MECHANICAL PROPERTIES
OF
POLYMER MODIFIED FERROCEMENT

A dissertation submitted

in partial fulfillment of the requirements for

the award of degree of

MASTERS OF ENGINEERING

IN

CIVIL (STRUCTURES) ENGINEERING

Submitted by

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JULY 2014

CERTIFICATE

I hereby declare that the work presented in dissertation entitled **"Mechanical Properties of Polymer Modified Ferrocement"**, is an authentic record of my study carried out as partially fulfillment of the requirements for the award of the degree of **Master of Engineering in Structural Engineering** at **Thapar University, Patiala** under the supervision of **Dr. Prem Pal Bansal,** Assistant Professor, Civil Engineering Department, Thapar University, Patiala. The matter embodied in this report has not been submitted in partial or full to any other university or institute for the award of any degree.

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

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Vinayak Kashyap

ABSTRACT

The ever increasing environmental pollution and the rise in emission levels have caused serious damage to the lives of millions, and millions of people have a lion's share in contributing to this environmental degradation. So there is need of construction technologies which are less energy intensive and help to reduce the pollution levels in comparison to conventional technologies. Here is a construction technology that is ferrocement, which is cost effective, energy efficient and environmentally sound and more appropriate than conventional technologies. Ferrocement is possessing unique properties of strength and durability. Ferrocement is an innovative technology which finds multiple applications in construction of new structures as well as retrofitting of existing structure. Ferrocement technology gaining popularity and acceptance as a sound retrofitting technique due to its unique feature over conventional techniques such as high ratio of strength to weight, speedy process of construction, low intensity of material used ,cost effectiveness and flexibility regarding to its cutting ,drilling , shaping and joining.

This research work presents an investigation on mechanical properties of polymer modified mortar (PMM) and polymer modified ferrocement elements (PMF) under dry curing condition. The experiment program has been carried out in three phases. In the first phase, the effect of addition of polymer on compressive strength, flexural strength and bond or adhesion strength of cement mortar is determined. Second Phase include to determination of the flexural strength and tensile strength of ferrocement elements. In Phase third X-ray diffraction (XRD) and Scanning Electron Microscope (SEM) has been conducted to determine the effect of addition of polymer to chemical properties and microstructure of cement mortar. The Cement mortar has been prepared using different polymer doses varying from 0% to 20% by weight of the cement content in the mortar mix, keeping the workability constant. The results indicated that addition of polymer reduce the water content to maintain the constant workability. SBR polymer modification increases the compressive strength, flexural strength, and bond or adhesion strength of cement mortar. Similarly significant increase in flexural strength and tensile strength has been noticed in polymer modified ferrocement (PMF) elements.

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CHAPTER 1
INTRODUCTION

1.1 General

Ferrocement is composite material consist of cement mortar and layer of reinforcing mesh or small diameter bars closely spaced .The reinforcement for ferrocement may be metallic or nonmetallic mesh uniformly spread out in the thickness of element. Ferrocement is reinforced in two directions and tends to have homogeneous and isotropic properties in both direction such as tensile strength, flexural strength, modulus of rupture and bond of wire mess with the mortar matrix. High strength and good flexural charactertics of ferrocement makes it a promising material. Ferrocement has shown increasing application in low cost fabrication, durable thin shell structure, marine, and agriculture and housing industries. Ferrocement is also widely used for repairing, restoration and rehabilitation of structures as it improves the function and performance of structures by increasing its strength and stiffness. It also improves appearance of the repaired surface and provides water tightness. Ferrocement has following advantages over other types of repair and strengthening techniques.

- Less or no-formwork required.
- Enhanced crack resistance combined with high toughness.
- Its rapid construction with no heavy machinery involved.
- It imposes small additional weight.
- The ferrocement material is a waterproof system and does not allow the penetration of water and atmospheric gases.
- It can totally replace deteriorated/ damaged RCC element such as chajjas with reduction in dead load.
- Considering an economical aspect, this material proves to be a cost effective solution for rehabilitation and general applications.

No doubt that ferrocement with conventional cement mortar matrix is gives satisfactory performance. But further improvements of the properties of ferrocement elements are necessary to meet the challenging requirement of present scenario so that full potential of this wonderful material can be utilized. This can be achieved by polymer modification of conventional cement matrix of ferrocement. Research and development of polymer modification has been performed for past 70 years or more. As a result, many effective polymer modification systems for cement mortar have been developed. Polymer modification improves or modifies the properties such as strength, deformability, adhesion, water tightness and durability of cement mortar. Polymer Modified Mortar has gained acceptance worldwide due to higher strength, impermeability, durability and cost effectiveness. Polymer modified mortar are prepared by mixing either polymer or monomer in a dispersed, powdery, or liquid form with fresh cement mortar. Synthetic polymer latexes, such as styrene-butadiene rubber (SBR) latex in cement system gained widely applied in construction industry. This experimental investigation is to study and evaluate the effect of addition of SBR polymer on mechanical properties of PMM such as compressive strength, flexural strength, bond or adhesion strength and flexural strength, tensile strength of polymer modified ferrocement (PMF) elements exposed to dry curing condition.

1.2 Polymer Modified Mortar

Polymers are the materials with long chain molecules that are composed of large number of repeating unit of identical structure. Polymer made of one type of monomer is called homopolymer, while those made of more than one monomer called copolymer. An admixture which consists of a polymeric compound as a main ingredient effective at improving or modifying the properties of cement mortar are called polymer based admixture or cement modified. Polymer Modified mortar is defined as cement mortar in which polymer based admixture are added for modifying and improving properties such as strength, deformability, adhesion ,waterproofing and durability .The concept of polymer modification for cement mortar is not new, considerable research and development have been performed over the past 70 years. As a result, various polymer based admixtures have been developed. Polymer based admixtures are mainly classified as Polymer latex, redispersible polymer powder, water soluble polymer and liquid resin modified. Classification of Polymer based admixture shown below in Fig. 1.1.

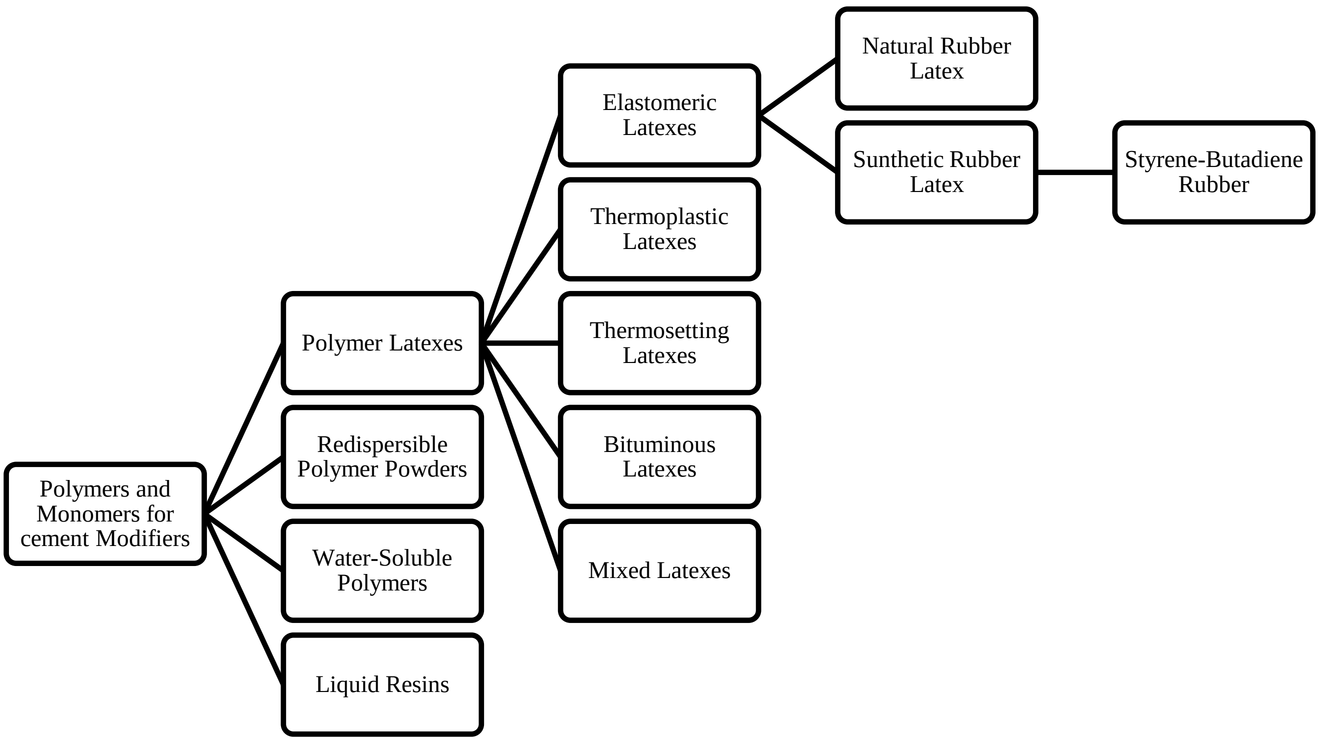


Fig. 1.1 Classification of Polymer Based Admixture

Out of these polymers based admixture, polymer latexes has widely used as cement modifier. Polymer latexes (or dispersions) consist of particle of diameter 0.05-5 µm in diameter. Polymer particles dispersed in water are usually produced by emulsion polymerization. In our experimental program we are using Styrene –butadiene copolymer latex as cement modifier. Structure of Polymer Styrene –butadiene copolymer latex are shown in Fig. 1.2.

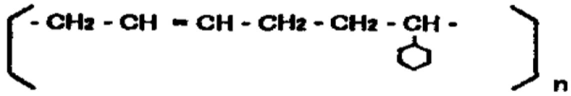


Fig. 1.2 Chemical Structure of SBR

1.3 Ferrocement

Ferrocement derives the name from 'Ferro' meaning steel or iron and 'cement' meaning a binder or cementitious substance. Ferrocement is a thin element consists of rich cement mortar and one or more layers of continuous/ small diameter steel wire netting reinforcement. In ferrocement, cement matrix does not crack since cracking forces are taken over by wire mesh reinforcement. It requires no skilled labour for casting, and employs only little or no formwork.

Ferrocement is a highly versatile form of Reinforced cement concrete possessing unique properties of strength and durability. The Ferrocement Technology is gaining popularity and acceptance by the people is primarily attributed to following unique features and advantages over conventional building materials.

- A high ratio of strength to weight in comparison to RCC
- Cost - effectiveness compared to RCC
- Lower intensity of material use
- Speedy process of construction
- Flexibility with regards to cutting, drilling & joining
- High acceptability in terms of shape and form
- More energy efficient than their equivalents made in Reinforced Cement Concrete.

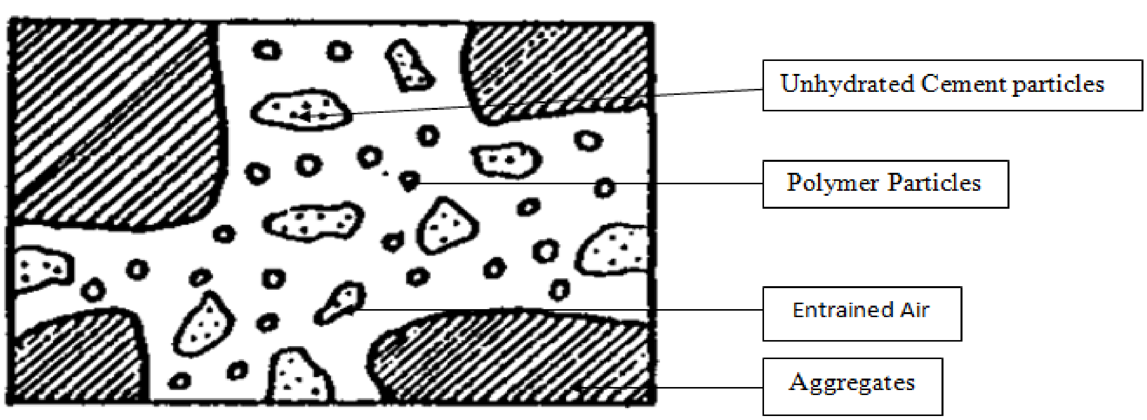
The ferrocement finds multiple applications in housing units, shell roofs, water tanks and swimming pools, biogas digesters, silos, food storage units. It is preferred over reinforced concrete for some specialized applications such as floating marine structures due to light weight.

1.4 Need of PMM in Ferrocement

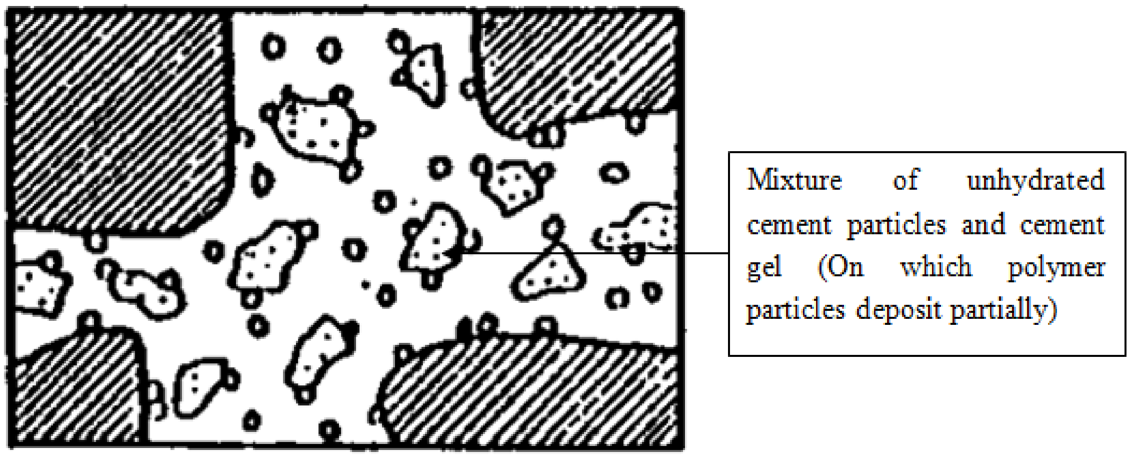
The success of ferrocement as a building material depends upon its durability. The durability of a ferrocement structure may be defined as its ability to resist weathering action, chemical attack, abrasion, cracking and any other process of destruction. For ferrocement to be durable, it is essential for component materials, namely mortar and wire-mesh reinforcement, and the bond between these materials to retain their strength with time when exposed to any environment. The transformation of ferrocement materials into a high durable material is a great challenge. One of the way to enhance durability of the ferrocement through a polymer modification of cement mortar. Conventional cement mortar can be modified with polymer based admixture and improved mechanical and physical properties of PMM can be fully utilized. The Research has shown that polymer modification can improve properties of cement mortar significantly. Improved behavior of PMM is due to presence of latex network in addition to cement matrix in the latex cement co-matrix. High tensile strength and bond or adhesion strength of Latex network results in high flexural strength and cracking resistance of PMM. So in the ferrocement use of PMM has been becoming popular instead of the ordinary cement mortar due to higher strength, impermeability, durability. In particular, use of SBR and EVA modified mortar as matrix is very effective in improving their flexural behavior, impact resistance, drying shrinkage and durability.

1.5 Mechanism of Formation of Polymer-Cement Co-Matrix

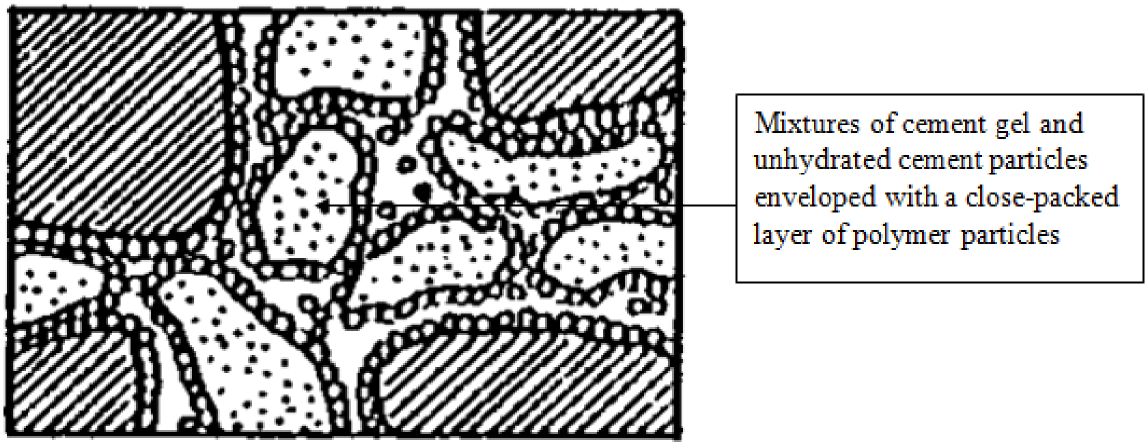
Polymer latex modification of cement mortar and concrete is governed by both cement hydration and polymer film formation in their binder phase. The cement hydration generally precedes the polymer film formation by the coalescence of polymer particles in polymer latexes. In due course, a co-matrix phase is formed by both cement hydration and polymer film formation processes. The co-matrix phase is generally formed according to the simplified model shown in Fig. 1.3.



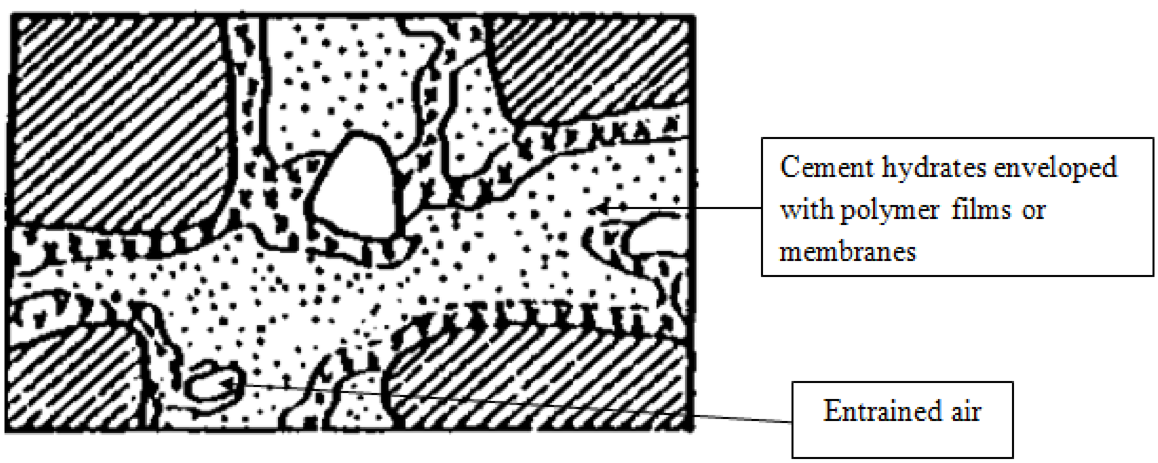
(a) Immediately after mixing (Interstitial spaces are water)



(b) First Phase



(c) Second Phase



(d) Third Phase (Hardened Structure)

Fig. 1.3 (a to d) Simplified Model of Formation of Polymer-Cement Co-Matrix. (Ohama 1998)

Cement hydration and polymer film formation provide a monolithic network structure in which the cement hydrate phase and polymer phase interpenetrate. Aggregates are bound by such a co-matrix phase, resulting in superior properties compared with conventional cementitious composites. Some chemical reactions may take place between the particle surfaces of reactive polymers and calcium ions (Ca^{2+}), $Ca(OH)_2$ solid surfaces, or silicate surfaces over the aggregate, as explained in Fig.1.3 . These reactions are expected to improve the bond between the cement hydrates and aggregates, and to improve the properties of hardened latex-modified mortar.

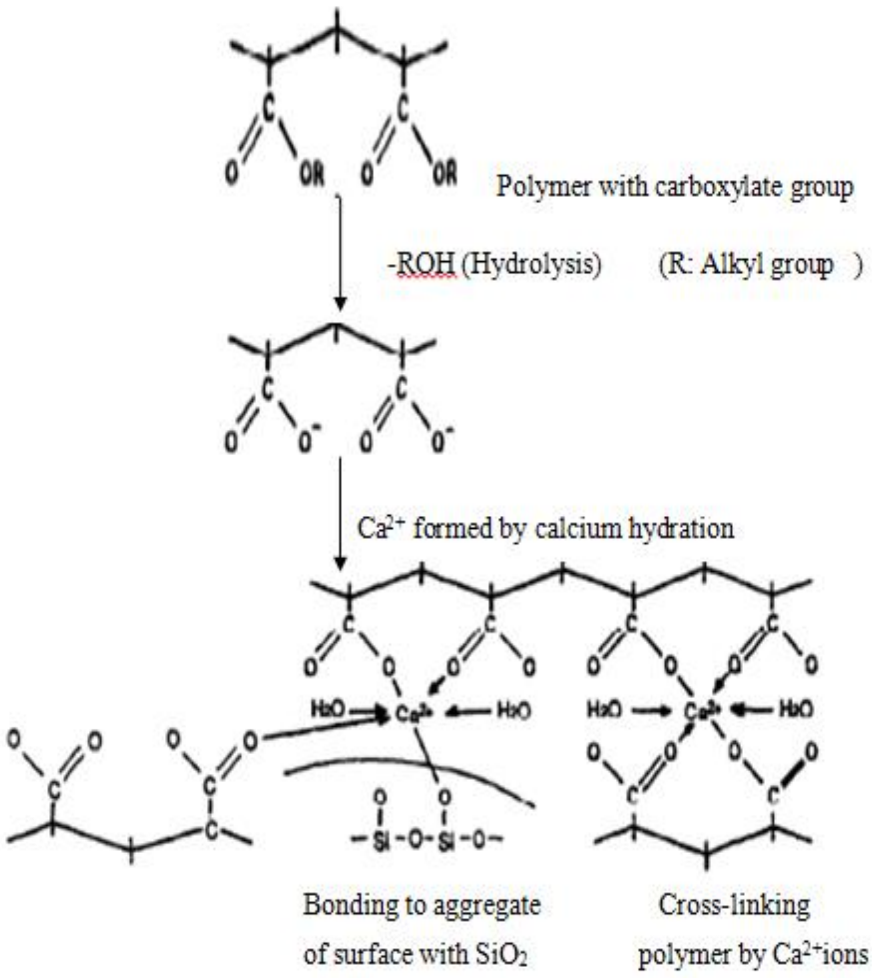


Fig. 1.4 Schematic Illustration of Reaction between Polymer with Carboxylate Group, Ordinary Portland cement And Aggregate. (Ohama 1998)

1.6 Wire Mesh Reinforcement

Ferrocement consist of continuous layer of small diameter steel wire mesh welded or woven, metallic or non-metallic as reinforcement with high volume fraction (2 to 8%). The reinforcing steel wire mesh has openings large enough for adequate bonding. The closer uniform distribution of reinforcement, transform the brittle mortar into a high performance material. Shape of mesh may be square, hexagonal/aviary, expended as shown in Fig. 1.5.

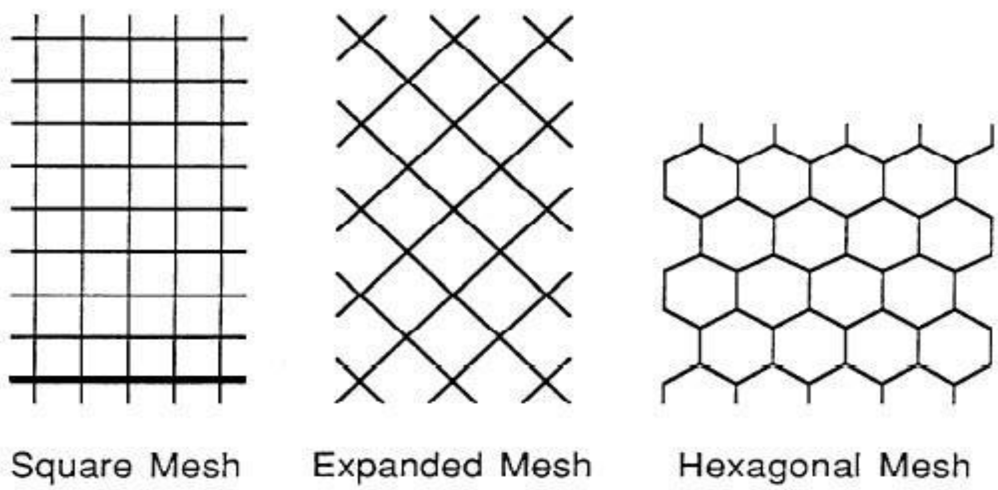


Fig. 1.5 Types of Wire Mesh

1.7 Aim of Work

Aim of work is to present the effect of addition of SBR polymer latex on mechanical properties of polymer modified mortar such as compressive strength, flexural strength, bond or adhesion strength of polymer modified mortar and flexural strength, tensile strength of polymer modified ferrocement element.

1.8 Objectives of Work

- To study the effect of addition of SBR polymer on the workability of PMM.
- To study the effect of addition of SBR polymer on mechanical properties of PMM such as compressive strength, flexural strength, bond or adhesion strength.
- To study the effect of addition of SBR polymer on flexural strength and tensile strength of PMF.

CHAPTER 2
REVIEW OF LITERATURE

2.1 Introduction

Ferrocement is a versatile construction material. It can be successfully used in the construction of many structures such as wall, lintel, roofing and flooring elements, water tanks, sunshades, shell and folded plate elements and boats. These structures in services may be subjected to moderate load. The success of ferrocement as a building material depends upon its durability. The durability of a ferrocement structure may be defined as its ability to resist weathering action, chemical attack, abrasion, cracking and any other process of destruction. For ferrocement to be durable, it is essential for component materials, namely mortar and wire-mesh reinforcement, and the bond between these materials to retain their strength with time when exposed to any environment. The transformation of ferrocement materials into a high durable material is a great challenge. One of the ways to enhance durability of the ferrocement through a polymer modification of cement mortar. The Research has shown that polymer modification can improve properties of cement mortar significantly. Ferrocement has very high tensile strength to weight ratio and superior cracking behavior. In the developing countries like India, Indonesia, Srilanka etc., ferrocement is being extensively used in housing, marine, agricultural sector and repair and rehabilitation .

2.2 Review of Papers of Mechanical Properties of PMM

Various papers which presented work done on mechanical properties of PMM are as follows:-

Diab et. al. (2014) Carried out investigation aims to determine the participation ratio of cement matrix and latex network in latex cement co-matrix strength. The first phase of study was carried out to investigate the effect of styrene butadiene rubber (SBR) on cement matrix participation ratio by measuring degree of hydration, compressive strength. The second phase was carried out to evaluate the latex participation ratio in mortar and effect of latex particle size on latex network strength. The test results are shown below indicated that the latex participation ratio in co-matrix strength is influenced by type of cement matrix, type of curing, latex type, latex solid/water ratio, strength type and age. The effect of SBR latex solid/water ratios on latex network and cement matrix compressive strength at 28 days for cement paste co-matrix subjected to dry curing is shown in Fig 2.1.

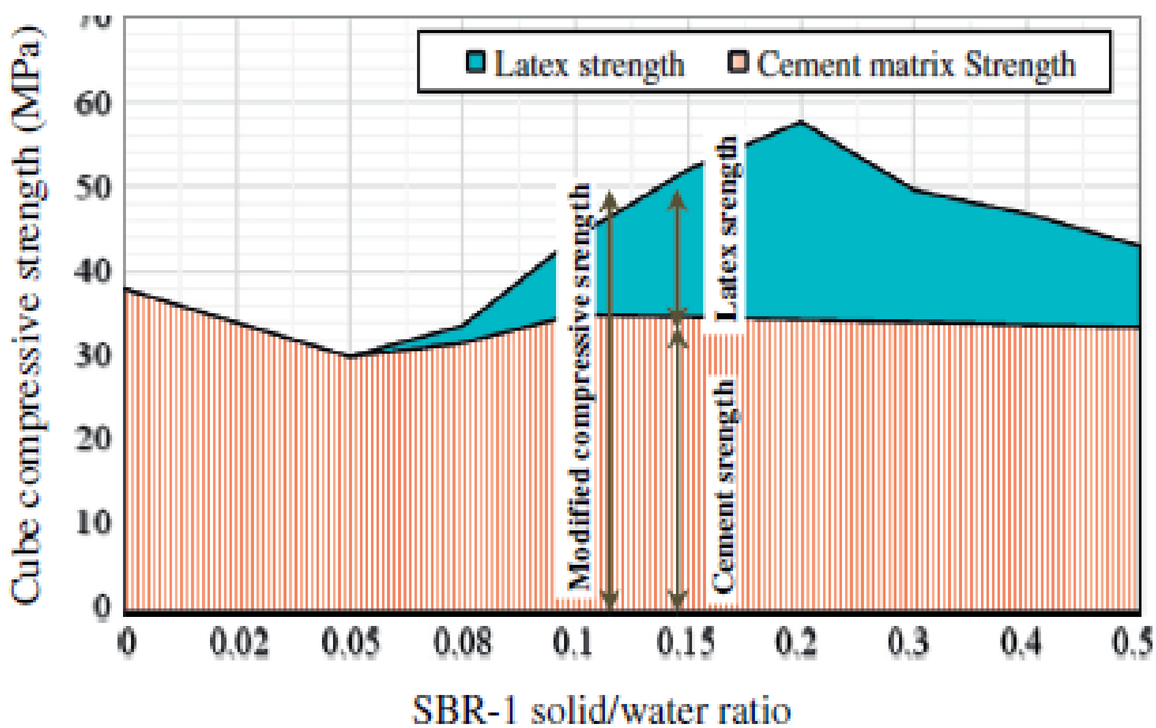


Fig. 2.1 Effect of SBR Latex Solid/Water Ratios on Latex Network and Cement Matrix Compressive Strength at 28 Days for Cement Paste Co-Matrix Subjected to Dry Curing. Diab et. al. (2014)

For modified cement paste with low solid/water ratio (0– 0.05) subjected to dry curing, the 28-day compressive strength is only due to the cement matrix strength. While the latex network strength increases as SBR solid/water ratio increases up to 20% and then latex network compressive strength decreases for higher values of solid/water ratio due to high reduction in cement degree of hydration.

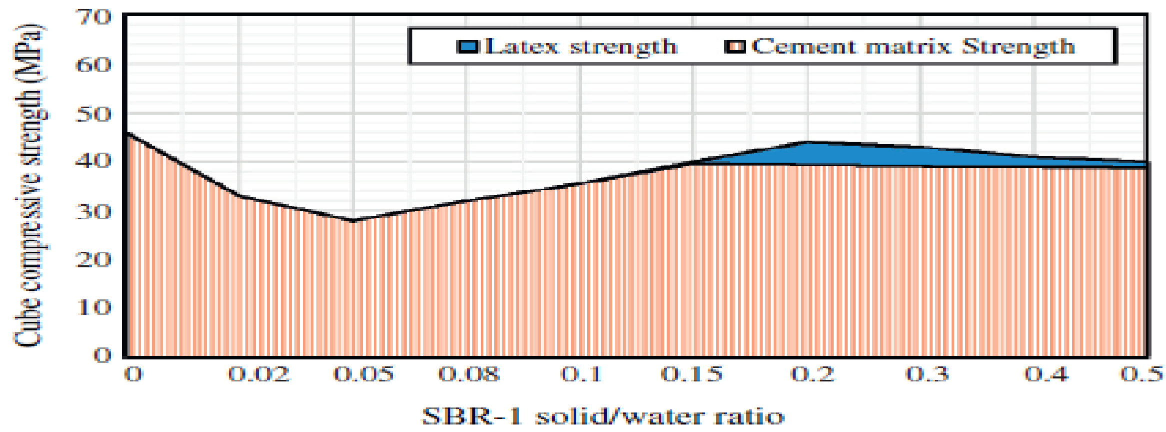


Fig. 2.2 Effect of SBR Latex Solid/Water Ratios on Latex Network and Cement Matrix Compressive Strength at 28 days for Cement Paste Co-Matrix Subjected to Wet Curing. Diab et. al. (2014)

The negative effect on latex participation in co-matrix compressive for modified cement paste subjected to wet curing is obviously observed in Fig. 2.2. From this figure, the latex participation ratio in compressive strength of modified mortar subjected to wet curing is insignificant due to the hydrolysis of latex network in the water. In addition, the cement participation ratio in co-matrix strength increases slightly in the water curing due to the slight increase in cement hydration degree.

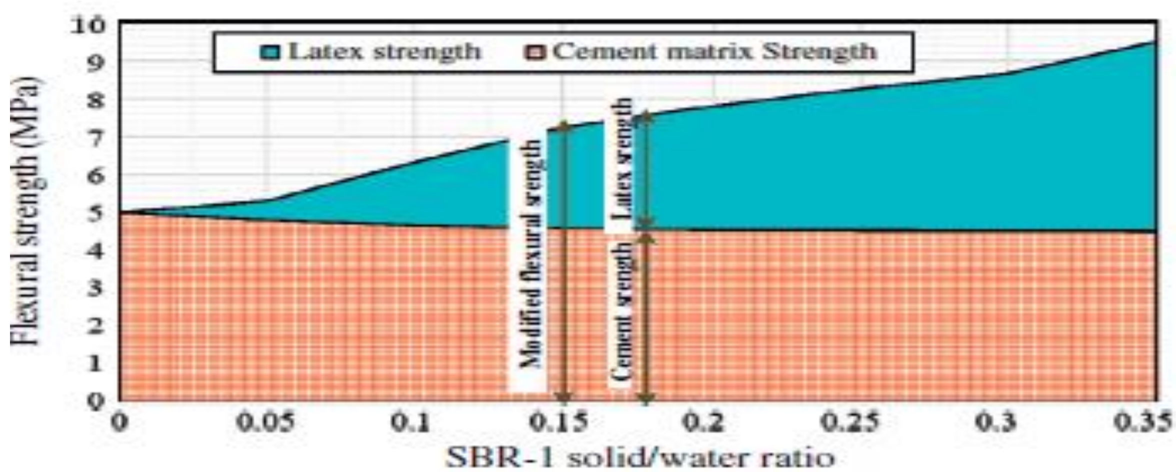


Fig. 2.3 Effects of SBR Latex Solid/Water Ratios on Latex Network and Cement Matrix Flexural Strength at 28 days for Latex Modified Concrete Subjected to Dry Curing. Diab et. al. (2014)

Participation ratios of cement matrix and latex network in flexural strengths of latex modified concrete shown in Fig. 2.3. It can be noticed that for modified concrete when the SBR solid/water ratio increases the latex participation ratios in flexural increase. The increase in latex participation in flexural compared with its participation in compressive strength for cement paste or mortar is due to the high tensile and adhesion strength of latex, while the low compressive strength of latex leads to a low contribution of latex network on co-matrix compressive strength.

Diab et. al. (2012) focus on factor 'latex solid/water ratio' which is defined as the ratio of weight of solid latex to weight of total water content of cement composite including the water in latex itself. The effect of this factor on some properties of cement paste, mortar and concrete were experimentally evaluated. Properties of cement paste include the produced calcium hydroxide and ettringite content during hydration process Furthermore, the effect of this factor on the compressive and flexural strengths, modulus of elasticity were explored. The test results are shown below indicated that the latex participation ratio in co-matrix strength using different cement contents, sources of latex, water–cement ratios and slump values, it can be generally concluded that the latex solid/water ratio is a dominant factor affecting different properties of latex modified mortar sand concrete.

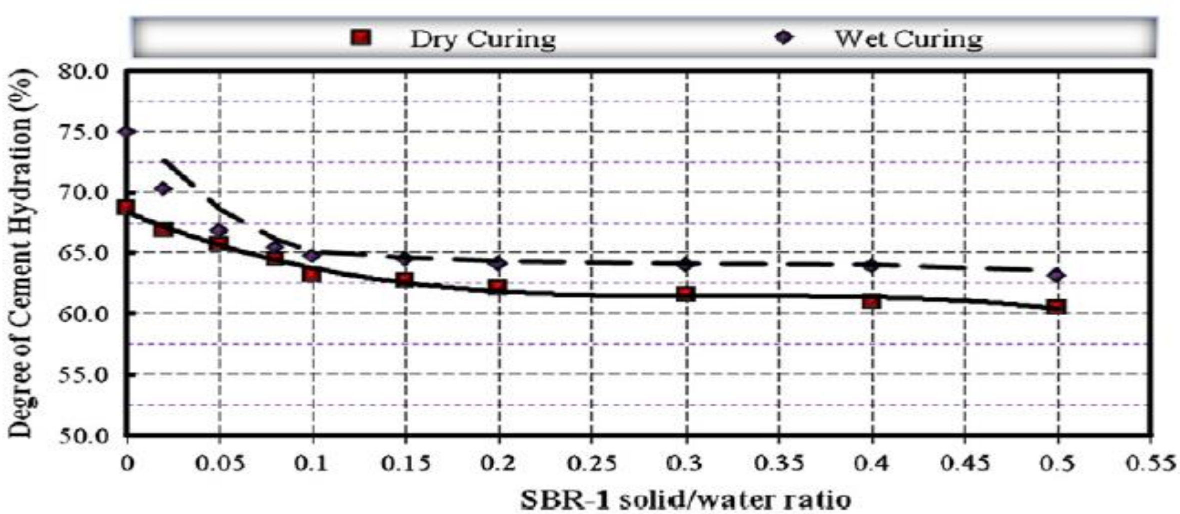


Fig. 2.4 Correlation between 28-Day Degree of Cement Hydration of Cement Pastes and SBR Solid/Water Ratio at Water/Cement Ratio of 0.35. (Diab et. al. 2012)

Correlation between 28-day degree of cement hydration of cement pastes and SBR solid/water ratio at water/cement ratio of 0.35 is shown in Fig. 2.4. From general prospective, the degree of cement hydration of both conventional cement paste and modified cement paste improves under wet curing conditions. Wet curing enhances cement paste to increase its cement hydration degree after latex hydrolysis phenomenon that happens to latex film after immersing under water for 28 days. However the increase of cement hydration degree is slightly because of the presence of the high amount of impermeable ettringite layers. The results show that for cement pastes under wet curing conditions, the degree of cement hydration for modified cement paste increases by 3%, 4%, and 5% more than that of dry curing cement paste with 5%, 20%, and 40% SBR solid/water ratio, respectively.

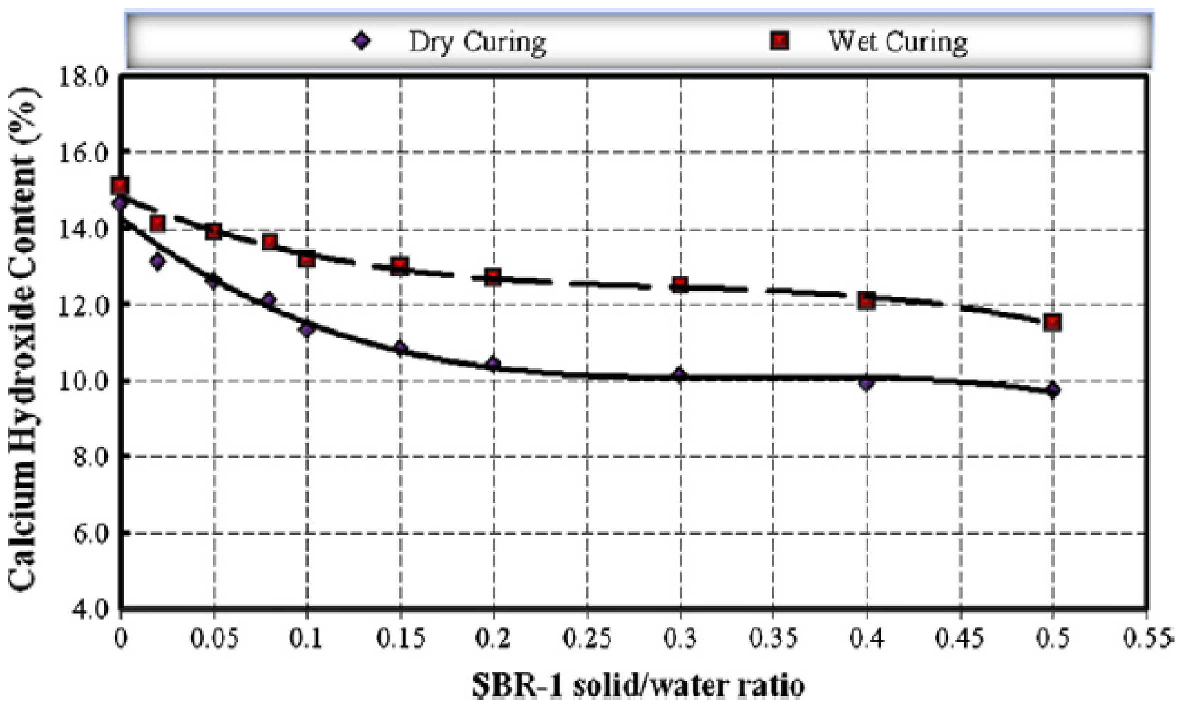


Fig. 2.5 Correlation between Calcium Hydroxide Content and SBR Solid/Water Ratio for Cement Paste Containing 0.35 of W /C Ratio at 28 days.(Diab et. al. 2012)

Correlation between Calcium Hydroxide Content and SBR Solid/Water Ratio for Cement Paste Containing 0.35 of Water Cement Ratio at 28 days shown in Fig.2.5.The wet curing type increases the calcium hydroxide content of both conventional cement paste and modified cement paste because the wet curing increases the degree of cement hydration. The results show that the calcium hydroxide content for unmodified cement paste increases by 5% at wet curing, while for modified cement paste calcium hydroxide content increases by 11%, 20%, and 23% with 5%, 20%, and 40% SBR solid/water ratio, respectively. At wet curing method, SBR solid/water ratio is a very significant factor affecting calcium hydroxide content.

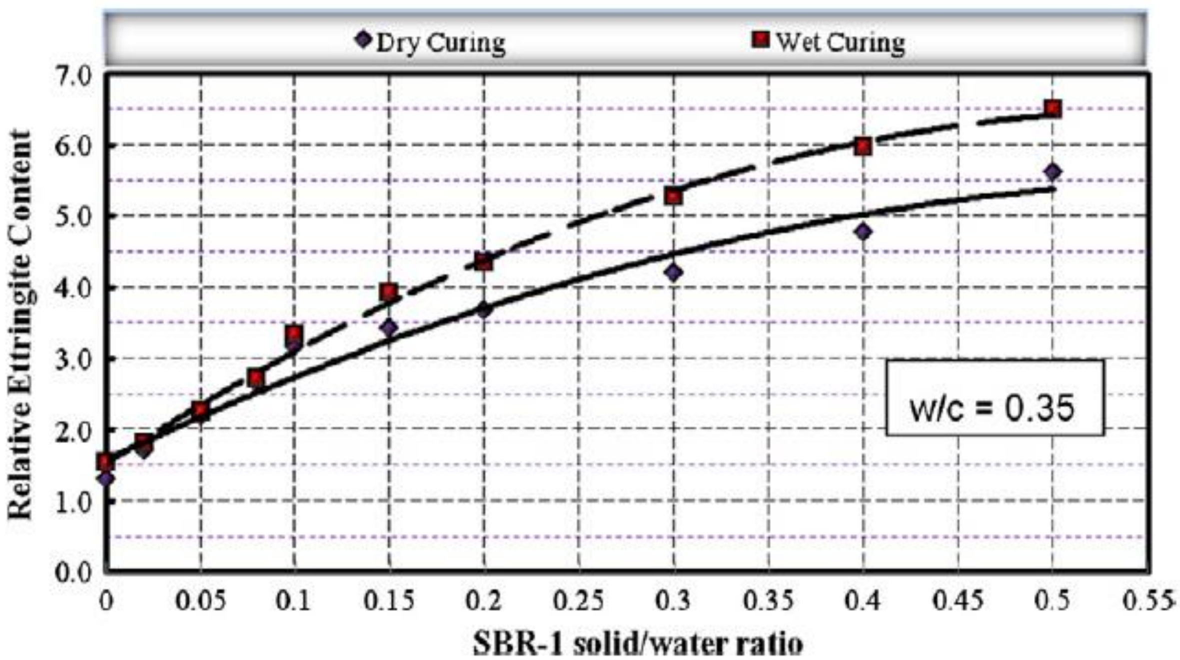


Fig. 2.6 Relative Ettringite Content at 28 Days for Cement Paste Cured under Dry and Wet Conditions Containing 0.35 of Water Cement Ratio. (Diab et. al. 2012)

Relative ettringite content at 28 days for cement paste cured under dry and wet conditions at 0.35 of water cement ratio shown in Fig. 2.6. Relative ettringite content means the ratio of ettringite content of any mix at any age with respect to that for control mix at the age of 7 days. The wet curing type increases the ettringite content of both conventional cement paste and modified cement paste because the wet curing breaks the ettringite impermeable shell. The results shows that the ettringite content for unmodified cement paste increases by 16% at wet curing, while for modified cement paste the ettringite content increases by 7%, 20%, and 22% more than that of dry cement paste with 5%, 20%, and 40% SBR solid/water ratio, respectively. For wet and dry curing method, SBR solid/water ratio is a very significant factor affecting the ettringite content of modified cement paste.

Wang, et al (2004) Concluded that properties of PMM are influenced by its phase state i.e. the polymer film, cement hydration, and combined structure between organic and inorganic phases .Cement hydration and polymer film formation increase the strength . The structure of cement mortar get changed due formation of coherent polymer films. This result in formation of interpenetrating structure in polymer modified mortar .The coherent polymer film reduces weakness in the mortar by arresting tiny cracks and reduces rigidity of mortar and as a results improving toughness of the mortar. If polymer addition is more than that require for formation of fully developed interpenetrating structure, polymer film become thicker and structure of mortar still interpenetrating. So higher percentage of polymer addition affect cement hydration process. Thus, the properties of the mortars are not improved further with the increment of P/C above 10%. It also reveals why the relationship between the strength and the apparent bulk density at P/C above 10% is no longer in accordance with the linearity at P/C below 10%. SBR film is very tough, like rubber for SBR comprising both the flexible butadiene chains and the rigid styrene chains. The hardened cement mortar is rigid. Their properties complement each other. As a result, polymer-modified mortar composites with excellent properties can be achieved when the P/C is appropriate.

Barluenga and Olivares (2004) conducted experimental study on SBR latex modified mortar. Percentage of Latex were used as 0%, 5%, 10%, 15%, 20% and 25% with respect to weight of cement. Cement sand ratio 1:3 used and Flow value of 180,200 and 220 mm±10mm fixed. The result of w/ c ratio are shown in fig. 2.7 as percentage of latex increasing w/c ratio going down this is due to fact that latex improve consistency of cement mortar by providing ball bearing action of polymer particles.

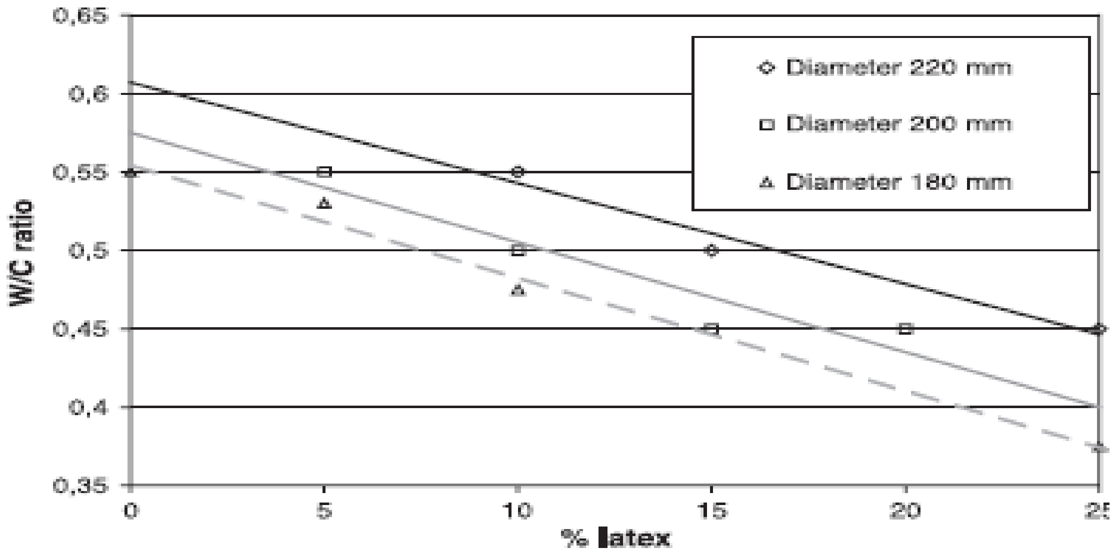


Fig. 2.7 W/C Ratio of LMM Vs Percentage of Latex. Barluenga and Olivares (2004)

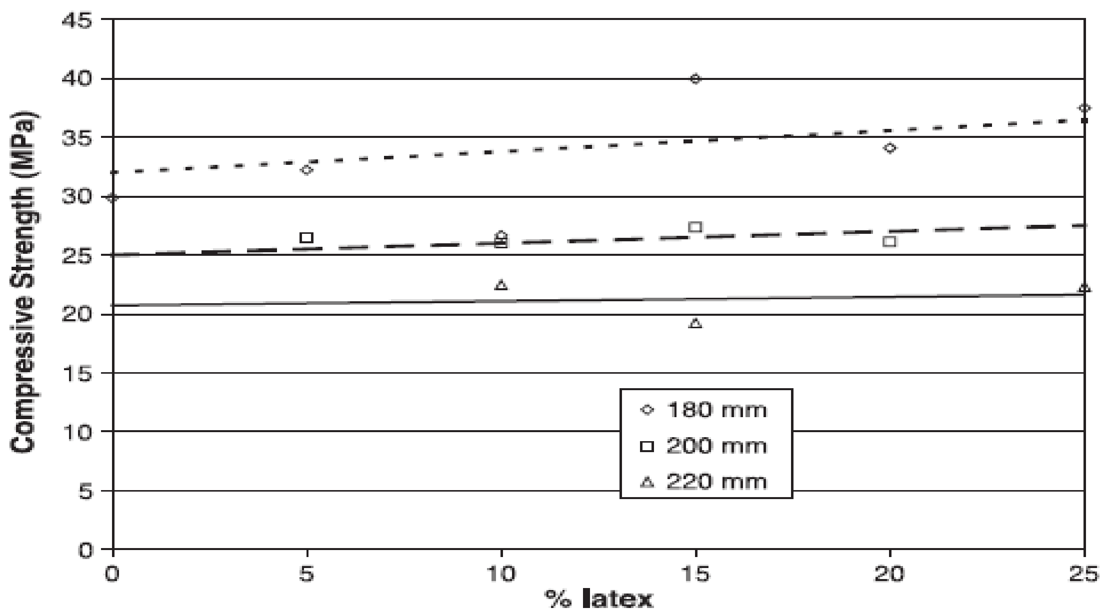


Fig. 2.8 Compressive Strength of LMM Vs Percentage of latex. Barluenga and Olivares (2004)

Compressive strength was nearly constant as shown in Fig. 2.8 for any percentage of latex; though decrease for large flow value. They concluded that in the hardened state LMM stiffness decreased with increase of latex, as Latex stiffness is lower than mortar stiffness. The inclusion of SBR latex in cement mortar produces a decrease of compressive strength, due to the lower mechanical capacity of latex with regard to cement mortar, for a fixed consistency. This decrease is compensated by the reduction of W/C due to the plasticizer effect of latex. Both phenomena together maintain compressive strength nearly constant for any percentage of latex.

Bending test results of LMM with fixed flow value at 28 days are resented in the Fig. 2.9. They concluded that Flexural strength increase with the percentage of latex and decrease for large flow value.

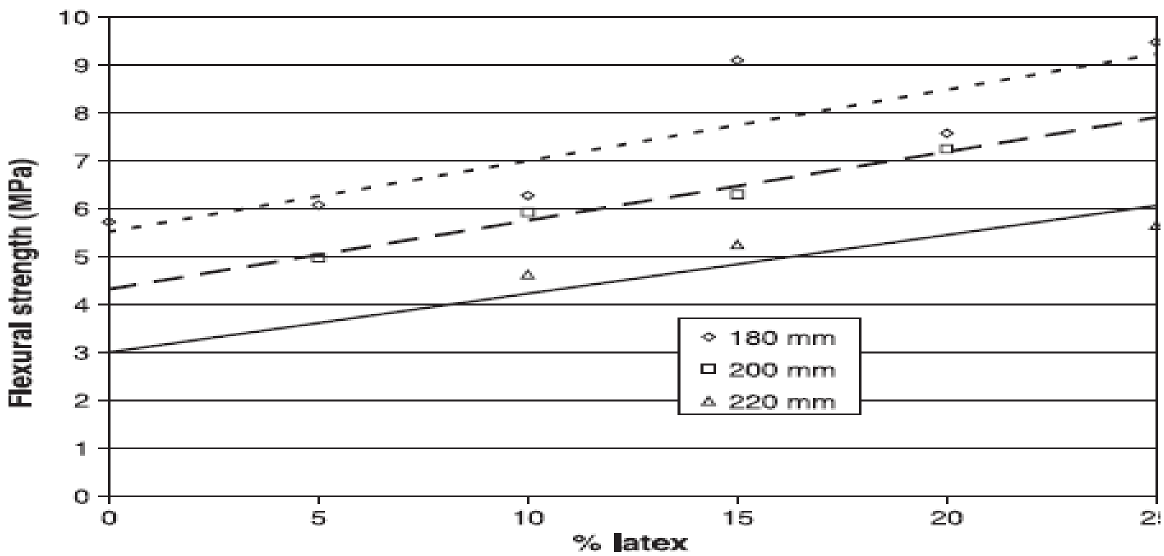


Fig. 2.9 Flexural Strength of LMM Vs Percentage of latex for flow value 180,200 and 220±10mm. Barluenga and Olivares (2004)

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

2.3 Review of Papers of Polymer Modified Ferrocement

Various papers which presented work done on polymer modified ferrocement are as follows:-

Sheela and Ganesan (2014) studied the behavior of 3m length different shaped ferrocement flexural elements. The samples prepared with varying percentage of SBR polymer and volume fraction of reinforcement. The prepared specimens were tested under third point loading. It is found that crack propagation of specimens without modification show sudden increase in crack width at higher loads as compare to the polymer modified specimens. Propagation was steady and crack widening was lesser for modified specimens in comparison to specimens without polymer content. The polymer modification resulted in the development of large number of finer cracks rather than a fewer number of wider cracks in normal ferrocement specimens. Among the three shaped elements the corrugated specimens show the crack propagation and widening of cracks were slow and gradual.

Ramli (2012) evaluated the load-deflection characteristics of PMM. Three commercial polymer-modified ferrocements namely styrene- butadiene rubber (SBR), polyacrylic ester (PAE), and vinyl acetate–ethylene (VAE), and unmodified ferrocement elements cured in air and saltwater exposure conditions. The flexural properties of ferrocement were also determined from the test specimens, 500X100 X25 mm, reinforced with three layers of square welded mesh with a volume fraction of 0.91%. A four point loading was used to determine the load deflection properties. When the specimens were subjected to continuous exposure to 4% sodium chloride solution for a period of nine months after initial curing there was surprisingly an improvement in both compressive and flexural strengths of the polymer-modified ferrocements. The flexural strength was found to increase by approximately 10–17%, whereas the increase in compressive strength was nearly 5% compared to prolonged air exposure. However, the flexural strength of the unmodified control specimen increased by approximately 8%, but its compressive strength showed a decrease of nearly 1%. Although the decrease was small, saltwater exposure did not seem favourable to the unmodified specimen. Instead, all the PMF specimens seemed to have a significant benefit from prolonged saltwater exposure. The increase in flexural strength may be attributed to the fact that the salt deposits coated the surface and increased the overall stiffness of the specimens. Sodium chloride permeated into the pores of the mortar matrix, and crystallized and bridged the particles of cement and aggregates into a denser and more compacted mortar matrix. Furthermore, the hydration reactions of Portland cement would continue to form extra binding sodium chloride hydrates that filled the pores within the mortar matrix and the interfacial zone between the wire mesh and the matrix. This in turn would account for the enhanced flexural strength of the ferrocement. The unmodified specimen showed the lowest flexural strength at this exposure condition. They concluded that polymer modification has significantly improved the mechanical properties of the ferrocement specimens, and the flexural behaviour of all the PMF has been greatly enhanced, irrespective of the adopted exposure conditions.

Medeiros (2009) Carried out experimental work to determine the direct-shear bond strength generated in the interface between the repair mortar and the concrete substrate. Specimens 40 mm X 40 mm X160 mm were molded with concrete and cured in water for 28 days. After that, the specimens were sawed in two equal parts. The cut surfaces were jetted with sand to increase the roughness of the substrate surface. Then repair portion is prepared and stress was applied on the repair mortar 5 mm from the interface between the two materials. The direct-shear bond strength (DBS) was calculated by dividing the maximum load by the area of the bonded surface. They verified that, in all cases using polymers the bond strength in direct-shear was bigger than in unmodified mortar. It indicates that the polymers are an important factor in bond strength, besides the direct-shear bond strength, the type of rupture was also used in the interpretation of the results. The more number of specimens with rupture occurring in the concrete substrate. This represents an ideal case in which the bond strength is sufficiently high in order for the rupture to occur in the concrete substrate. Unmodified mortars have not revealed satisfactory performance in relation with the rupture section

Zulkarnain and Suleiman (2008) carried out investigation to evaluate the characteristics of polymer-modified ferrocement under static flexure. This 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 ferrocement 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 ferrocement 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.

CHAPTER 3
EXPERIMENTAL PROGRAM

3.1 Introduction

The aim of work is to determine effect of SBR polymer modification on properties of PMM and PMF elements. Experimental program started with determination of water content for maintaining constant workability. The whole experimental work is divided in following three phases.

- Phase first includes determination of effect of SBR polymer addition on mechanical properties of PMM such as compressive strength, flexural strength, and bond or adhesion strength.
- Phase second includes determination of effect of SBR polymer addition on flexural strength and tensile strength of PMF elements.
- Phase third includes X-ray diffraction (XRD) and Scanning Electron Microscope (SEM) analysis to determine effect of addition of polymer to chemical properties and microstructure of cement mortar respectively.

3.2 Material

Cement, fine aggregate, GI wire mesh and SBR polymer are used in casting of specimens. The properties of material used for making mortar mix are determined in laboratory as per relevant codes of practice. In experimental study specimens has been prepared in cement mortar 1:2(1cement:2sand) using SBR Polymers addition of 0%, 5%, 10%, 15%, and 20% by weight of Cement and silicon based antifoaming agent has been added at the rate 1% of solid content of SBR. The specimens have been cured under the dry curing condition. Dry curing refer to curing of sample in water for 1-day after demoulding the sample and remains dry at room temperature up to the age of testing.

3.2.1 Cement

Portland pozzolana cement was tested and used in the experimental program. The physical properties obtained from various tests are listed in Table 3.1. All tests are carried out in accordance to procedure laid in IS 1489 (Part 1): 1991.

3.2.2 Fine Aggregate

In this experimental program, Local natural sand was used as fine Aggregate in cement mortar. Sieve analysis and physical properties of fine aggregate are tested as per IS: 383-1970 and results are as shown in Table 3.2 and Table 3.3.

3.2.3 GI Wire Mesh

GI steel wire mesh of average diameter 0.47 mm . Wire woven in square pattern was used in ferrocement element. The grid size of mesh was 7.50mm X 7.10 mm as shown in Fig. 3.1.Properties of G.I. wire mesh given in Table 3.4.

3.2.4 Polymer

Polymer having brand name SIKA Latex Power used in this experiment work .The properties are given in Table 3.5.

Table: 3.1 Physical properties of Cement

Sr.No	Charactertics	Test Value	Value Specified By IS : 1489-1991(part1)
1	Standard consistency (%)	34	----
2	Fineness of Cement as retained on 90 Micron Sieve (%)	5	10 (max.)
3	Setting Time Initial (minutes) Final (minutes)	 120 410	 30 (min.) 600 (max.)
4	Soundness of cement (Le Chatelier method)	2 mm	10 mm (max.)
5	Specific Gravity of cement	3.02	--

Table: 3.2 Physical Properties of Fine Aggregate

Sr.No.	Charactertics	Value
1	Type	Natural Sand
2	Specific Gravity	2.62
3	Water Absorption	1.02 %
4	Fineness Modulus	2.21
5	Grading Zone	III

Table 3.3 Sieve Analysis of Fine Aggregate

Total weight of sample =1500gm

Sieve Size	Weight retained (gm)	Percentage of Weight retained	Percentage of Weight passing	Cumulated Percentage of retained
10mm	-	-	100	-
4.75mm	-	-	100	-
2.36mm	75	5	95	5
1.18mm	220	14.70	80.30	19.70
600µm	230	15.30	65	35
300µm	440	29.30	35.70	64.30
150µm	500	33.3	2.30	97.70
Pan	35		ΣF	221.70

Fine Modulus of Fine aggregate = 2.21

Table 3.4 Properties of GI Wire Mesh

Diameter of wire	0.46mm – 0.48mm
Mash opening size	7.50 X 7.10 mm

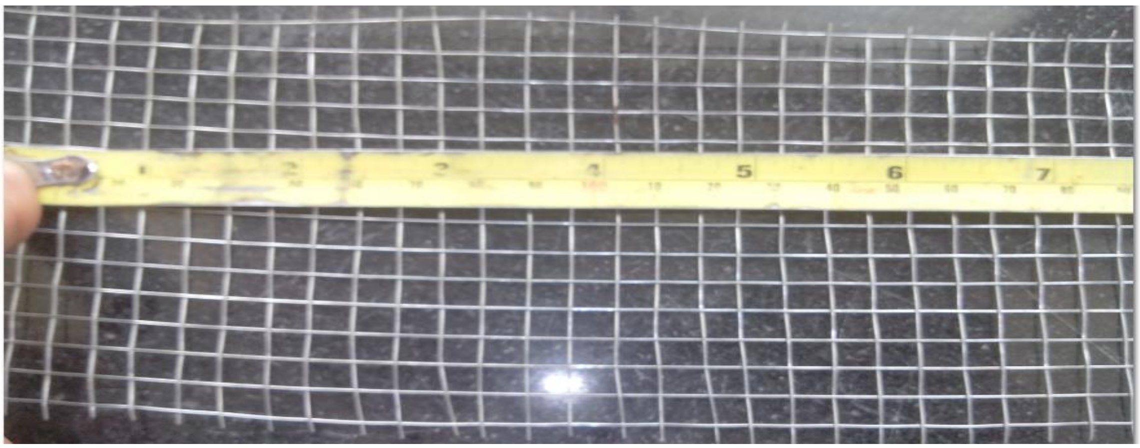


Fig. 3.1 Showing GI Wire Mesh

Table 3.5 Properties of SBR Polymer

Sr.No.	Properties	SBR Polymer
1	Colour	White Liquid
2	Odour	Slight
3	pH	8.5-11
4	Water Solubility	Soluble
5	Relative Density(g/cc)	1.01-1.025
6	Solid Content (%)	45-47.5
7	Particle Size	0.15

3.3 Experimental Outline

The experimental work is divided into three phases. The detail of cement, sand, water and SBR polymer content along with curing conditions and flow values for samples to be casted and tested in all the three phases of experimental program are shown in Table 3.6.

Table 3.6 Detail Description of Samples to be Casted and Tested during Experimental Program

Sr. No.	Designation	Cement (Kg)	Sand (Kg)	Water Content (Kg)	SBR Latex Power (Kg.)			Total Liquid Content (Kg)	Curing Condition	Flow Value (mm)
					Total	Solid	Liquid			
1	SW-0	1	2	0.580	-	-	-	0.580	Wet*	105
2	S-0	1	2	0.580	-	-	-	0.580	Dry**	105
3	S-5	1	2	0.4425	0.050	0.0225	0.0275	0.47	Dry	107
4	S-10	1	2	0.3650	0.100	0.0450	0.0550	0.42	Dry	110
5	S-15	1	2	0.3075	0.150	0.0675	0.0825	0.39	Dry	112
`6	S-20	1	2	0.250	0.200	0.090	0.110	0.36	Dry	114

** Wet curing refer curing in water after demoulding the sample up to age of testing*

***Dry Curing is refer to curing in water for 1-day after demoulding the sample and remains dry at room temperature up to the age of testing.*

3.3.1 First Phase

The first phase of testing includes following.

a) Determination of water content for polymer modified mortar for maintaining the constant flow value 110±5 at SBR content varying from 0 to 20%. This is determined by flow table test. Detail regarding number of specimens given below.

%age of SBR Polymer	0%	5%	10%	15%	20%
No. of Specimens	3	3	3	3	3

Total Specimens = 15

b) Investigation of compressive strength of polymer modified mortar at SBR content varying from 0 to 20%. Mortar cubes of size 70.6 X 70.6 X 70.6mm casted for determination of compressive strength. Detail regarding number of specimen given below.

%age of SBR Polymer	0%	5%	10%	15%	20%
No. of Specimens	12	6	6	6	6

Total specimens = 36

c) Investigation of flexural strength of polymer modified mortar at SBR content varying from 0 to 20%.Specimens of size 40X40X160mm casted for determination of flexural strength. Detail regarding number of specimen given below.

%age of SBR Polymer	0%	5%	10%	15%	20%
No. of Specimens	12	6	6	6	6

Total Specimens = 36

d) Investigation of Bond Strength of polymer modified mortar at SBR content varying from 0 to 20%. Specimen of size 56 X 56 X 42mm casted for determination of bond strength. Detail regarding number of specimens given below.

%age of SBR Polymer	0%	5%	10%	15%	20%
No. of Specimens	12	6	6	6	6

Total Specimens = 36

3.3.2 Second Phase

In this phase following physical properties of polymer modified ferrocement (PMF) is determined. Specimen is casted by providing two and three layer of woven wire mesh.

a) Investigation Flexural strength of Polymer modified ferrocement (PMF) beams at SBR content varying from 0 to 20%. Specimens of size 500 X 100 X 20mm were 7casted and tested in accordance with ACI Committee 549 standards. Detail regarding number of specimens given below.

%age of SBR Polymer	0%	5%	10%	15%	20%
No. of Specimens for 2-layer woven wire mesh	12	6	6	6	6
No. of Specimens for 3-layer of woven wire mesh	12	6	6	6	6

Total No. samples = 72

b) Investigation of tensile strength of Polymer modified ferrocement (PMF) specimen at SBR polymer content varying from 0 to 20%. Specimens of size 500 X 100 X 20mm were casted and tested in accordance with ACI standards. Detail regarding number of specimens given below.

%age of SBR Polymer	0%	5%	10%	15%	20%
No. of Specimens for 2-layer woven wire mesh	12	6	6	6	6
No. of Specimens for 3-layer of woven wire meh	12	6	6	6	6

Total No. of samples = 72

3.3.3 Third Phase

In this phase X-ray diffraction (XRD) and Scanning Electron Microscope (SEM) has been conducted to determine effect of polymer to chemical properties and change in microstructure of cement mortar respectively. For XRD sample has been in prepared in powder form from tested samples and for SEM fracture surface of tested sample has been taken for testing.

3.4 Detailed Description of Experimental Work in First Phase

First of all the flow table test is conducted to find out the water-content for maintaining the constant flow value for polymer addition varying from 0 to 20% of weight of cement. After that compressive strength, flexural strength, bond strength is found out. Detail descriptions of tests are given below.

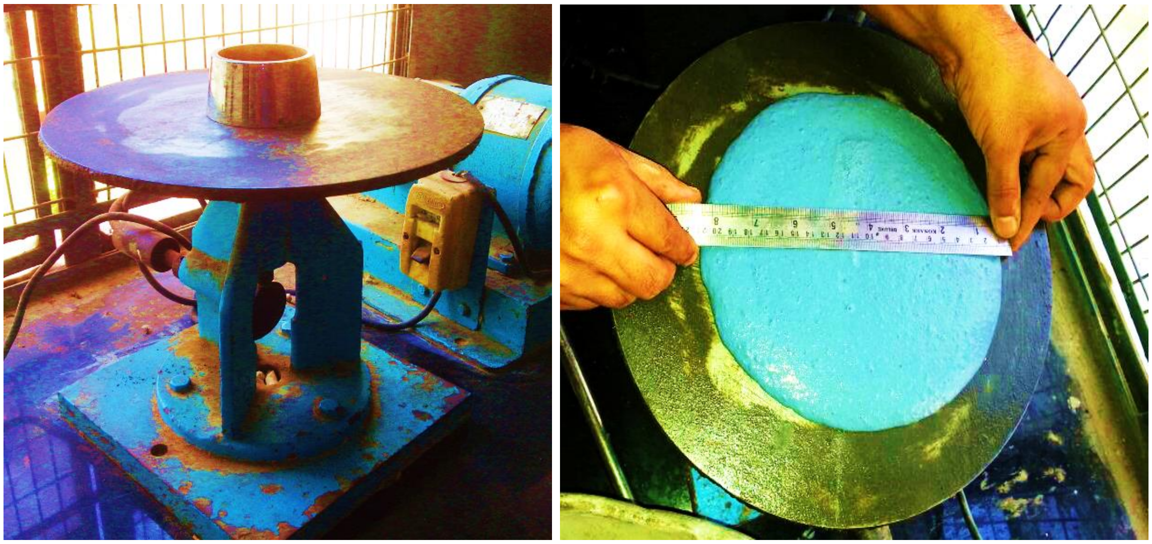
3.4.1 Flow test

Flow test has been conducted in accordance with ASTM C1437 "Test Method for Flow of Hydraulic Cement Mortar". In the experimental program flow is fixed to 110±5mm. Flow test is conducted to determine the water-content to maintaining constant flow of 110±5mm of Polymer modified cement mortar 1:2 (1cement: 2 sand).

a) Procedure for Flow Test

Test is conducted on flow table, standard mound of 100mm base diameter, 70mm top diameter, and 50mm height is used to conduct the test as shown in Fig.3.2. 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 25mm dia. Mild steel bar. After filling the mortar, mould is removed by applied 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. Then measure the diameter of spread mortar. Flow value is calculated as

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



(a) (b)

Fig. 3.2 (a) Flow Table. (b) Measurement of Flow.

3.4.2 Compression Test

The first phase of testing includes determination of compressive strength of polymer modified mortar at polymer content varying from 0 to 20% by weight of cement content. Cement mortar 1:2 (1cement: 2sand) is prepared by thoroughly mixing of cement, sand, water, polymer in appropriate proportion. Then fill the cement mortar in cube moulds having size 70.6 X 70.6 X 70.6mm. Compacting the cube mould for two minutes and place it at the room temperature. After 24hours, remove the specimen from mould and cured under dry condition up to age of testing. Compression test is conducted on Universal Testing Machine. During testing loading is applied gradually at the rate of 70Kn/min. Sample under compressive testing is shown as in Fig. 3.3.The Compressive Stress is calculated by following formula:

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

Where: f = Compressive Stress (MPa)

, F = Ultimate Load (N)

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

Fig. 3.3 Sample under Compressive Strength Testing

3.4.3 Flexural Strength

In this experimental program flexural test for PMM has been conducted in accordance with ACI Committee 549 standards. To determination of Flexural strength of polymer modified mortar at polymer content varying from 0 to 20% by weight of cement content. Cement mortar 1:2 (1cement: 2sand) is prepared by thoroughly mixing of cement, sand, water, polymer in appropriate proportion. Fill the cement mortar in beam mould having size 40 X 40 X 160mm. Compacting the beam mould for two minutes and place it at the at room temperature. After 24 hours, remove the specimen from mould and cured under dry condition up to age of testing. Flexural test is conducted on Universal Testing Machine by applying three points loading and rate of loading fixed at 2.65 KN/min. The effective length of beam is taken as 120mm. Failure of sample during flexural testing under three point loading is shown in Fig. 3.4 The flexural strength under three point loading can be find out by the bending or by the formula given below :

$$\sigma = 3Pl/2bd^2$$

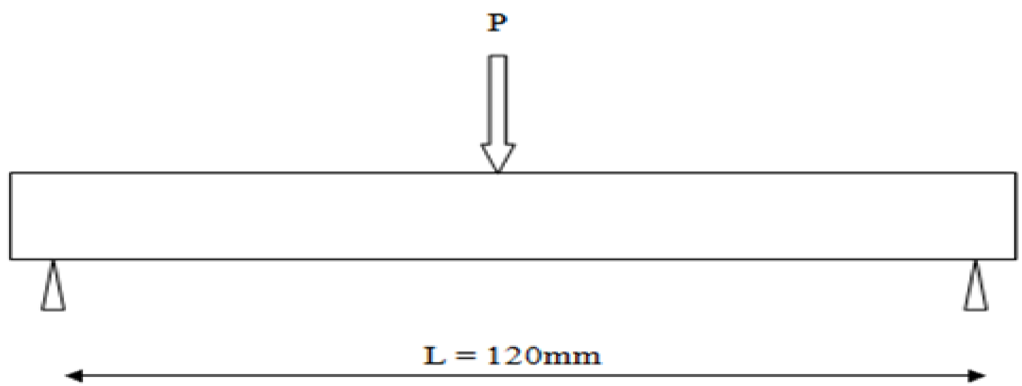


Fig. 3.4 Schematic Diagram for Three Point Loading

The flexural strength of beam under four point loading can be find out by formula as under:

$$\sigma = Pl/bd^2$$

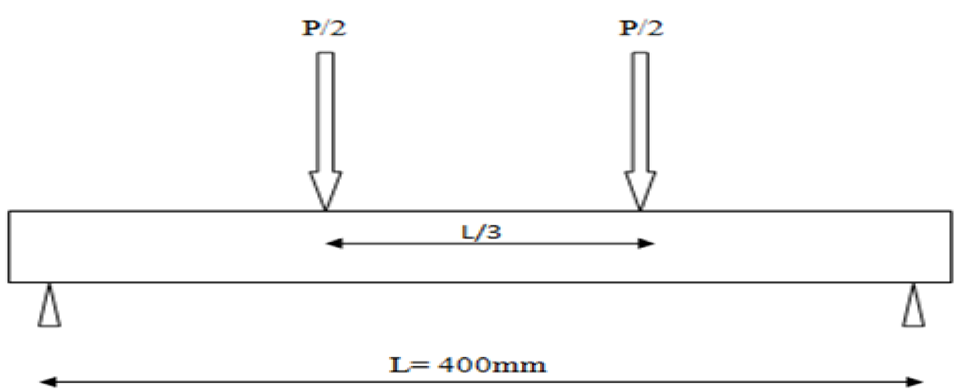


Fig. 3.5 Schematic Diagram for Four Point Loading

Where σ = Stress at outer fiber (N/mm^2), P= Load at fracture point (N), l = is Length of supported span (mm), b = width (mm), d = Thickness (mm).

Fig. 3.6 Failure of Sample during Flexural Testing under Three Point Loading

3.4.4 Bond Strength or Adhesion

The adhesion of PMM to ordinary cement mortar as substrate can be measured by four types of test method generally i.e. Adhesion in tension, flexural, direct shear, slant compressive shear or indirect compressive shear. In this program the adhesion or bond strength in direct shear in determined. For this specimens having size 56X56X42 is prepared in two parts as shown in Fig. 3.7. First, substrate of size 56 X 56 X 15mm is prepared in conventional cement mortar 1:2 (1cement: 2 sand) and cured in water for 7days. After 7days upper part of specimen casted by using PMM and cured under dry condition up to age of testing. Shear test is conducted in direct shear testing machine as shown in Fig. 3.8.Shear loading is applied to upper part of specimen gradually up to point of failure and shear stress is calculated as :

$$\tau = V / A$$

τ = bond or adhesion stress (MPa), V = Shear force in (N), A = Contact Area (mm^2)

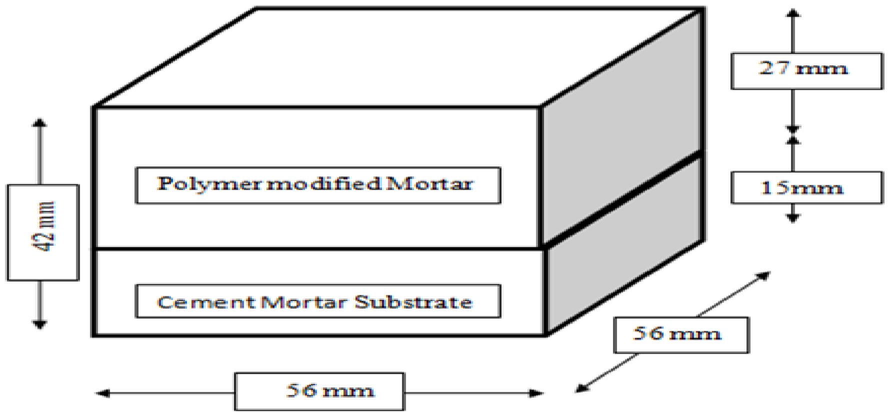


Fig. 3.7 Detail of Specimen for Adhesion or Bond Strength

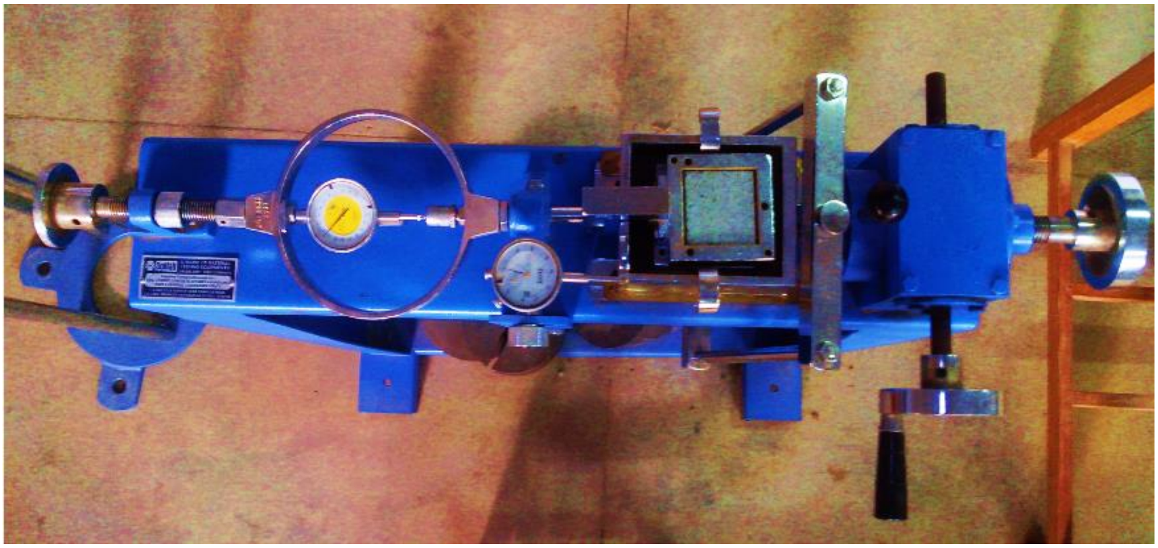


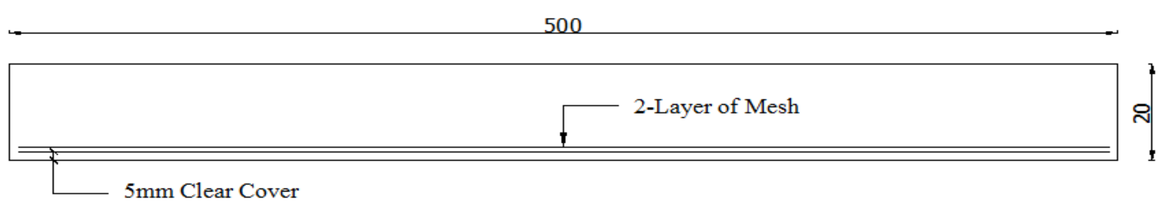
Fig. 3.8 Direct Shear Strength Testing for Bond Strength

3.5 Detailed Description of Experimental work in Second Phase

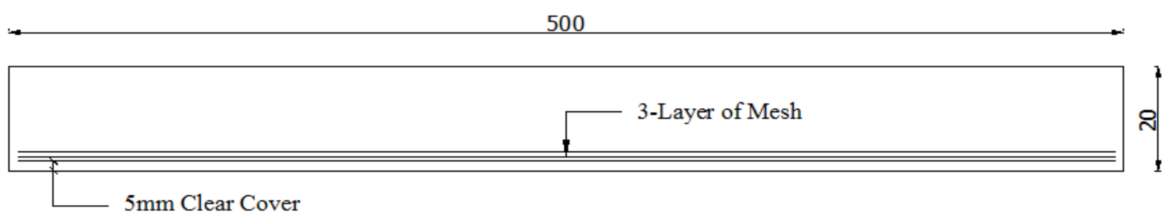
In this phase flexural strength and tensile strength of polymer modified ferrocement (PMF) is determined.

3.5.1 Flexural Test on Ferrocement Beams

In this experimental program flexural test for PMF beam has been conducted in accordance with ACI Committee 549 standards. Test specimen of size 500 X 100 X 20mm is prepared by providing 2-layer and 3-layer of wire mesh. Detail of ferrocement sample is given in fig.3.9 First cement mortar 1:2 (1cement: 2sand) is prepared by thoroughly mixing of cement, sand, water, polymer in appropriate proportion. Fill the cement mortar in beam moulds having size 500 X 100 X 20mm.Proper care should be taken during pouring of cement mortar to maintain the position of wire mesh and clear cover of 5mm from bottom. Compacting the beam mould for two minutes and place it at the room temperature. After 24hours, remove the specimen from mould and cured under dry condition up to age of testing. The flexural test is conducted on Universal testing machine four point loading is used over clear span of 400mm. Dial gauges are used to measure the deflection a center of beams. Flexural Strength Testing under Third Point Load of Ferrocement Sample is shown in Fig. 3.10.



(a) 2-Layer Sample



(b) 3- Layer Sample

Fig.3.9 (a & b) Detail of Polymer Modified Ferrocement Sample

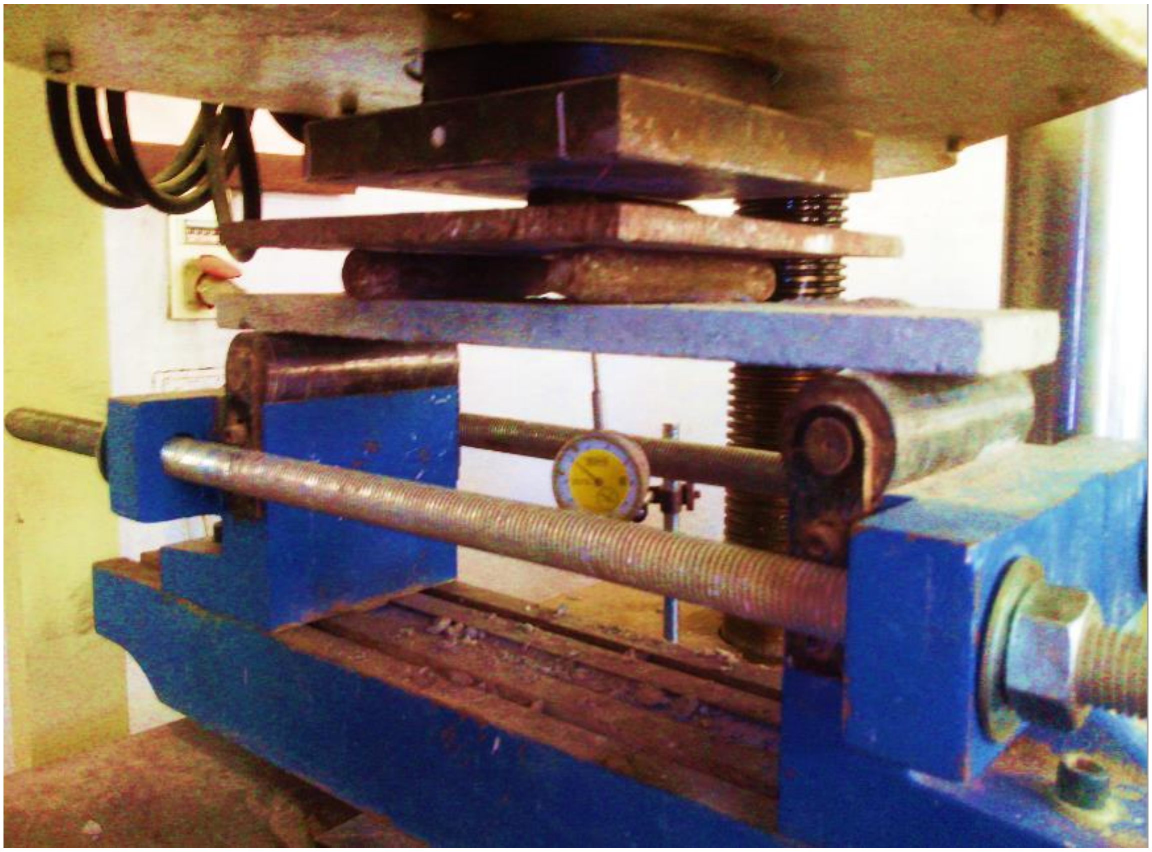


Fig. 3.10 Testing of Flexural Strength of PMF Beam under Four Point Loading

3.5.2 Tensile Test on Ferrocement Elements.

In this experimental program tensile test for PMF element has been conducted in accordance with ACI Committee 549 standards. Test specimen of size 500 X 100 X 20mm is prepared by providing 2-layer and 3-layer of wire mesh. First cement mortar 1:2 (1cement: 2sand) is prepared by thoroughly mixing of cement, sand, water, polymer in appropriate proportion. Then fill the cement mortar in beam moulds having size 500 X 100 X 20mm. Proper care should be taken during pouring of cement mortar to maintain the position of wire mesh and clear cover of 5mm from bottom. Compacting the beam mould for two minutes and place it at the room temperature. After 24hours, remove the specimen from mould and cured under dry condition up to age of testing. The tensile test is conducted on universal testing machine .Tensile load and corresponding elongation are recorded. Specimen under tensile load is shown in Fig. 3.1

. (a) (b)

Fig. 3.11 (a) Specimens for Tensile Test. (b) Specimen during Tensile Testing

3.6 Detailed Description of Experimental Work in Third Phase

In this phase X-Ray Diffraction (XRD) and Scanning Electron Microscope (SEM) analysis of polymer modified mortar (PMM) is conducted.

3.6.1 X-Ray Diffraction (XRD)

The X-ray diffraction carried out in the present study to determine changes in chemical properties of cement mortar. X-ray diffractometry is a sensitive technique. For this, Diffractometer with a X-ray source of Cu Kα radiation (λ = 1.54060 Å) was used. In carrying out the X-ray diffraction, the mortar samples are first ground into powder form. Then sample is put into the slot for testing. The scan step size [^{o}2Th.] was 0.0130, and in the range 2Θ CuKα from 10^o to 80^o.The X-ray tube voltage and current were fixed at 45 kV and 40 mA respectively. X-Ray Diffractometer is shown in Fig.3.12.

3.6.2 Scanning Electron Microscope

The SEM investigation of the PMM is conducted to study the major differences in its microstructure compared to that of the unmodified mortar. The specimens used for the investigation were obtained from the fractured surface of the mortar. The specimens were placed under the microscope and images of microstructure were taken and analyzed.

Fig. 3.12 X-Ray Diffractometer X'Pert-Pro

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter deals with the presentation of results obtained from various tests conducted on cement mortar and ferrocement specimens casted with addition of SBR polymer content. The main objective of the research program was to investigate the effect of addition of SBR polymer on workability, compressive strength, flexural strength, bond or adhesion strength of polymer modified mortar and flexural strength, tensile strength of polymer modified ferrocement. In order to achieve the objectives of present study, an experimental program is conducted results of which has been discussed as below.

4.2 Workability of Polymer Modified Mortar

The flow table test has been conducted as per procedure described in first phase of experimental program in previous chapter. The Flow value of cement mortar has been determined at SBR polymer content varying from 0 to 20% by weight of cement and results are shown in Fig.4.1 and Table 4.1. Experimental results show that workability increased by 26.66%, 63.80% and 81.90% for SBR polymer addition of 5%, 10% and 15% by weight of cement respectively in compression to cement mortar having 0% polymer addition. The results indicate that addition of polymer content has enhanced the workability of conventional cement mortar.

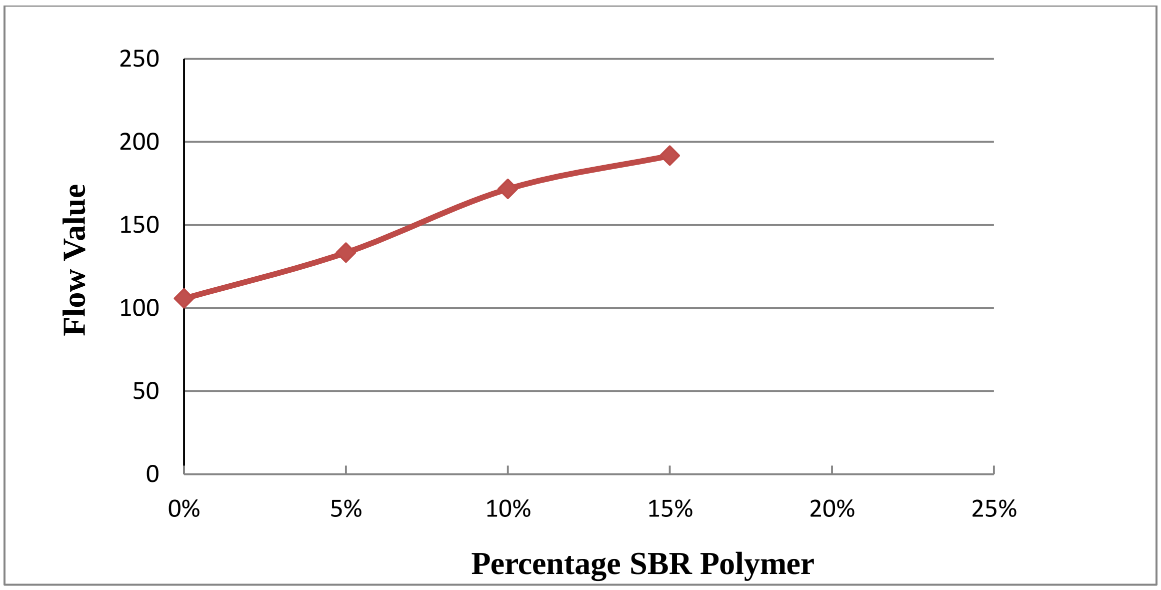


Fig. 4.1 Flow Value Vs Percentage of Polymer Content at Constant w/c Ratio

Table 4.1 Flow Value at various percentage of Polymer Content.

Sr. No.	Polymer/Cement Ratio	Water/Cement Ratio	Flow Value (mm)
1	0%	0.58	105
2	5%	0.58	133
3	10%	0.58	172
4	15%	0.58	191
5	20%	0.58	..

This is due to fact that polymer particle act as ball bearing among the cement particle to increase workability. Entrained air in Polymer modified mortar is another reason to increase workability. Entrained air introduced due to action of the surfactants contained as emulsifiers and stabilizer in polymer latexes.

4.2 Compressive Strength of Polymer Modified Mortar

The compression test has been conducted as per procedure described in first phase of experimental program in previous chapter. Compressive strength of SBR modified mortar is determined after 7-days and 28-days of dry curing at SBR polymer varying from 0 to 20% at constant workability. The results are shown in Fig.4.2,Fig. 4.3 and Table 4.2. It has been seen that compressive strength of cement mortar for 7-days is increased by 33.02%,41.01%,29.21% and 23.03% for SBR polymer addition of 5%,10%,15% and 20% by weight of cement respectively as compare to unmodified cement mortar under dry curing condition. Further the compressive strength for 28-days is increased by 26.05%, 36.28%, 32.03%and 24.06% for SBR polymer addition 5%, 10%, 15%, 20% by weight of cement respectively as compare to unmodified cement mortar under dry curing condition. It is found that compressive strength showing increasing trend up to addition of 10% of SBR polymer and after that compressive strength decreases from 10% to 20% of polymer addition. This trend is due to fact that compressive strength in PMM is provide by a monolithic network in which the polymer phase interpenetrates throughout the cement hydrate phase. Structure of PMM consists of interpenetrating polymer film in cement gel. For polymer addition up to 10%, higher contribution of cement hydration phase in compressive strength in comparison to latex phase increase the compressive strength of PMM. For polymer addition beyond 10% the interpenetrating polymer film become thicker and structure of mortar still interpenetrating. Now latex phase has more participation in comparison to hydration phase in the compressive strength of PMM. This results in decrease in compressive strength due to comparatively low compressive strength of latex network than hydration phase in co-matrix.

Another reason for decrease of compressive strength for higher dose of polymer content is due to the fact that in the latex-modified mortars a large quantity of air is entrained compared to that in ordinary cement mortar because of an action of the surfactants contained as emulsifiers and stabilizer in polymer latexes. Some air entrainment is useful to obtain improved workability. An excessive amount of entrained air causes a reduction in compressive strength. Moreover higher percentage of SBR polymer reduces the rate of hydration results in reduction of the compressive strength. For the total compressive strength in case of PMM, major contribution comes from the hydration phase.

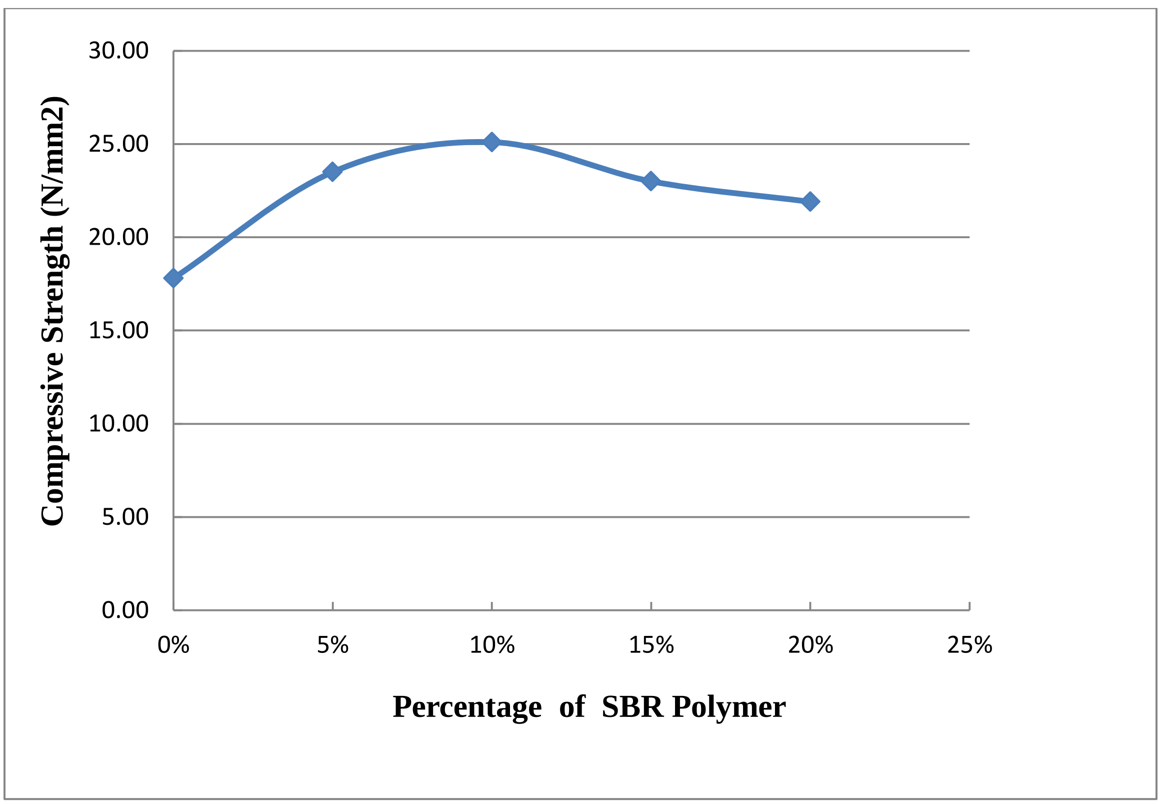


Fig. 4.2 Compressive Strength Vs Percentage of Polymer Content after 7-days

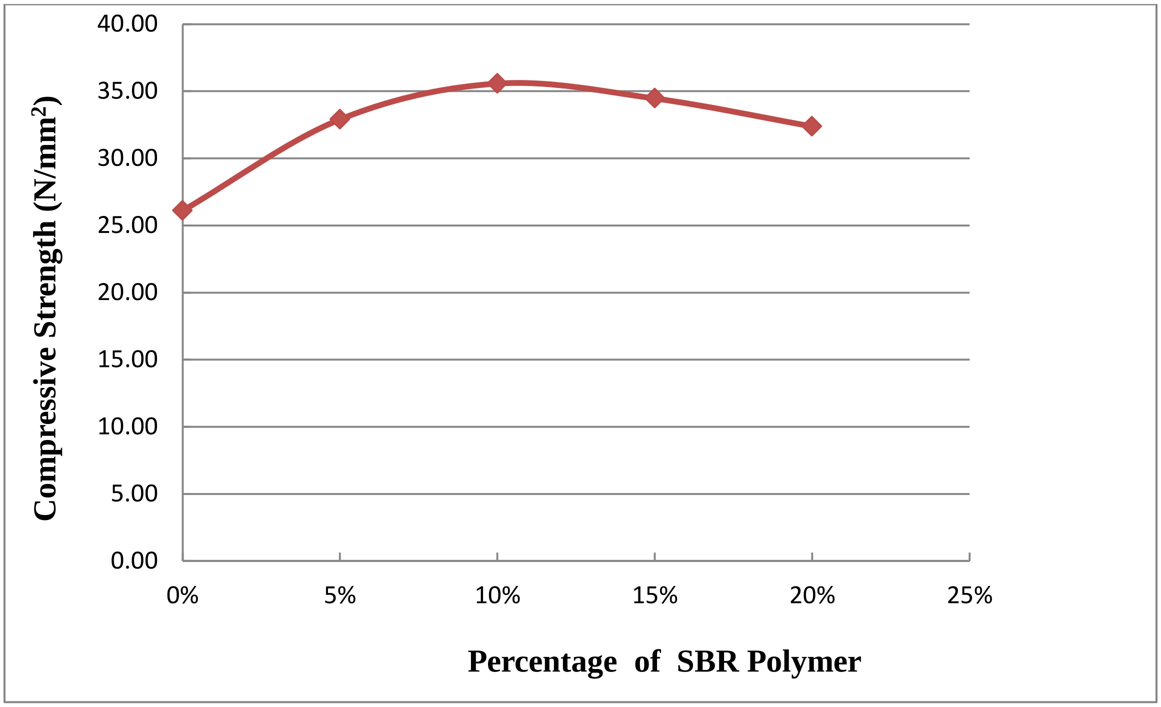


Fig. 4.3 Compressive Strength Vs Percentage of Polymer Content after 28-days

Table 4.2 Compressive strength at various percentage of SBR Polymer after 7 & 28-Days.

Mix Designation	Compressive Strength after 7-days (N/mm^2)	Compressive Strength after 28-days (N/mm^2)
SW-0	20.40	29.15
S-0	17.80	26.10
S-5	23.50	32.90
S-10	25.10	35.57
S-15	23.00	34.46
S-20	21.90	32.38

4.3 Flexural Strength of Polymer Modified Mortar.

The Flexural test has been conducted as per procedure described in first phase of experimental program in previous chapter. Flexural strength of SBR modified mortar is determined after 7-days and 28-days of dry curing at SBR polymer varying from 0 to 20% at constant workability. The results for flexural strength are shown in Fig.4.4, Fig. 4.5 and Table 4.3. It has been seen that flexural strength of cement mortar for 7-days is increased by 41.10%,50.60%,61.66% and 56.16% for SBR polymer addition of 5%,10%,15% and 20% by weight of cement respectively as compare to unmodified cement mortar under dry curing condition . Further the flexural strength for 28-days is increased by 40.9%, 52.7%, 61.36%and 55.68 % for SBR polymer addition 5%, 10%, 15%, 20% by weight of cement respectively as compare to unmodified cement mortar under dry curing condition.

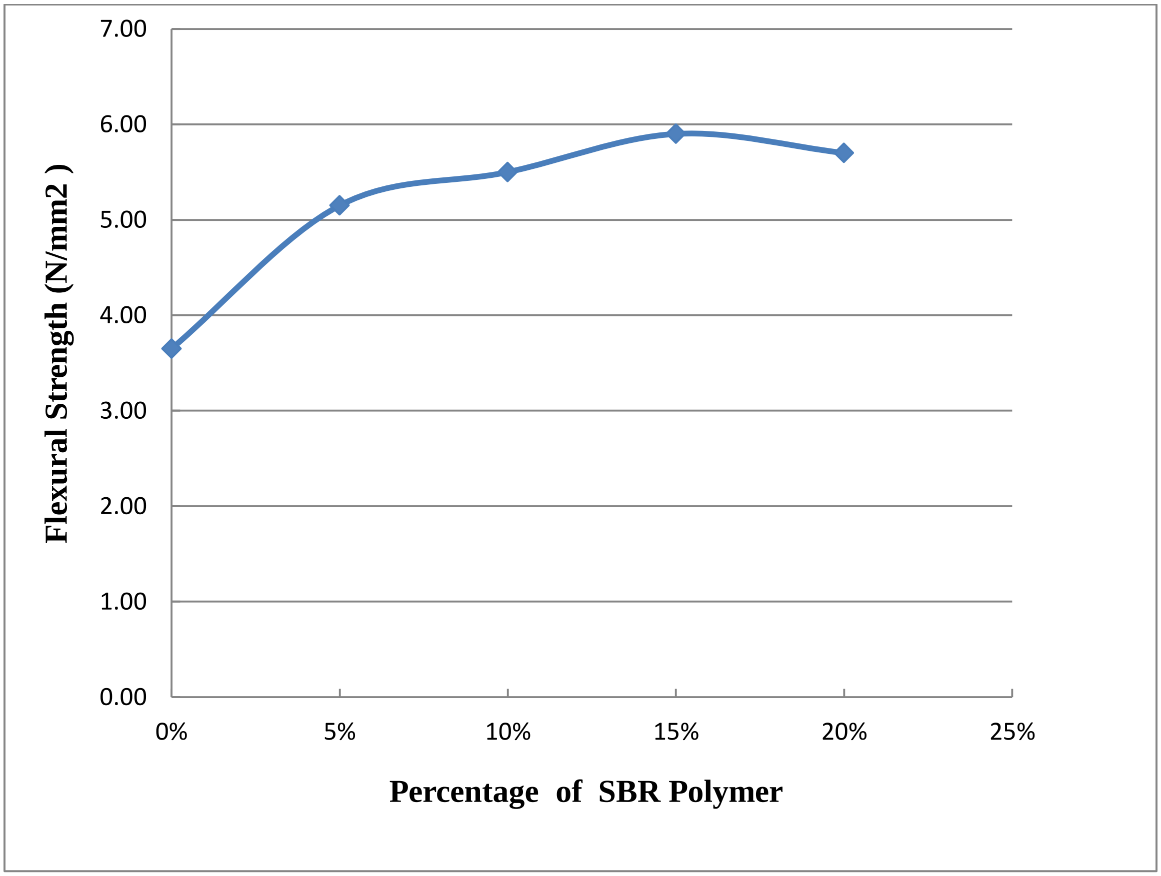


Fig. 4.4 Flexural Strength Vs Percentage of SBR Polymer after 7-Days

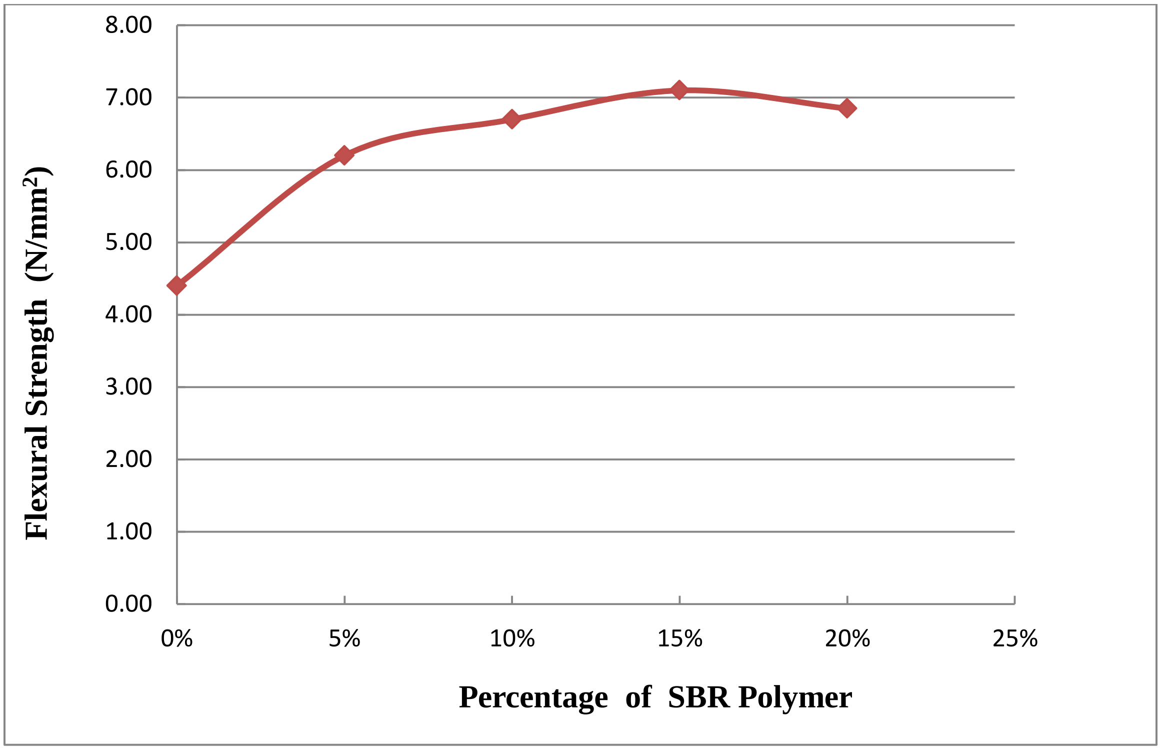


Fig. 4.5 Flexural Strength Vs Percentage of SBR Polymer after 28-Days.

Table 4.3 Flexural strength of SBR Polymer Modified Mortar after 7 & 28-Days.

Sr. No.	Mix Designation	Flexural Strength after 7-days (N/mm^2)	Flexural Strength after 28-days (N/mm^2)
1	SW-0	4.15	5.10
2	S-0	3.65	4.40
3	S-5	5.15	6.20
4	S-10	5.50	6.70
5	S-15	5.90	7.10
6	S-20	5.70	6.85

It is found that flexural strength showing increasing trend up to addition of 15% of SBR polymer and after that flexural strength decreases as polymer addition is more than 15% by weight of cement. The increase in flexural strength is due to the interpenetrating polymer film in cement gel. This film is very tough, as SBR comprising both the flexible butadiene chains and the rigid styrene chains. The hardened cement mortar is rigid. Here their properties complement each other up to 15% of polymer addition. More than 15% of SBR polymer addition leads to discontinuities in microstructure resulting reduction in flexural strength. Moreover beyond 15% of SBR polymer addition Flexural strength get reduced due to decrease in rate of hydration of cement as SBR polymer content increase.

4.5 Bond or Adhesion Strength of Polymer Modified Mortar

The direct shear test has been conducted as per procedure described in first phase of experimental program in previous chapter. Bond or Adhesion strength of SBR modified mortar is determined after 7-days and 28-days of dry curing at SBR polymer 0 to 20% at constant workability. The results for bond strength in direct shear are shown in Fig.4.6, Fig. 4.7 and Table 4.4.It has been seen that the bond or adhesion strength of cement mortar for 7-days is increased by 17.23%,46.20%,77.25% and 78.70% for SBR polymer addition of 5%,10%,15% and 20% by weight of cement respectively as compare to unmodified cement mortar under dry curing condition . Further the bond strength for 28-days is increased by 30.5%, 52.66%, 95.24% and 97.65 % for SBR polymer addition 5%, 10%, 15%, 20% by weight of cement respectively as compare to unmodified cement mortar under dry curing condition. It is found that Bond or Adhesion Strength increase sharply up to 15% of SBR polymer and after that bond or adhesion strength curve is nearly flat from 15% to 20% of polymer addition. Enhanced bond or adhesion strength is due to diffusion of the latex-modified pastes in the substrates mortar. This diffusion results in the monolithic bond between the substrates mortar and latex-modified pastes as shown in Fig. 4.8(a). Moreover, the very workable latex-modified pastes fill the non-uniform mortar substrates, and develop a good bond by micromechanical interlocking mechanisms.

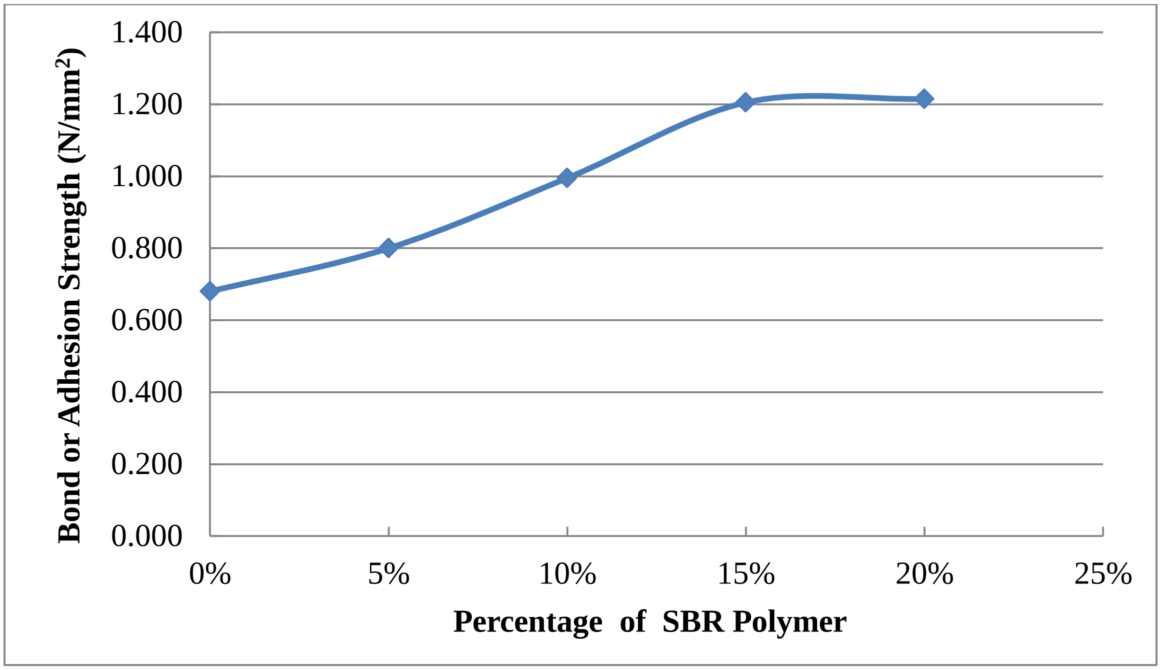


Fig. 4.6 Bond or Adhesion strength Vs Percentage of SBR Polymer after 7-Days.

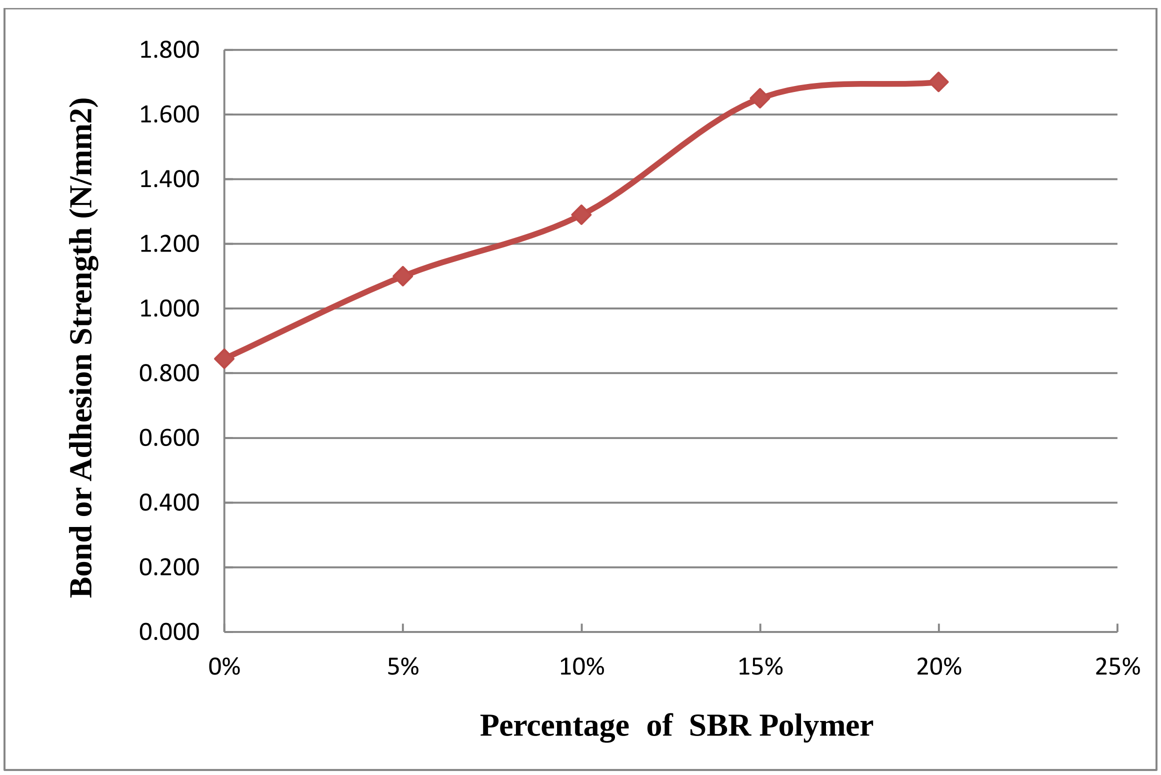


Fig. 4.7 Bond or Adhesion strength Vs Percentage of SBR Polymer after 28-Days.

Table 4.4 Bond or Adhesion strength in Direct Shear of SBR Polymer Modified Mortar after 7 & 28-Days.

Sr. No.	Mix Designation	Bond or Adhesion Strength after 7-days (N/mm^2)	Bond or Adhesion Strength after 28-days (N/mm^2)
1	SW-0	0.710	0.990
2	S-0	0.680	0.845
3	S-5	0.800	1.100
4	S-10	0.995	1.290
5	S-15	1.205	1.650
6	S-20	1.215	1.670

(a)

(b)

Fig. 4.8 Failure surface of Specimen with (a) PMM (b) Unmodified Mortar

4.6 Flexural Strength of Polymer Modified Ferrocement Elements.

The flexural test has been conducted as per procedure described in second phase of experimental program in previous chapter. Flexural strength of SBR polymer modified ferrocement is determined after 7-days and 28-days of dry curing at SBR polymer varying from 0 to 20% at constant workability. Flexural strength of 2-layered ferrocement samples are shown in Fig.4.9, Fig. 4.10 and Table 4.5. It has been seen that flexural strength of 2-layered ferrocement samples of cement mortar for 7-days is increased by 18.45%, 30.06%, 45.09% and 37.25% for SBR polymer addition of 5%, 10%, 15% and 20% by weight of cement respectively as compare to unmodified ferrocement samples under dry curing condition. Further the flexural strength of ferrocement samples for 28-days is increased by 15.60%, 26.67%, 47.18%and 36.92 % for SBR polymer addition 5%, 10%, 15%, 20% by weight of cement respectively as compare to unmodified ferrocement samples under dry curing condition.

Flexural strength of 3-layered ferrocement sample after 7-days & 28-days are shown in Fig.4.11,Fig. 4.12 and Table 4.7. It has been seen that flexural strength of 3-layered ferrocement samples of cement mortar for 7-days is increased by 22.2%, 32.13%, 50.94% and 41.58% for SBR polymer addition of 5%, 10%, 15% and 20% by weight of cement respectively as compare to unmodified ferrocement samples under dry curing condition. Further the flexural strength of ferrocement samples for 28-days is increased by 34.43%, 42.73%, 53.52%and 50.20% for SBR polymer addition 5%, 10%, 15%, 20% by weight of cement respectively as compare to unmodified ferrocement samples under dry curing condition.

It is found that Flexural strength increasing up to 15% of SBR polymer and after that flexural strength decreases at 15% to 20% of polymer addition. Addition of SBR results in formation of interpenetrating polymer film. SBR Polymer chain comprising both flexible butadiene chains and the rigid styrene chain. As latex film is very tough it strengthen the microstructure and enhance the flexural strength of interpenetrating structure comprising of cement hydrates and polymer film .But this is valid up to 15% of polymer addition. As polymer addition increased from 15% to 20%, the discontinuities in microstructure occur due to increase in thickness polymer film in interpenetrating structure. It is also found that use of polymer modified cement mortar is more effective in 3-layered sample as compared to 2-layered sample. Results showed that maximum percentage increase in flexural strength of 3-layered sample is 53.52% where as in case of 2-layered sample percentage increase in flexural strength is 47.18% after 28 day of dry curing.

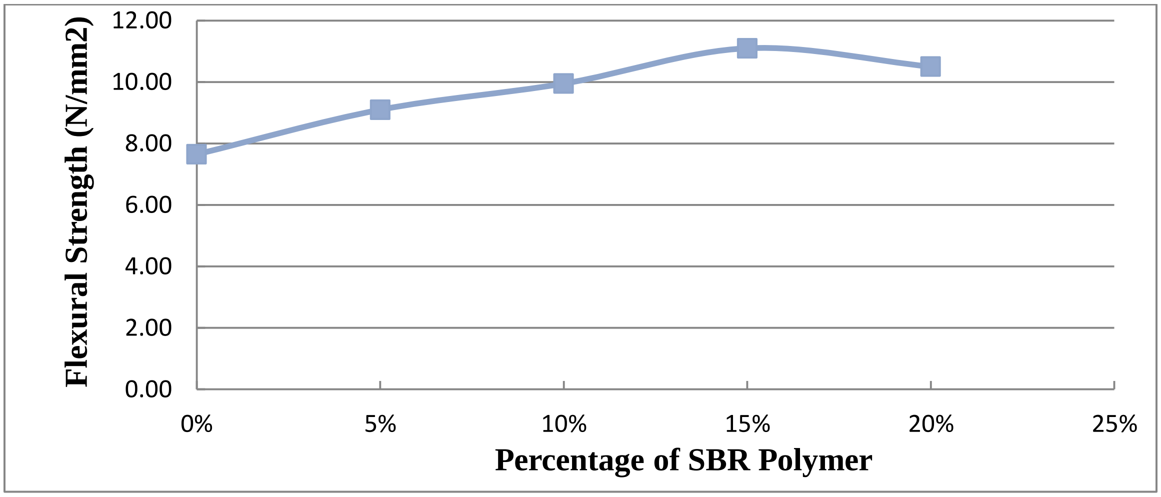


Fig. 4.9 Flexural Strength Vs Percentage of SBR Polymer for 2-Layered PMF after 7-Days.

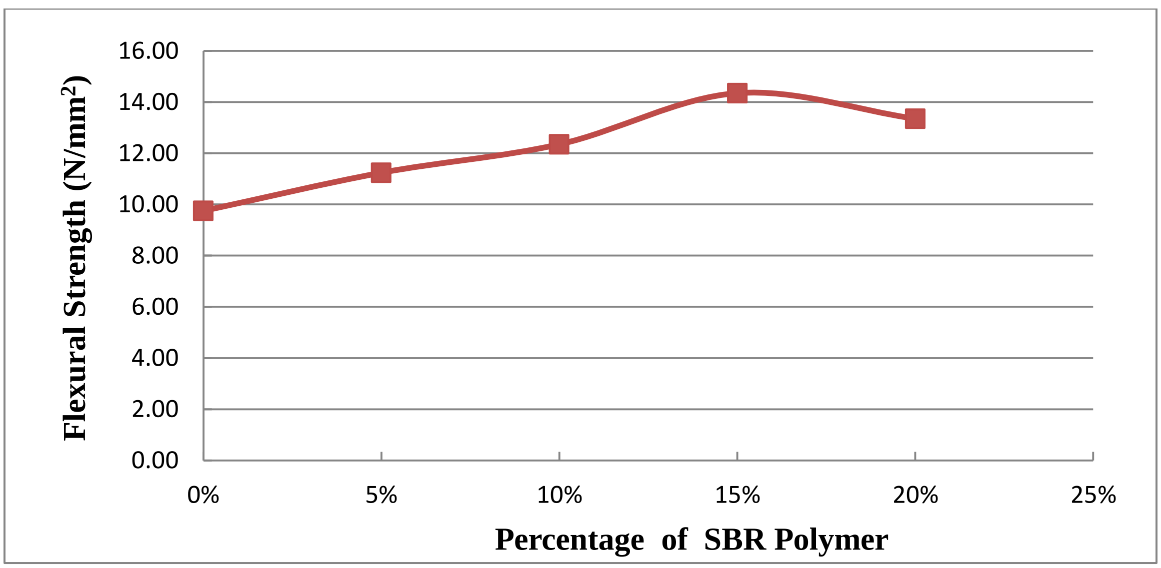


Fig. 4.10 Flexural Strength Vs Percentage of SBR Polymer for 2-Layered PMF after 28-Days

Table: 4.5 Flexural Strength of 2-Layered PMF after 7-Days & 28 Days

Mix Designation	2-Layer After 7-Days		2-Layer After 28-Days	
	Flexural Strength (N/mm^2)	Deflection (mm)	Flexural Strength (N/mm^2)	Deflection (mm)
SW-0	8.65	7.52	10.13	8.12
S-0	7.65	6.65	9.75	7.51
S-5	9.10	7.61	11.24	8.45
S-10	9.95	7.81	12.35	8.99
S-15	11.10	8.15	14.35	9.25
S-20	10.50	7.92	13.35	9.05

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Table: 4.6 Maximum Loads and Deflection of 2-Layered PMF after 7 & 28 Days

Mix Designation	2-Layer After 7-Days		2-Layer After 28-Days	
	Maximum Load (KN)	Deflection (mm)	Maximum Load (KN)	Deflection (mm)
SW-0	0.865	7.150	1.013	8.120
S-0	0.765	6.650	0.975	7.510
S-5	0.910	7.325	1.124	8.450
S-10	0.995	7.810	1.235	8.990
S-15	1.110	8.150	1.435	9.250
S-20	1.050	7.915	1.335	9.050

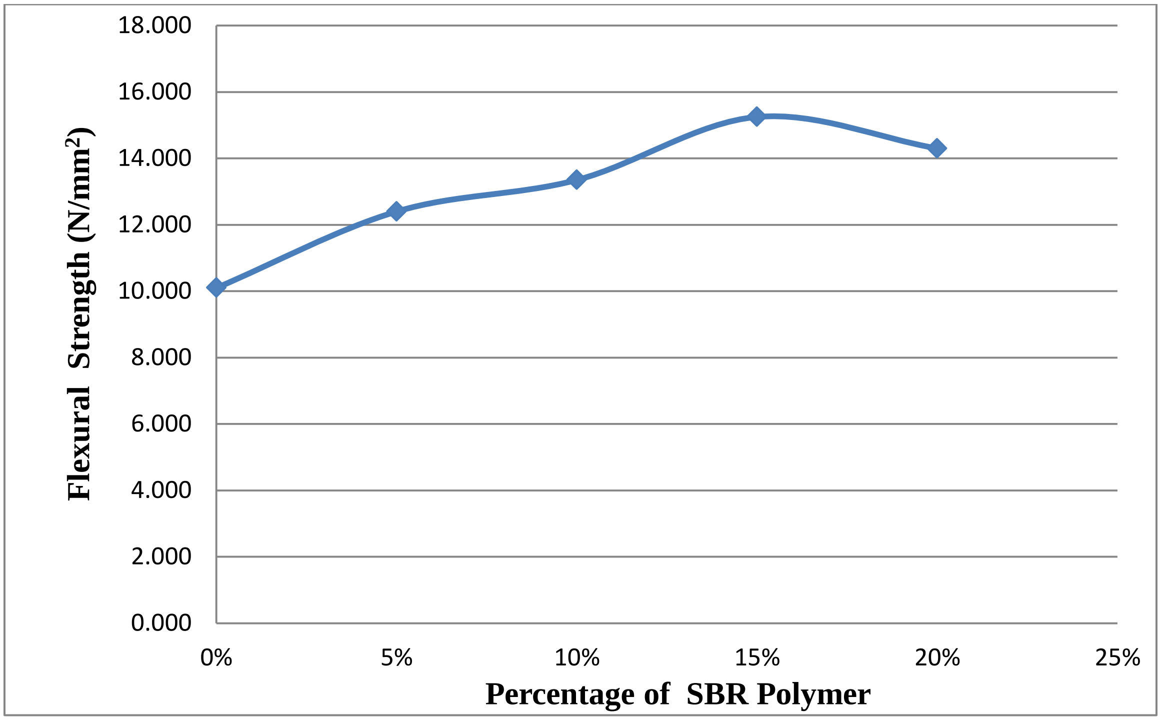


Fig. 4.11 Flexural Strength Vs Percentage of SBR Polymer for 3-Layered PMF after 7-Days.

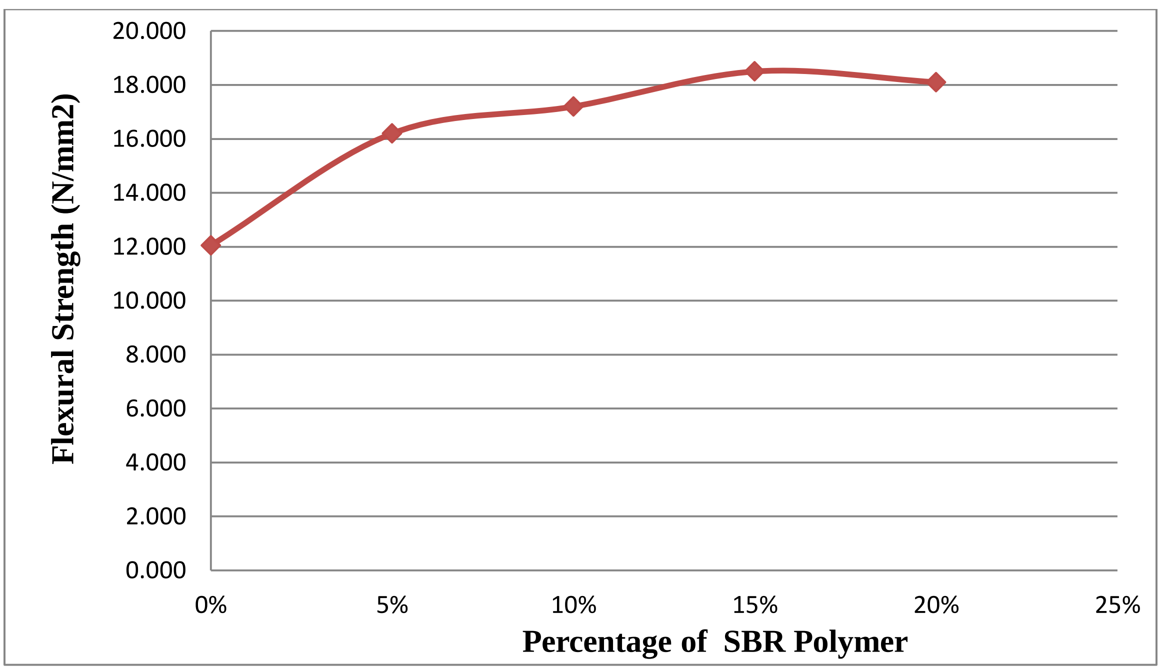


Fig. 4.12 Flexural Strength Vs Percentage of SBR Polymer for 3-Layered PMF after 28-Days.

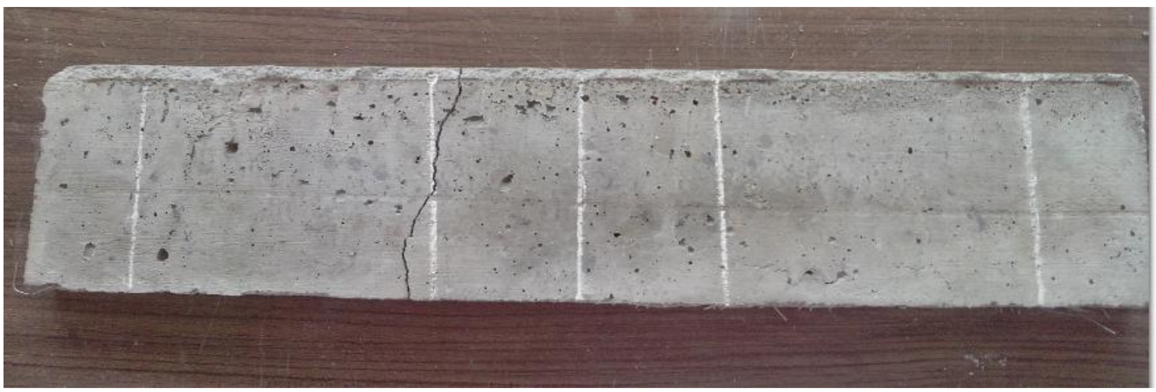
Table: 4.7 Flexural Strength of 3-Layered PMF after 7 & 28-Days.

Mix Designation	3-Layer After 7-Days		3-Layer After 28-Days	
	Flexural Strength (N/mm^2)	Deflection (mm)	Flexural Strength (N/mm^2)	Deflection (mm)
SW-0	11.400	6.870	13.360	8.200
S-0	10.100	7.100	12.050	7.990
S-5	12.400	7.850	16.200	8.500
S-10	13.350	8.105	17.200	9.145
S-15	15.250	9.650	18.500	10.250
S-20	14.300	8.850	18.100	9.450

Table: 4.8 Maximum Load & Deflection of 3-Layered PMF after 7-Days & 28Days.

Mix Designation	3-Layer After 7-Days		3-Layer After 28-Days	
	Maximum Load (KN)	Deflection (mm)	Maximum Load (KN)	Deflection (mm)
SW-0	1.140	7.320	1.335	8.200
S-0	1.010	7.100	1.205	7.990
S-5	1.240	7.850	1.620	8.500
S-10	1.335	8.105	1.720	9.145
S-15	1.525	9.650	1.850	10.250
S-20	1.430	8.850	1.810	9.450

During the testing of ferrocement element cracks observed in flexural zone and propagation in vertical direction for both modified and unmodified samples. With the increase of load, the cracks were distributed in the tensile zone. Propagation of cracks was steady and crack widening was comparatively lesser for polymer modified ferrocement sample as compare to unmodified ferrocement samples. This is due to the fact that polymer interpenetrating film contributed to flexural strength. Specimens without polymer modification show sudden increase in crack width at higher loads. The cracking pattern is shown in Fig.4.13.



(a)

(b)

Fig. 4.13 Crack Pattern for (a) PMF (b) Unmodified Ferrocement Samples.

4.7 Tensile Testing of Polymer Modified Ferro cement

The tensile test has been conducted as per procedure described in second phase of experimental program in previous chapter. Tensile strength has been determined after 7-days and 28-days of dry curing at SBR polymer varying from 0 to 20% at constant workability. Tensile load carrying capacity of 2-layered ferrocement samples are shown Fig.4.14, Fig. 4.15 and Table 4.9. It has been seen that Tensile load carrying capacity of 2-layered ferrocement samples of cement mortar for 7-days is increased by 15.84%, 22.88%, 27.2% and 28.40% for SBR polymer addition of 5%,10%,15% and 20% by weight of cement respectively as compare to unmodified ferrocement samples under dry curing condition . Further the flexural strength of ferrocement samples for 28-days is increased by 21.99%, 32.74%, 41.59%and 42.48 % for SBR polymer addition 5%, 10%, 15%, 20% by weight of cement respectively as compare to unmodified ferrocement samples under dry curing condition.

Tensile load carrying capacity of 3-layered ferrocement sample after 7-days & 28-days are shown in Fig.4.16, Fig. 4.17 and Table 4.10. It has been seen that flexural strength of 3-layered ferrocement samples of cement mortar for 7-days is increased by 18.18%, 27.97%, 39.72% and 41.25% for SBR polymer addition of 5%, 10%, 15% and 20% by weight of cement respectively as compare to unmodified ferrocement samples under dry curing condition. Further the flexural strength of ferrocement samples for 28-days is increased by 27.42%, 38.63%, 50.86%and 52.86 % for SBR polymer addition 5%, 10%, 15%, 20% by weight of cement respectively as compare to unmodified ferrocement samples under dry curing condition.

It is seen that tensile load carrying capacity increase as percentage of SBR polymer increase this is due to fact that polymer film has higher tensile load carrying capacity. Tensile load carrying capacity increasing sharply up to 15% of SBR polymer as shown in Fig. 4.14 to 4.17 and after 15% addition curve become flatter. This indicating that further addition of polymer is not as effective as higher percentage of polymer affect the rate of hydration of cement. It is also found that use of polymer modified cement mortar is more effective in 3-layered sample as compared to 2-layered sample. Results showed that maximum percentage increase in tensile load carrying capacity of 3-layered sample is 52.86% where as in case of 2-layered sample percentage increase in tensile load carrying capacity 42.48% after 28 day of dry curing.

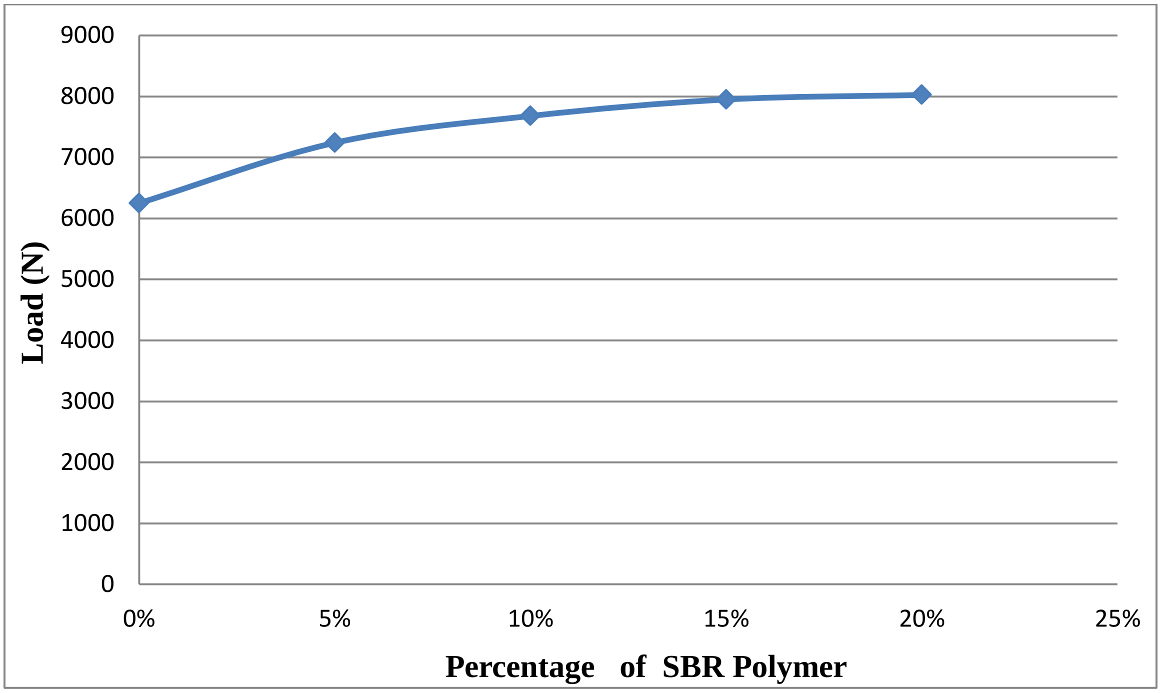


Fig. 4.14 Tensile Load Vs Percentage of Polymer for 2-Layered PMF after 7-Days

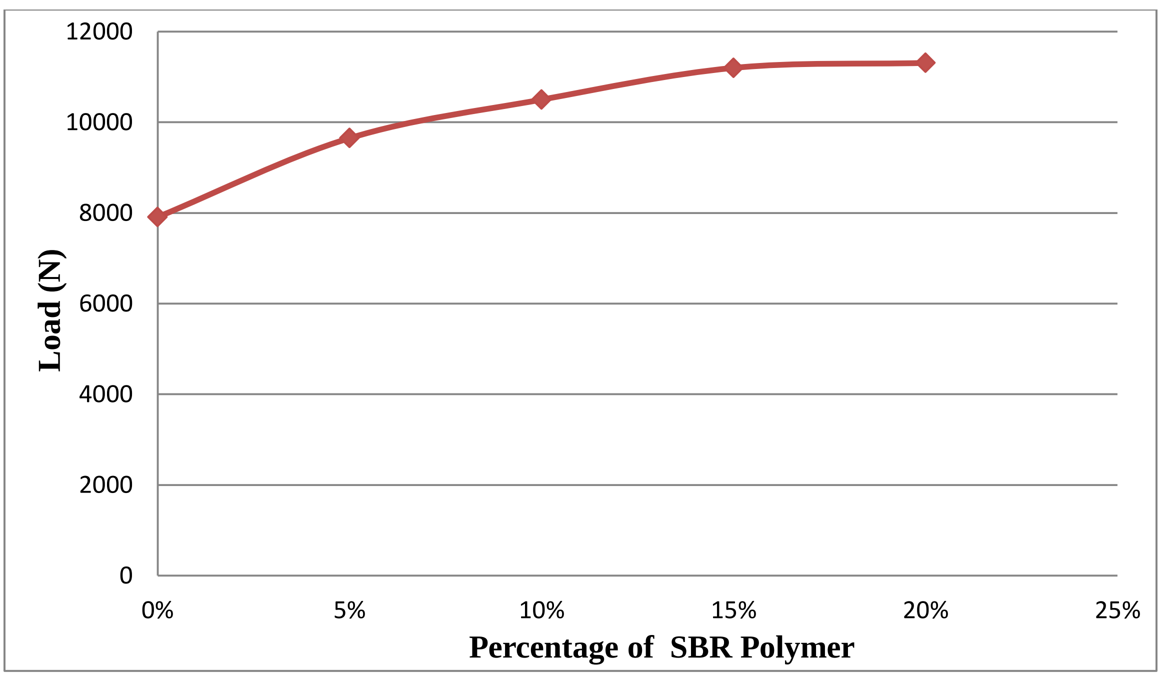


Fig. 4.15 Tensile Load Vs Percentage of Polymer for 2-Layered PMF after 28-Days.

Table: 4.9 Tensile Load & Elongation for 2-Layered PMF after 7-Days & 28-Days.

Mix Designation	2-Layer After 7-Days		2-Layer After 28-Days	
	Maximum Tensile Load (N)	Elongation (mm)	Maximum Tensile Load (N)	Elongation (mm)
SW-0	6450	6.95	8050	7.85
S-0	6250	6.84	7910	7.52
S-5	7240	7.42	9650	8.10
S-10	7680	7.68	10500	8.65
S-15	7950	8.24	11200	9.25
S-20	8025	8.50	11310	9.45

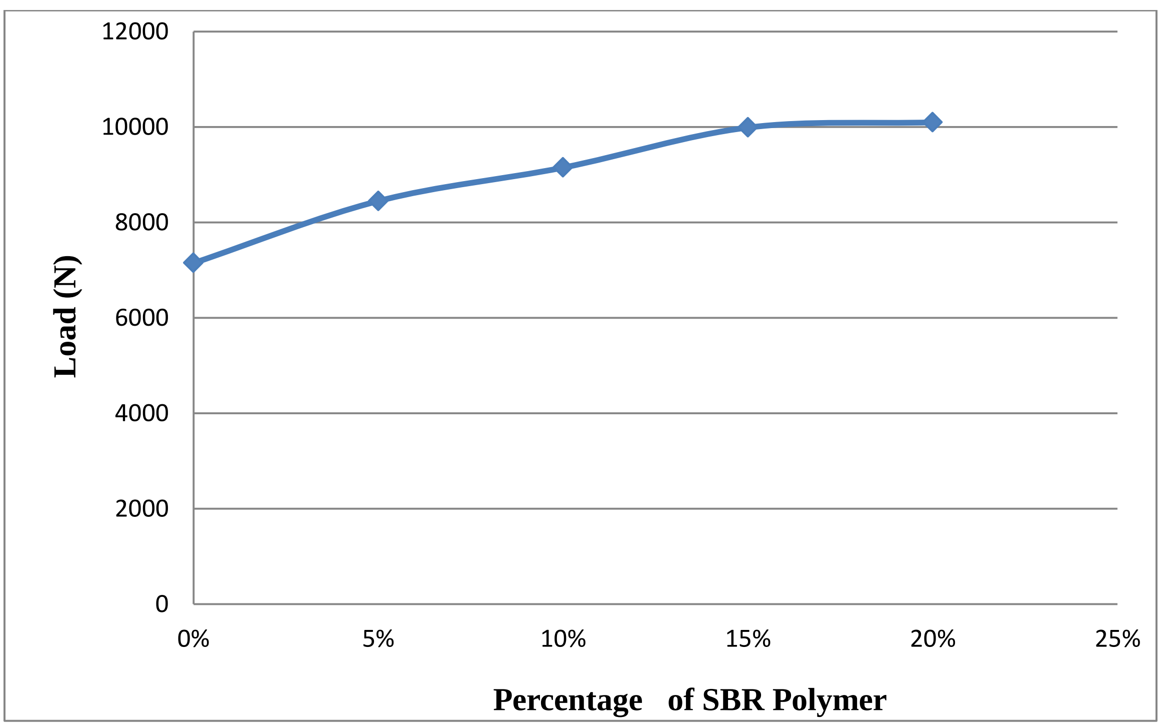


Fig. 4.16 Tensile Load Vs Percentage of Polymer for 3-Layered PMF after 7-Days.

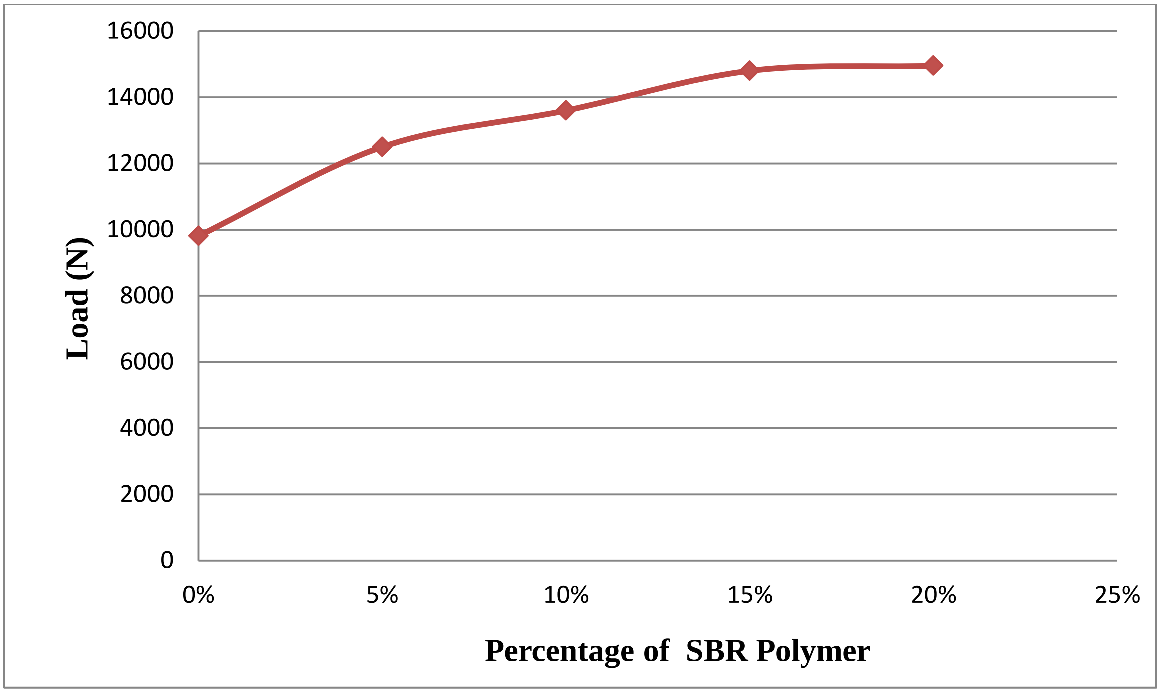


Fig. 4.17 Tensile Load Vs Percentage of Polymer for 3-Layered PMF after 28-Days.

Table: 4.10 Tensile Load & Elongation for 3-Layered PMF after 7-Days & 28-Days.

Mix Designation	3-Layer After 7-Days		3-Layer After 28-Days	
	Maximum Tensile Load (N)	Elongation (mm)	Maximum Tensile Load (N)	Elongation (mm)
SW-0	7260	7.15	9950	8.30
S-0	7150	6.95	9810	7.90
S-5	8450	7.73	12500	8.65
S-10	9150	8.45	13600	9.60
S-15	9990	9.55	14800	10.65
S-20	10100	10.35	14950	11.40

4.8 Effect of Curing Conditions on Mechanical Properties of PMM.

Curing conditions play very important role in PMM because in PMM strength is governed by both cement hydration and polymer film formation. In present work percentage increase observed at 5%, 10%, 15%, 20% of polymer addition as compare to 0% polymer addition was 26.05%,36.28%,32.03%,24.06 % for compression strength and 40.90%, 52.70%, 61.36%,55.68% flexural strength after 28-days of dry curing as shown in shown in Table 4.11,4.12.respectively.

Sharma (2013) carried out experimental study the effect of addition of SBR polymer on mechanical properties of cement mortar under wet curing condition and observed that the percentage increase at 5%, 10%, 15%, 20% of polymer addition in comparison to 0% polymer addition was 34.91, 40.66%, 43.55,37.35% for compression strength and 37.44%,48.50%,54.50%,53.20% for flexural strength after 28-days of wet curing as shown in Table 4.11, 4.12 respectively .

It can be concluded that wet curing is more effective in increasing compressive strength. The percentage increase in compressive strength for wet curing is 8.86%, 4.38%, 11.52%, 13.29% more than dry cured sample for polymer addition of 5%, 10%, and 15%, 20% respectively. This is due to fact that in case of wet curing, contribution of cement hydration phase in total compressive strength of co-matrix is comparatively higher due to higher rate of hydration than in dry curing.

But scenario has been reversed in case of flexural strength, dry curing is more effective in increasing flexural strength. The percentage increase in flexural strength for dry curing is 3.46%, 4.20%,6.86%,3.48% more than wet cured sample for polymer addition of 5%,10%,15%,20% respectively. This is due to fact that in case of dry curing, contribution of polymer film phase in total flexural strength is comparatively higher than in wet curing. Latex network in wet curing is comparatively less effective due to hydrolysis of latex film may occur due to presence of water.

Table 4.11 Comparison between percentage Increase in Compressive Strength of Present Work and Sharma (2013)

SBR Polymer	Present Work		Sharma (2013)	
	Dry Curing for period of 28days		Wet Curing for period of 28days	
	Mix Designation	Percentage increase in Compressive strength w.r.t. controlled sample	Mix Designation	Percentage increase in Compressive Strength w.r.t. controlled sample
5%	S-5	26.05	S1	34.91
10%	S-10	36.28	S2	40.66
15%	S-15	32.03	S3	43.55
20%	S-20	24.06	S4	37.35

Table 4.12 Comparison between Percentage Increase in Flexural Strength of Present Work and Sharma (2013)

SBR Polymer	Present Work		Sharma (2013)	
	Dry curing for period of 28days		wet curing for period of 28days	
	Mix Designatin	Percentage increase inFlexural strength w.r.t. controlled sample	Mix Designation	Percentage increase in Flexural strength w.r.t. controlled sample
5%	S-5	40.90	S1	37.44
10%	S-10	52.70	S2	48.50
15%	S-15	61.36	S3	54.50
20%	S-20	55.68	S4	53.20

4.9 XRD Analysis

X-Ray Diffraction (XRD) test has been conducted. XRD patterns of polymer modified cement mortar at varying percentage of SBR polymer from 0 to 20% are shown in Fig. 4.18(a & b). It is observed from XRD pattern that $Ca(OH)_2$ contents decrease up to 15% addition of polymer and beyond 15% addition it starts increasing. Where as C-S-H is increasing with addition of polymer and then decline after getting maximum value at 15% of polymer addition.

These trends are due to some chemical reactions that take place between the particle surfaces of reactive polymer and calcium ions (Ca_2^+), calcium hydroxide crystal surfaces, or silicate surfaces over the aggregates. Schematic illustration of reaction between polymer with cement and aggregate has already shown in chapter-1. Such reactions are expected to improve the polymer-cement co-matrix and the bond between the cement hydrates and aggregates and also improve the properties of hardened latex-modified mortars. However, the effects of the chemical bonds on the properties of the latex-modified mortars appear to be governed by their volume fraction in the latex-modified mortars, and the chemical bonds do not necessarily act effectively to improve the properties. The effects of the chemical bonds are to be offset by increasing entraining air. (Ohama 1998).

XRD patterns have been shown good agreement with the results of experimental work. Experimental results indicated that compressive strength has been in increasing trend up to maximum value at 10% polymer dose after that it decline for higher doses of polymer. The increase in compressive strength can be correlated with increase in C-S-H with increase in polymer addition. But higher percentages of polymer introduce more entraining air in co-matrix results to decline of compressive strength. Flexural strength has been shown the slightly different trend than compressive strength as it increases up to maximum value at polymer dose of 15% than after it decline. This is due to fact that $Ca(OH)_2$ has been absorbed on the surface of or in the polymer film formed in latex-cement matrix which results in full development of flawless continuous polymer film formation. Similarly for Bond strength showing upward trend due to fact that chemical reaction between the particle surfaces of reactive polymers and silicate surfaces over the aggregates improve the bond between the cement hydrates and aggregates.

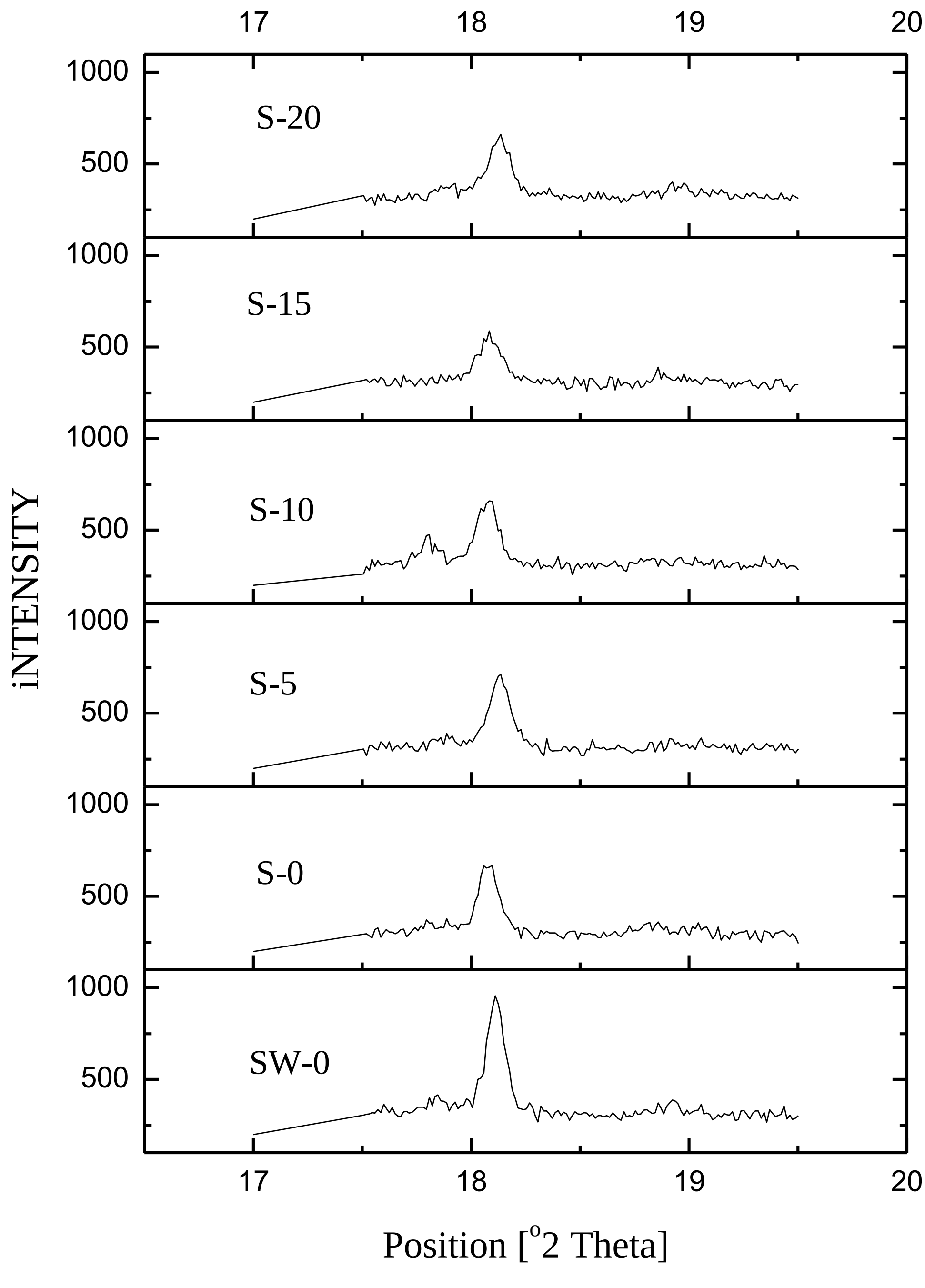


Fig. 4.18 (a) XRD Patterns of CH

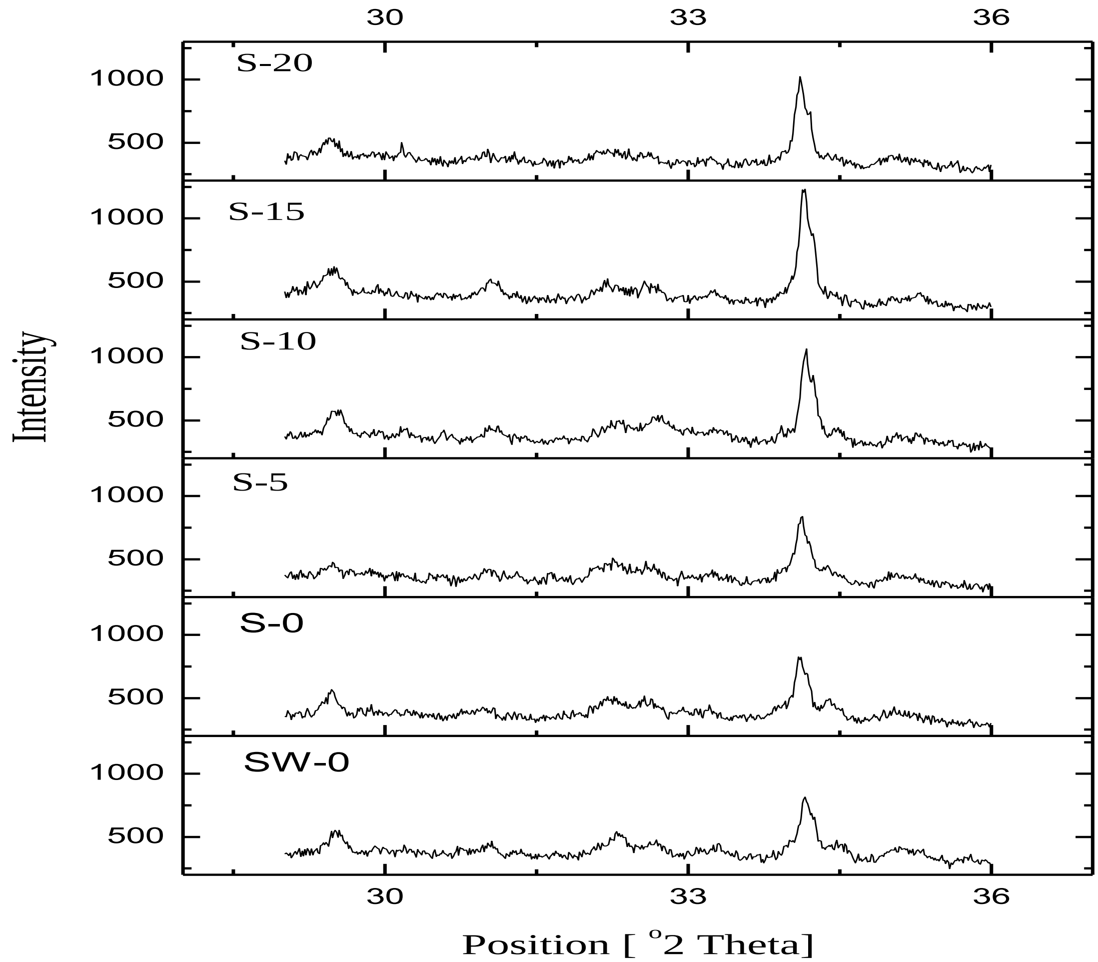
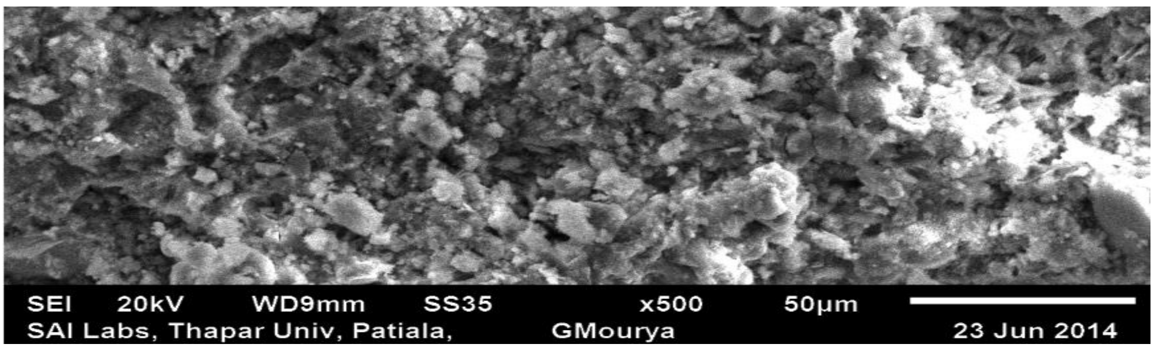


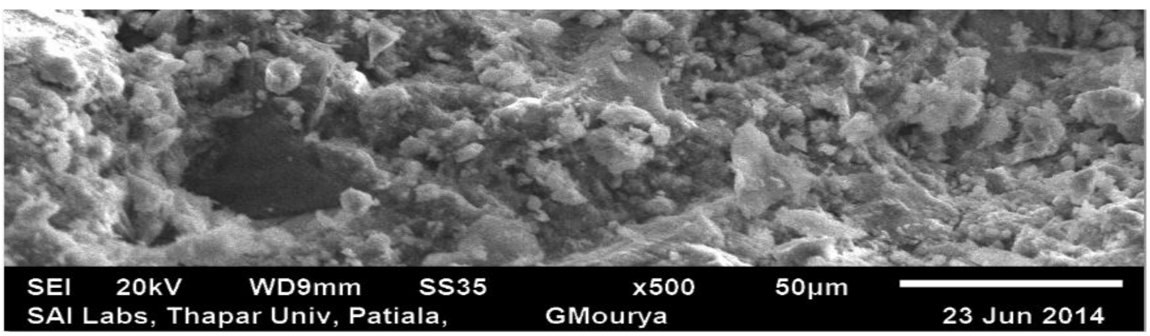
Fig. 4.18(b) XRD Pattern for C-S-H

4.9 Scanning Electron Microscope (SEM) Analysis

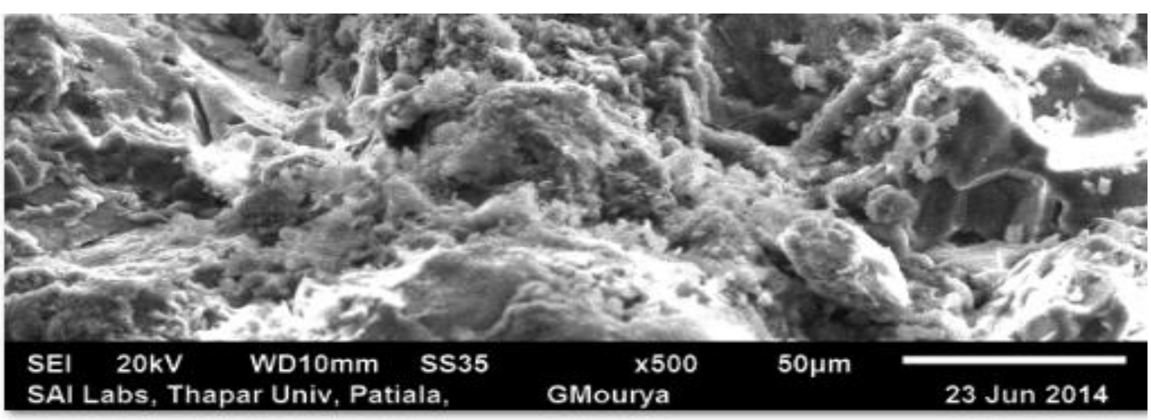
The Scanning Electron Microscope (SEM) has been conducted and SEM micro images of the fracture surface of polymer- modified mortars at varying percentage of SBR polymer from 0 to 20% are shown Fig. 4.19 (a to e). SEM image (a) is of the cement mortar at 0% of SBR polymer content. SEM images from (b) to (e) are of modified cement mortar at 5%, 10%, 15% and 20% addition of polymer by weight of cement respectively. The SEM analysis exhibits that the constitute of the cement mortar at 0% are loosely joined with each other in image (a). By contrast, the structure of the mortar at 5% is compactly joined with each other, although no polymer film is formed in image (b). Some scattered polymer films are found in the surface in the fracture surface of the modified mortar at polymer addition of 10% in image (c). Coherent polymer film forms in the modified mortar beyond 10% of polymer addition, so the interpenetrating structure between the polymer and cement hydrates form and the structure fully develops for 15% of polymer addition in image (d). Further addition of polymer above 15%, the formed polymer film in the modified mortars becomes thicker and the structure of the modified mortars is still interpenetrating image (e).



(a)



(b)



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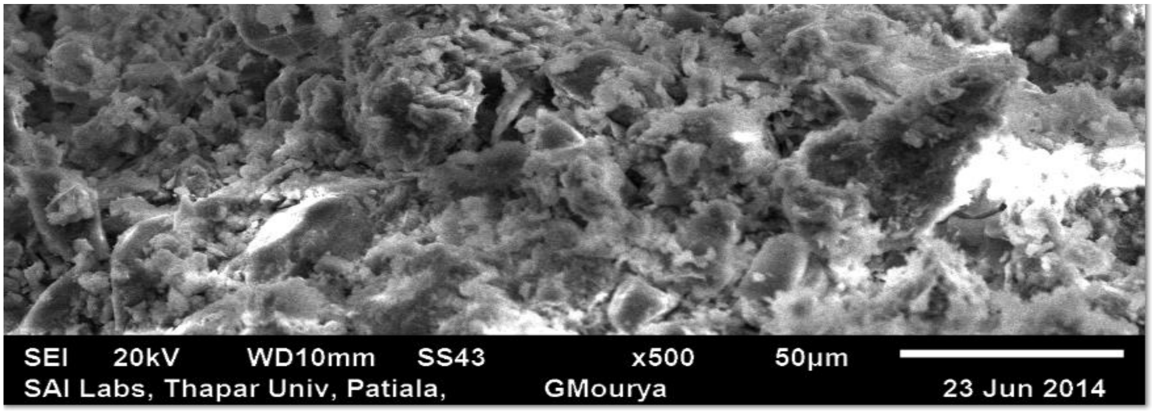
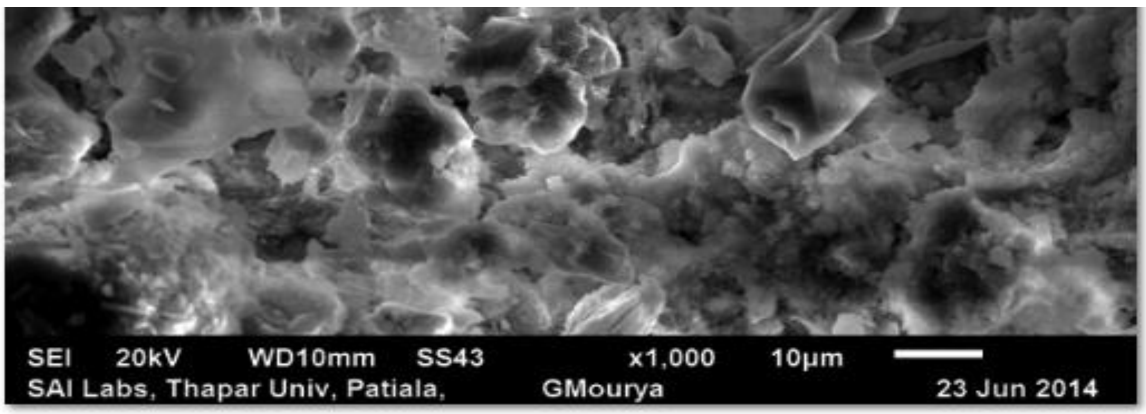


(d)



(e)

Fig. 4.19 (a to e) SEM Micro photos of PMM

The SEM images show good agreement with experimental work. Experimental results shows that increase in compressive strength up to 10% addition of polymer this can be correlated to increase in compactness of loosely joined constitute of the cement mortar as shown in image (b). flexural strength increases up to 15% polymer addition can be correlated to fully developed structure of polymer film as shown in image (d) and further addition decrease the flexural strength due to discontinuity in microstructure due to thickening of polymer film as shown in image (e).Bond strength increase sharply up to 15% of polymer addition can be correlated to full development of polymer film as sown in image (d) and further addition shows not much improvement due thickening of polymer film as shown in image (e).

CHAPTER 5
CONCLUSION

5.1 General

The experimental program was carried out to determine the effect of addition of SBR polymer on mechanical properties of PMM and PMF elements. Tests were performed on sample prepared in cement mortar with SBR polymer content varying from 0 to 20% by weight of cement and cured under dry condition at room temperature .The compressive strength , flexural strength ,bond strength of PMM and flexural strength , tensile strength of PMF elements were observed and at dry curing ages of 7 and 28days. Discussions of the results were carried out and major conclusions drawn from the study are elaborated here in

5.2 Workability, Compressive Strength, Flexural strength, Bond Strength of PMM

1. The addition of SBR polymer in cement mortar improves the workability due to entrained air and ball bearing action of polymer particles. The workability of PMM at 15% of SBR polymer addition by weight of cement increased 1.81 times more than unmodified cements mortar.
2. PMM attains maximum percentage increase in compressive strength i.e. 36.28% at 10% SBR polymer addition by weight of cement as compare to unmodified cement mortar after 28-days of dry curing. This is due to increase in compactness of loosely joined constitutes of the cement mortar.
3. PMM attains maximum percentage increase in flexural strength i.e. 61.28% at 15% SBR polymer addition by weight of cement as compare to unmodified cement mortar after 28-days of dry curing. The significant increase in flexural strength of PMM is due to formation of interpenetrating Polymer film.
4. Bond or adhesion strength of PMM increase significantly is due to diffusion of the latex-modified pastes in the substrates mortar. This diffusion results in the monolithic bond between the substrates mortar and latex-modified paste. Bond

strength of PMM for addition of 15% SBR polymer by weight of cement after 28 days of dry curing is 1.95 times more than unmodified cement mortar.

5. Improvement in flexural strength and bond strength of PMM is more in comparison to it compressive strength. This is due to fact that the latex network in co-matrix has comparatively high tensile and bond strength than its compressive strength.

5.3 Flexural Strength &Tensile Strength of PMF Element

1. PMF 2-layered beams attains maximum percentage increase in flexural strength i.e. 47.18% at 15% SBR polymer addition by weight of cement as compare to unmodified cement mortar after 28-days of dry curing .
2. PMF 3-layered beams attains maximum percentage increase in flexural strength i.e. 53.25% at 15% SBR polymer addition by weight of cement as compare to unmodified cement mortar after 28-days of dry curing .
3. SBR polymer modification is 6.34% more effective for 3-layered PMF beams as compare to 2-layered PMF beams for 15% addition of SBR polymer by weight of cement under 28-days of dry curing.
4. Tensile load carrying capacity of PMF 2-layered elements after 28-days of dry curing increased by 41.59% for addition of 15% SBR polymer by weight of cement as compare to unmodified mortar.
5. Tensile load carrying capacity of PMF 3-layered elements after 28-days of dry curing increased by 50.86% for addition of 15% SBR polymer by weight of cement as compare to unmodified mortar.
6. SBR polymer modification is 9.27 % more effective for 3-layered PMF elements as compare to 2-layered PMF beams for 15% addition of SBR polymer by weight of cement under 28-days of dry curing.

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