 21 day dry .the increase is approximately 12-15 percent.

- Chloride ions were passed more in control mixture as compared to fluoropolymer emulsion modified cement mortar mix for both conditions (1 day wet 27 day dry & 7 day wet 21 day dry) curing conditions.
- The permeability is reduced by increasing the percentage addition of fluoropolymer emulsion in the mix.
- With 7 day wet 21 day dry the water permeability is almost half times in comparison with 1 day wet 27 day dry curing.
- The sorptivity is reduced by increasing the percentage addition of fluoropolymer emulsion in the mix.
- The amount of water absorbed in capillary suction goes on decreasing as we go on increasing the flouropolymer content from 0 to 30 percent.
- Moreover the Sorpitivity value was further less in sample's of (7 day Wet 21 day Dry curing condition) as compared to those of (1 day Wet 27 day Dry cured sample's)

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