“MECHANICAL PROPERTIES OF POLYMER MODIFIED FERROCEMENT”

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CERTIFICATE

This is to certify that the thesis titled," **MECHANICAL PROPERTIES OF POLYMER MODIFIED FERROCEMENT** " in partial fulfillment of the award of degree of **MASTER OF ENGINEERING (STRUCTURAL ENGINEERING)** in the **Department Of Civil Engineering, Thapar University,** is a bonafied work carried out by him under my guidance and supervision and that no part of this thesis report has been submitted for the award of any other degree.

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ABSTRACT

In an effort to improve the performance of mortar, polymer is introduced into mortar. It has been reported that polymer-modified mortar (PMM) is more durable than conventional mortar due to higher strength. This research was carried out to establish the effects of polymer addition on compressive strength, flexural strength, modulus of elasticity of mortar and flexural strength and tensile strength values on polymer modified ferrocement samples with mortar of constant flow value. Two types of polymers were used i.e **SBR** and **VAE** polymer. The mixes were prepared with polymer-cement ratio of 0% , 5%, 10%, 15% and 20% for each and a flow value of 110 +_ 5 is fixed for every mix of mortar.

The addition of polymer in the mortar results in reduction of w/c ratio for the mixes with constant flow value while mixes with same w/c ratio result in increase in flow value. The results indicated that the compressive strength of polymer modified mortar is lower than the unmodified mortar for constant w/c ratio after 7 and 28 days of wet curing days. The compressive strength of SBR polymer modified mortar increases but of VAE modified mortar decreases after 7 and 28 days at varied w/c ratio. The flexure strength increases for both mixes of the varried w/c ratio at the same flow value. The main aim of polymer addition is to increase the flexure or bending stress of conventional mortar. The modulus of elasticity of conventional mortar is higher than that of polymer modified mortar and the failure of conventional mortar was found more brittle and less deflection value as compared to the polymer modified mortar.

The flexure strength of ferrocement samples also increases on polymer addition for third point loading test.

Polymer modification of cement paste increases its tensile and flexural strength and reduces its brittle nature. We will conclude by showing that future use of polymer modified cement composites will likely be in the area of durability and performance improvements of cement materials applied in thin sections.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Ferrocement is one of the relatively cementitious composite considered as a construction material. It is a type of thin walled reinforced concrete commonly consists of cement mortar reinforced with closely spaced layers of continuous and relatively small wire mesh (ACI 549R, 1997; ACI 549 2R, 2004). The closely-spaced and uniformly-distributed reinforcement in ferrocement, transforms the brittle material into a superior ductile composite. Thus, ferrocement has been regarded as highly versatile construction material possessing unique properties of strength and serviceability. Its advantageous properties such as strength, toughness, water tightness, lightness, durability, fire resistance, and environmental stability cannot be matched by any other thin construction material (Naaman, 1999).

In order to cope with the problem of thickness, one of the options currently suggested is to develop ferrocement elements. This technique provides not only the thickness but makes the element lightweight as well. Presently, it has gained attention to be used as an effective structural form in the building and construction industries.

Ferrocement construction form has distinct advantages over conventional structural sections, because it promises high stiffness and high strength to weight ratios. The introduction of materials such as ferrocement, for the materials like polymer modified mortars presents new possibilities in the design of construction.

Polymer-modified mortars (PMMs), using recently developed high grade redispersible polymer powders and aqueous polymer dispersions, have become popular construction materials in the world. This is because of their excellent performance and durability. PMMs are also considered to be able to become highly sustainable construction materials.

1.2 POLYMER AND FERROCEMENT

1.2.1 Introduction

The word polymer comes from Greek words poly meres, where poly meaning “many” and meres meaning “parts”. In short, polymers are materials with long chain molecules that are composed of a large number of repeating units of identical structure. Polymers made up of one type of monomer are called homopolymers, while those made up of one or more monomers are called copolymers. “Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small diameter wire mesh; the mesh may be made of metallic or other suitable materials” (ACI 549R, 1997; ACI-549 2R, 2004).

1.2.2 Structure of Polymer

Polymers can be divided into 3 main structures named linear polymers, branched polymers, and crosslinked polymers. Linear polymer consists of monomers that are linked in a long chain. This structure cannot turn in any directions. Among the polymers found with this structure are polyethylene, polyvinyl alcohol and polyvinyl chloride (PVC).

Branched polymers have another chain that is bonded to the long molecular chain. This chains are formed with the presence of monomer from reactive group.

Crosslinking polymers have two or more chains that are linked by short side chains. A more complex link will gives us a three dimensional structure while lowly linked chains will give a two dimensional structures.

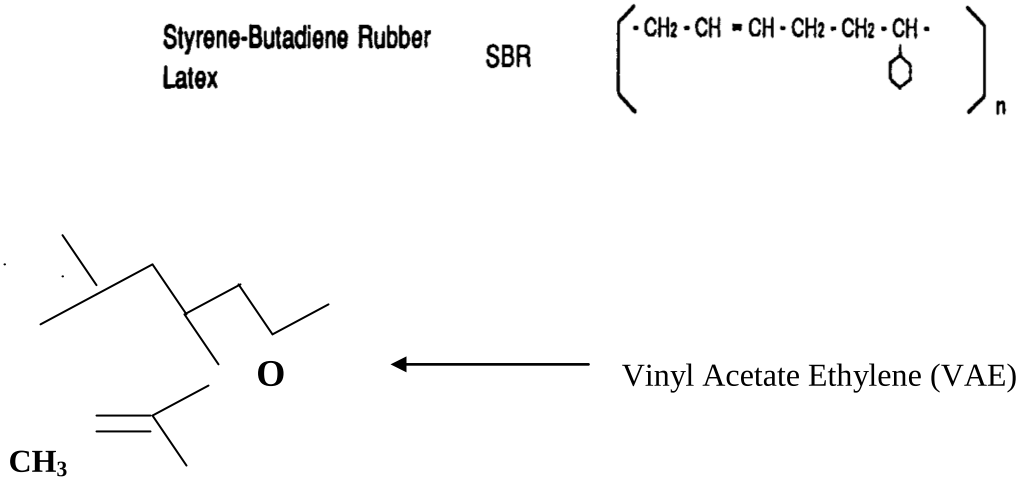

Figure : 1.1 Structure of VAE and SBR polymer.

Figure: 1.2 VAE Polymer in powdered form

1.2.3 Classification of Polymer

All polymers can be divided into three major groups based on their thermal processing behaviour, type and relative amount of cross linking of the polymer chains as discussed before. They are thermoplastics, thermosetting, and elastomers.

Those polymers that can be heat-softened in order to process into a desired form are called thermoplastics. The chains are short and it dissolves in water very well.

Thermosets are polymers whose individual chain have been chemically linked. These crosslinked networks resist heat softening, creep, and solvent attack but cannot be thermally processed (Fried, 1995).

Elastomers are rather weak in molecular chains crosslinking compared to thermoplastics and thermosetting polymers. This, however, produced a rubbery characteristic and no significant shape. As the temperature increases, elastomers will loose their elasticity (Su, 1995).

1.2.4 Hydration Process

When cement is exposed to water, chemical reactions begin to take place. These reactions are called hydration process, which in return will produce a firm and hard mass. In these reactions, it is of interest to know whether the hydration products contribute to the strength of the hydrated cement (Mindess and Young, 1981).

$$\text{Cement} + H_2O \rightarrow \underset{\text{(gel)}}{C - S - H} + Ca(OH)2$$

In the early stage, gypsum will react to control the setting time and the reaction that takes place is exothermic. For the first 14 days, the strength of concrete is provided by C_3S. For the next two weeks, it is then taken over by C_2S, which reacts much more slowly. Rates of reactions bear no relation to strength development as both C3S and C2S contribute equally to ultimate strength. C3A have high early strength but does not contribute significantly to the ultimate strength and is prone to sulphate attack. C4AF only gives a small effect on the strength of concrete (Zakaria, 1987)

1.2.5 Polymer-Modified Mortar

The incorporation of polymers into mortar system requires compatibility between both polymer and aqueous solutions. Polymer may be added in a dispersed, powdery, or liquid form into the fresh mortar.

Among the few types of polymer-modified mortars are latex-redispersible polymer powder, water-soluble polymer, liquid resin, and monomer-modified mortar. Of these, the latex-modified mortar is the most widely used cement modifier. In the polymer-modified mortar, aggregates are bound by monolithic phase and polymer phase interpenetrate. This co-matrix phase results in an improved properties of polymer-modified mortar compared to ordinary mortar (Ohama, 1995).

1.3 PRINCIPLES OF LATEX MODIFICATION

The co-matrix phase of latex modification of cement mortar and concrete is formed by both cement hydration and polymer film formation processes. Generally, the polymer film formation comes after the cement hydration process.

1.3.1 Polymers Improve Mortars In Four Main Ways

1. More extensive cement cure. Cement/concrete strength depends on proper curing, a chemical reaction (hydration) between water and cement that causes crystals to grow and wrap around the mix components. During the early stages of cure (roughly the first five to seven days), there must be enough water to maintain the hydration process or the cement/concrete will not harden properly.Polymers reduce the rate of water evaporation, allowing the crystal structure to keep growing and building strength during these critical early curing stages. This reduced water evaporation is especially important in thin applications, where the surface area for evaporation is high, relative to the volume of the mortar.

2. Improved workability. Polymer modification noticeably improves application characteristics, making the mortar more fluid and easier to handle and apply. Certain polymers also prolong the hydration period, which can increase working time, an important characteristic in hot climates. This means contractors can use less water for workability purposes. The polymer acts as a water reducer, ultimately leading to a stronger mortar with fewer voids, or weak spots.

3. Improved adhesion. Polymer modifiers act as an adhesive to enable the modified mortar overlay to stick to a variety of surfaces such as concrete, masonry, brick, wood, rigid polystyrene and polyurethane foam, glass, and metals. Adhesion is an important property, especially in thin section overlay mortar applications such as spray coatings, stuccos, and underlayments, and applications with excessive vibration and heavy traffic.

4.Improved strength and durability. Cured polymer-modified mortars generally have improved tensile strength, flexural strength, impact and abrasion resistance, water resistance, and chemical resistance versus unmodified mortars. Also, the polymer in the mortar helps restrain micro-crack propagation, which improves the overall toughness of the mortar.

1.4 MECHANISM OF POLYMER-CEMENT CO-MATRIX FORMATION

A co-matrix phase which consists of cement gel and polymer films is generally formed as a binder according to a three-step simplified model.

Step– 1

Mixtures of unhydrated cement particles and cement gel (On which polymer particles deposit partially)

Step -2

Mixtures of cement gel and unbydrated cement particles enveloped with a close-packed layer of polymer particles

Step – 3 (Hardened structure)

Cement hydrates enveloped with polymer films or memberanes & Entrained air.

1.4.1 DETAILS OF Mechanism Of Polymer-Cement Co-Matrix Formation

First Step:

When polymer latexes are mixed with fresh cement mortar or concrete, the polymer particles are uniformly dispersed in the cement paste phase. In this polymer-cement paste, the cement gel is gradually formed by the cement hydration and the water phase is saturated with calcium hydroxide formed during the hydration, whereas the polymer particles deposit partially on the surfaces of the cement-gel-unhydrated cement particle mixtures. It is likely that the calcium hydroxide in the water phase reacts with a silica surface of the aggregates to form a calcium silicate layer. It is confirmed that the formation of the calcium hydroxide and ettringite in the contact zone between the cement hydrates and aggregates is attributed to the bond between them.

Second Step:

With drainage due to the development of the cement gel structure, the polymer particles are gradually confined in the capillary pores. As the cement hydration proceeds further and the capillary water is reduced, the polymer particles flocculate to form a continuous close-packed layer of polymer particles on the surfaces of the cement-gel-unhydrated cement particle mixtures and simultaneously adhere to the mixtures and the silicate layer over the aggregate surfaces. In this case, the larger pores in the mixtures are found to be filled by the adhesive and autohesive polymer particles.

Third Step:

Ultimately, with water withdrawal by cement hydration, the close-packed polymer particles on the cement hydrates coalesce into continuous films or membranes, and the films or membranes bind the cement hydrates together to form a monolithic network in which the polymer phase interpenetrates throughout the cement hydrate phase. Such a structure acts as a matrix phase for latex-modified mortar and concrete, and the aggregates are bound by the matrix phase to the hardened mortar and concrete.

1.5 CONSTITUENTS OF FERROCEMENT

Ferrocement is defined as being made of cement-based mortar mix and steel wire mesh reinforcement. However, a broader definition of ferrocement includes the use of skeletal steel in addition to the mesh system.

1.5.1 Mortar Mix

The hydraulic cement mortar mix consists of Portland cement, fine aggregate (sand), water, polymers (VAE AND SBR) and antifoaming agent in it.. Naaman (2000) proposed that the actual mix design should be optimized, whenever possible, with respect to the available local materials and environmental conditions.

1.5.2 Wire Mesh Reinforcement

Steel wire meshes are considered the primary mesh reinforcement. This include the various types of the shape; square woven or welded meshes, chicken (hexagonal/aviary) wire mesh, expanded metal mesh lath etc. Except for expanded metal mesh, generally all the meshes are used galvanized. Figure 2.2 shows the typical steel wire meshes used in ferrocement applications as below.

Figure- 1.3 Square woven wire mesh..

1.6 FERROCEMENT VERSUS REINFORCED CONCRETE (DISTINCT CHARACTERISTICS)

As stated in the definition, ferrocement is a type of reinforced concrete construction. While, such a definition implies many similarities between ferrocement and reinforced concrete, there is a number of differentiating factors sufficiently important to explain the differences in their behaviour. Compared to reinforced concrete, ferrocement is.

- Is a thinner material.
- Has distributed reinforcement.
- Is reinforced in two directions (transverse and longitudinal).
- Has matrix made of fine mortar or paste instead of concrete which contains larger size aggregates (the maximum size of the particles in ferrocement is controlled by the average opening of the stack of mesh system to be encapsulated).

1.7 AIM

The study was aimed to present the effects of polymer addition on compressive strength, flexure strength and modulus of elasticity of mortar and also on flexure and tensile strength of ferrocement beams.

1.8 OBJECTIVES

- To determine the workability of the fresh polymer modified mortar with different polymer cement ratio.
- To determine the effect of polymer addition on water cement ratio while maintaining the same workability.
- To obtain the compressive strength of ordinary mortar with polymer modified mortar with constant and varied water cement ratio.
- To obtain the flexure strength and modulus of elasticity of ordinary and polymer polymer modified mortar with the varied water cement ratio.
- To obtain the flexure strength, tensile strength and corresponding deflection or elongation of the polymer modified ferrocement beams.

CHAPTER - 2

LITERATURE REVIEW

2.1 GENERAL

The world is witnessing a revolution in construction practices along with a new phase of development fuelled by the rapid economic growth and the high rate of urbanization. Construction provides the direct means for the development, expansion, improvement and maintenance of urban settlements The growing need for affordable houses is a much discussed subject because due to spiraling construction cost, housing today is not an affordable proposition for the common people even on the international scene. In the case of developing countries, the gap between demand and supply of adequate housing is continuously increasing (Shaikh, 1999; Arif *et al.,* 2001; Waleed *et al*., 2004). In this context, there is need for the adoption of cost-effective and environmentally appropriate technology and materials.

2.2 FERROCEMENT: A COMPOSITE AND A MEMBER OF THE STRUCTURAL CONCRETE FAMILY

Cement-based composites are generally viewed as two-component materials: the cement-based matrix and the reinforcement. In fact, the matrix alone (which generally comprises cement, sand, water, and other additives) may be considered a composite by itself; while steel reinforcement is not a composite material. A composite is a material made of at least two different components, resulting in a synergism where the composite property of interest for a particular application is better than either of components taken separately. (Naaman, 2000).

Although ferrocement was the first type of reinforced concrete, today it is considered a member of the general family of structural concrete materials, or, using different terminology, of cement-based composites. The family includes conventional reinforced concrete, prestressed concrete, partially prestressed concrete, fiber reinforced concrete, and several of their combinations. The flow chart shown in Figure attempts to place ferrocement in this family and shows that each member can stand alone or in combination with other members. Applications where a combination of materials or concepts is used include, for instance, where ferrocement is applied as a jacket to confine reinforced concrete columns, or where discontinuous fibers are added to ferrocement to provide a hybrid composite with improved properties.

2.3 MECHANICAL PROPERTIES OF FERROCEMENT

Many of the properties unique to ferrocement derive from the relatively large amount of two-way reinforcement made up of relatively small elements with much higher surface area than conventional reinforcement. In the words of Nervi (ACI 549R, 1997), who first used the term ferrocement, its most notable characteristics are “greater elasticity and resistance to cracking given to the cement mortar by the extreme subdivision and distribution of the reinforcement. Where, volume fraction and the specific surface area are the two factors that recognize the definition of extreme subdivision and distribution of reinforcement in ferrocement.

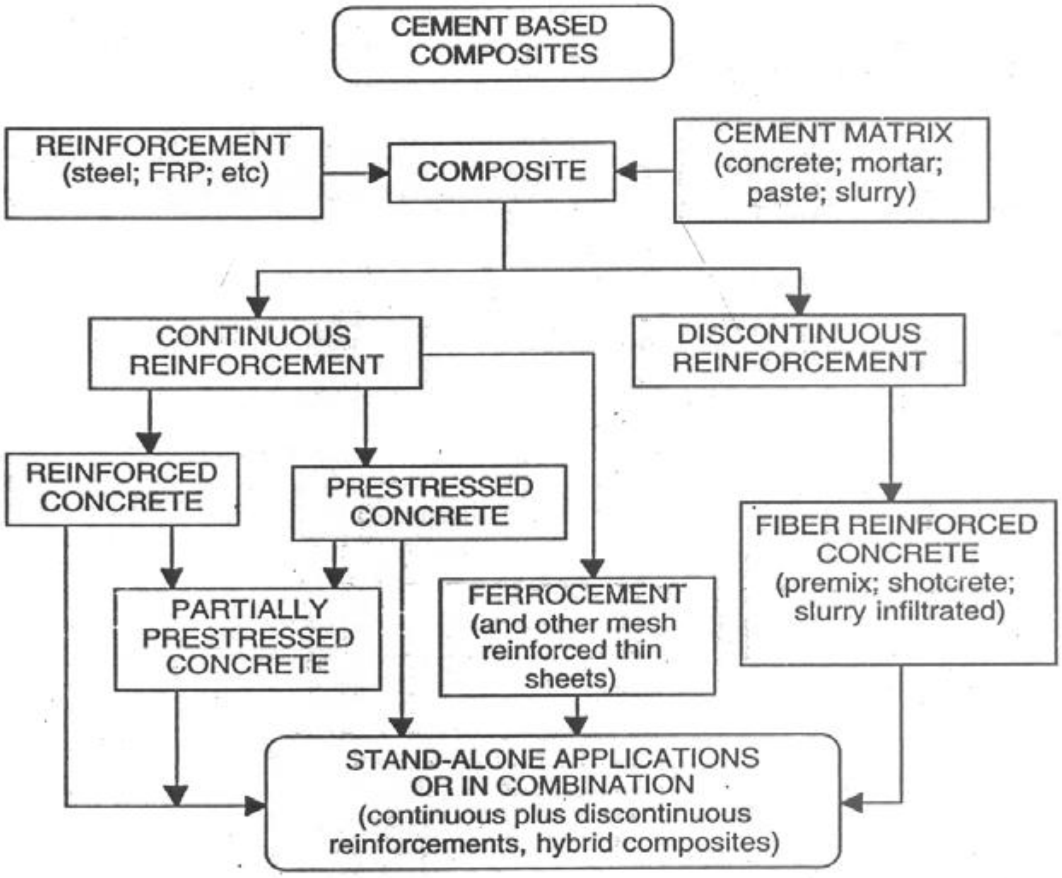

Figure: 2.3 Ferrocement as a member of structural concrete family (Naaman,2000)

2.3.1 Tensile Strength

Ferrocement is often described in the professional literature as a wonder material that does not crack and that has a variety of marvelous properties. In fact, ferrocement can be considered a small-scale model of a super reinforced concrete; it does indeed crack, but cracking in ferrocement under service loads can be so fine that it is not visible to the naked eye. Ferrocement possesses a distinct behaviour in tension compared to that of reinforced concrete. The behaviour of ferrocement in tension is extremely interesting since ferrocement seems to adapt slowly to increasing load by increasing its extensibility. When cracks keep forming, crack width does not increase proportionately to the applied load, and thus crack widths tend to remain smaller than otherwise in reinforced concrete. The stress, at which no more new cracks formed, is called the stabilization stress. Beyond the stabilization stress (at crack saturation), the width of the existing cracks increases with loading and the behaviour of the composite is controlled. However, crack widths in ferrocement can be one or two orders of magnitude smaller than in reinforced concrete by that of the reinforcement.

In tension, the load carrying capacity is essentially independent of specimen thickness because the matrix cracks before failure and does not contribute directly to composite strength (ACI 549R, 1997). Typically the tensile strength of ferrocement is directly proportional to the number of layers (volume fraction) of the wire mesh layers. However, what is the counter intuitive is that the elongation at failure also increases when the volume fraction of reinforcement (layers of reinforcing mesh) increases.

One of the key characteristics of ferrocement when compared to reinforced concrete is its substantially higher (one to two orders of magnitude) specific surface of reinforcement for a volume fraction of reinforcement of about the same order. This leads to a number of features particular to ferrocement behaviour, as observed in numerous experimental investigations. The studies have observed that, everything else being equal, the tensile strength at first cracking in ferrocement is directly proportional to the specific surface of reinforcement (Naaman, A.E 2000).

The tensile strength of ferrocement depends on the mesh orientation and whether the applied loading is uniaxial or biaxial because of the change in volume fraction in the loading direction.

2.3.2 Compressive Strength

The compressive strength and the related properties of ferrocement are generally controlled to a great extent by the properties of the cementitious mortar mix. Typical compression test results of ferrocement prisms suggest that the compressive strength of ferrocement is smaller than that of the matrix alone, where, the delamination (due to splitting transverse tensile stresses) and buckling of the mesh reinforcement in compression account for the reduction in strength 1988; ACI 549R, 1997; (Naaman, 2000). In general, the compressive strength of ferrocement is considered as that of the mortar mix (ACI 549R, 1997; IFS- 10, 2001). On the contrary, solid and hollow columns prophetically reinforced with wire mesh exhibited enhanced strength significantly. This is attributed to the lateral wires in the mesh acting in a manner similar to conventional helical reinforcement by restraining the enclosed matrix (ACI 549R, 1997).

Everything else being equal, the mesh type (expanded or hexagonal versus square) and its orientation (such as 45 versus 0 or 90 degrees) also influence the compressive strength The hexagonal and expanded metal meshes oriented in the direction of loading are less effective than similarly oriented welded square wire meshes. Meshes oriented at 45 degrees are also less effective than meshes aligned along the loading direction (ACI 549R, 1997)

2.3.3 Bending (Flexure)

Bending reflects the combined influence of parameters controlling both tensile and compression properties, such as mortar compressive strength, mesh type, mesh properties and mesh orientation. Moreover, it is believed that the two-way nature of the mesh reinforcement generally imparts some additional strength and safety when bending is considered in one direction only (one-way bending). Similar to the case of tension, ferrocement exhibits typical behaviour in bending also. The ferrocement with the mesh layers even bundled at the centre of the crosssection behaves similar to that of the plane mortar under bending. Thus, in ferrocement bending elements, as in reinforced concrete, the most efficient layer of mesh is that closest to the extreme fiber or face of the element (Paramasivam and Ravindarajah, 1988). The specific surface of reinforcement does not have as strong an influence on the cracking behaviour in bending as in tension. The average crack width in ferrocement bending elements is primarily a function of the tensile strain in the extreme layer of mesh and the transverse wire spacing (Naaman, 2000).

Everything else being equal, square welded wire meshes perform better in bending than the other meshes. This is due to the transverse wires in welded meshes provide a better anchorage for bond zone, thereby strengthening the matrix through biaxial confinement. Hexagonal mesh has the poorest performance among the wire meshes. Likewise in tension, the orientation of meshes at 45 degrees is the weakest configuration in bending also (ACI 549R, 1997; Naaman, 2000; Arif *et al.,* 2001).

In ferrocement crack width at working load remain very small compared to that of reinforced concrete, thereby leading towards to good impermeability, stiffness, and durability. However, the compressive strength of mortar does not seem to have much influence on the bending resistance of ferrocement beams. Everything else being equal, an 80 percent increase in mortar compressive strength led to an average increase of only 11% in bending strength (Montesinos and Naaman, 2004)

2.3.4 Shear

The shear strength of ferrocement is reported to be approximately equal to 32 percent of its equivalent bending strength regardless the type and content of mesh or mortar strength used However, in general, shear failure is preceded by the attainment of flexural capacity of ferrocement Whereas, cracking shear strength of ferrocement is reported to increase with the decrease in span-to-depth ratio and increase in mesh layers and mortar strength. Ferrocement beams behave in a manner similar to conventional concrete beam, except for demonstrating excellent crack control characteristics in shear. Furthermore, unlike the beams failing in flexure, the beams failing in shear exhibits little sign of impending failure besides the formation of a large number of diagonal cracks and a negligible plastic behaviour after the multiple cracking.

2.3.5 Durability

Durability can be defined as the resistance to deterioration of properties when the ferrocement composite is subjected to various loading and environmental exposures. Although the measures required to ensure durability in conventionally reinforced concrete also apply to ferrocement, two other factors which affect durability are unique to ferrocement,

(a) The cover of mortar to the mesh reinforcement is small and consequently it is relatively easy for corrosive liquids to reach the reinforcement.

(ii) The surface area of the reinforcement is unusually high; so that area of contact over which corrosion can take place, and the resulting rate of corrosion are potentially high (Naaman, 2000).

However, these factors assume varying degrees of importance, depending on exposure conditions. An adequate cover should essentially be provided during the construction of ferrocement elements. The armature cover in compressed regions could be as much as 6mm, however in case of medium aggressive environments this value must be at least 10mm.
(Mansur *et al*., 1996) An OPC mortar cover of 5mm is reported to provide sufficient protection for the galvanized weldmesh against corrosion for a simulated load-marine corrosion environment (Xiong, 1997).
Deterioration of wire mesh fabric in ferrocement showed deterioration due to sustained exposure in saline water casting and curing conditions. However, the strength of panels under saline casting and saline curing condition is more as compared to panels under normal casting and saline curing condition because of better pore structure minimizing the ingress of water, due to the presence of fly ash and the saline water during casting. Ferrocement subjected to180 drying and wet cycles in fresh water showed unaffected strength of ferrocement elements in flexure, rather, the continued hydration of cement and resulting increase in the maturity of the mortar contributed to an improvement in the first crack strength in flexure (Al-Rifai and Al-Shukur, 2001).

2.4 APPLICATIONS OF FERROCEMENT

In its role as a thin reinforced concrete product and as a laminated cement-based composite, ferrocement can be used in numerous applications. These applications can be classified in three major categories; marine applications, terrestrial applications, and repair and strengthening applications.

2.4.1 Strengthening /Confinement

Ferrocement is useful for repair of concrete structures. It can restore the durability of structures which may undergo distress due to aggressive environments causing the corrosion of embedded reinforcement. Its application as overlays on masonry walls can increase its total load capacity, tension and shear strength. It also provides the ductility and cracking control. The application of ferrocement overlays is potential option in the situations where high performance of the walls is required. A significant enhancement in stiffness, strength, and durability can be achieved under compression when concrete is confined with various degree of ferrocement confinement. Compressive strength enhancement of the order of 20 to 30% was achieved by ferrocement confinement.

Ferrocement jacketing of RC columns is a feasible technique to prevent their shear failure and to provide the ductility when loaded in compression. It enhances the stiffness, strength, energy dissipation, and ductility significantly, where, the mode of failure changed from brittle shear failure to ductile flexural failure. Ferrocement jackets were produced by wrapping the required number of wire mesh layers over R/C columns and injecting the mortar slurry in meshes. Confinement of high strength concrete in ferrocement shell in addition to rectangular ties under axial compression indicated that the additional confinement in the form of ferrocement shell improved ultimate strength, strain, strain at ultimate strength and the ductility of high strength concrete. It also improved the dimensional stability.

CHAPTER 3

EXPERIMENTAL PROGRAM

3.1 INTRODUCTION

The main aim of study is to find out the optimum value of polymer in ferrocement mortar and its effect on the properties of mortar. The polymer modified ferrocement beams were casted to find these parameters.

Prior to evaluate these parameters the flow value of controlled as well as polymer modified mortar was find out at constant and varied water cement ratio. On the basis of constant flow values obtained by flow test, the different amount of w/c ratio was fixed at each polymer- cement ratio. Different properties i.e compressive strength, flexural strength and modulus of elasticity were studied and later on its effect was studied on flexure and tensile strength of ferrocement samples having a square wire mesh inside it.

3.2 BASICS AND PURPOSE

Polymer-modified mortar is made by adding a portion of the traditional binders with polymers. Polymers are added to mortar to increase characteristics that may include compression, flexural or tensile strength. Polymers act to improve the workability and adhesion of non-hardened mortar and often require less added water than does traditional mortar, which results in fewer pores.

3.3 MATERIALS

The criteria between mix proportions, water binder ratio, dosage of polymer for addition in the mix at constant and varied w/c ratio. The dosage of the polymers applied to reduce the water-binder ratio at specific flow.

3.3.1 Cement

Cement is a binding material used in construction and engineering, often called hydraulic cement, typically made by heating a mixture of limestone and clay until it almost fuses and then grinding it to a fine powder. ACC cement was used in as Portland Pozolana cement. The physical properties of cement are shown in Table:3.1.

Table : 3.1 Physical Properties of cement

Sr. no.	**characteristics**	**Test values**	**Value specified by IS :1489-1991 (Part 1)**
1	Standard Consistency (%)	34	----
2	Fineness of cement as retained on 90 micron sieve (%)	0.015	10(max.)
3	Setting times (minutes)		
	Initial	102	30(min.)
	final	320	600(max.)
4	Soundness of cement(mm)	2	10 mm
5	Specific gravity of cement	3.03	

3.2 Sand:

Table: 3.2 Physical properties of fine sand

Sr. no.	**Characteristics**	**Value**
1	Type	Natural sand
2	Specific gravity	2.62
3	Water absorption	1.06 %
4	Moisture content	0.12 %
5	Fineness modulus	2.26
6	Grading zone	III

Mix proportion: binder : sand
1 : 2

Polymers: 0 %, 5 % , 10 %, 15 % and 20 % by weight of total binder as partial addition of cement.

Antifoaming agent : 5 part per million.

Curing regime : Water

Strength development : 7 and 28 days

PROPERTIES OF POLYMER LATEX:

Properties	SBR
Colour	White liquid
Odour	Slight
Ph	8.5-11
Water solubility	soluble
Relative density(g/cc^3)	1.01-1.025
Solid content (%)	45-47.5
Particle size	0.15

3.4 EXPERIMENTAL OUTLINE

(i) First Phase: -

The first phase of testing will include investigation of compressive strength of polymer modified mortar for variations in polymer content (0 to 20%) (*VAE polymer, SBR Latex).* Mortar cubical specimens of size 70.6mm will be cast for checking the compressive strength.

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

Total Cubes = 27

(ii) Second Phase: -

The second phase of testing will include: -

(i) Investigation of flexural strength of polymer modified mortar for variations in polymer content (0 to 20%) (*VAE polymer, SBR Latex)*. Mortar specimens of size 40x40x160mm will be cast for checking the flexural strength.

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

Total specimens = 27

(ii) Investigation of modulus of elasticity of polymer modified mortar for variations in polymer content (0 to 20%) (*VAE polymer, SBR Latex)*. Mortar cylindrical specimens of size 100x200mm will be cast for checking the modulus of elasticity.

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

Total specimens = 27

(iii) Third Phase: -

In the third phase, the following physical properties of Polymer Modified Ferrocement (PMF) by using two and three layered woven wire mesh will be investigated as per the relevant standards.

a) ***Flexural strength of ferrocement:*** **-**Ferrocement specimens will be tested in accordance with **ACI Committee 549** standards.

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

Specimen 500x100x20 mm (27 nos.) X 2 = 54 (for 2 and 3 layers)

b) ***Tensile properties of the mesh reinforcement:*** **-**Reinforcement meshes will be tested directly in tension in accordance with **ACI Committee 549** standards.

Specimens 3 X 2 = 6 (for 2 and 3 layers)

c) ***Tensile test of ferrocement:*** **-**Ferrocement elements will be tested directly in tension in accordance with **ACI Committee 549** standards.

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

Specimen 500x100x20 mm (27 nos.) X 2 = 54 (for 2 and 3 layers)

3.5 DETAILED DESCRIPTION OF EXPERIMENTAL WORK

To obtained the different parameter like compressive strength, flexure strength, modulus of elasticity of controlled mortar and polymer modified mortar it was necessary to find the the w/c ratio for each flow value and effect of polymer addition on workability of mortar. Hence flow test was conducted to fix such values and also to find out the water cement ratio at constant workability of mortar. The Detailed description of flow test is given below.

3.5.1 Flow Test

The flow test is conducted first to find the flow value of at constant and varied water cement ratio. The cement sand ratio was used as 1: 2. The constant flow value 110±5 was fixed at 0 % polymer. The effects of two polymers SBR and VAE was studied. It was find that flow of mortar increases by adding polymer at constant w/c ratio. The amount of polymer was added 5%, 10%,15% and 20% for each. The SBR was used in latex form and VAE in powder form. It was found that SBR increases the flow value as compared to VAE polymer but these flow values are always more than the without addition of polymer. This is mainly interpreted in terms of improved consistency due to the ball bearing action of polymer particles and entrained air and the dispersing effect of surfactants in the latexes.

Hence a fixed value of w/c ratio is find out at each particular addition of polymer. the detail of flow test is given below:

3.5.1.1 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. The mix is filled in the 2 layers compacted in each layer with 20 numbers of blows with a 25mm diameter mild steel bar. The tamping pressure was just sufficient to ensure uniform filling of the mould. After filling, the mould was removed and the flow table was vibrated, by dropping it from standard height of 12.5mm at the rate of 25 drops in 15 seconds.

Flow value = ((final diameter- initial diameter)*100) /(initial diameter)

Figure: 3.1 Apparatus and measurements of flow value

3.6 PHASE -1

3.6.1 Compressive Strength

The first phase of testing will include investigation of compressive strength of polymer modified mortar for variations in polymer content (0 to 20%) (*VAE polymer, SBR Latex).* Compressive strength is the major test done during this study the cubes were tested on UTM installed in concrete structure laboratory. Before conducting the test, all the specimens were checked for any kind of deformation such as broken edges and cracks. Then the specimens were placed at the center of the cleaned platens of the machine followed by the application of gradual and without shock loading. The rate of loading was maintained at a constant value 70 Kilo Newton per minute until the failure of the specimens.

The samples were casted for each constant and varied w/c ratio i.e 27 samples for each. it was supposed that the results of maximum compressive strength out of these parameters will be adopted for further remaining work.

Cubes	Size of cube (mm)	No. of cubes	Water- cement ratio	Cement: sand
At const. w/c ratio	70.6*70.6	27	Constant (0.58)	1:2
At varied w/c ratio	70.6*70.6	27	Varied	1:2

The compressive strength was calculated by following formula:

$$f = F/A$$

Where:

f = Compressive strength (MPa)

F = Ultimate load (N)

A = Cross-sectional area perpendicular to loading direction (mm^2)

It was found that compressive strength for the varied w/c ratio was more as compared to the constant w/c ratio.

3.7 PHASE-II

3.7.1 Flexural Strength

Flexural strength is a measurement that indicates a material's resistance to deforming when it is placed under a load. The values needed to calculate flexural strength are measured with rectangular samples of the material placed under load in a 3 or 4 point testing setup.

Flexural strength, also known as **modulus of rupture**, **bend strength**, or **fracture strength i**s defined as a material's ability to resist deformation under load. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress The transverse bending test is employed, in which a rod specimen having a circular cross-section is used to fracture the beam sample under three point loading.. The size of the sample was chosen as 160*40*40 mm. The rate of loading was fixed as 2.65 kilo newton per minute. the effective length of the beam is taken as 120 mm. the sample includes the different percentages of mortar detailed in the second phase of experimental outline.

It was found that the flexure strength of the polymer modified mortar increases as compared to the unmodified mortars. The maximum strength is achieved by SBR is 7.26 n/mm^2.

The flexure strength of the beam under three point loading can be find out by the bending equation or by the formula as given below:

$$\sigma = 3F.L/2\ B\ D^2$$

The flexure strength of the beam under third point loading can be find out by the formula as under:

$$\sigma = F.L/\ B\ D^2$$

Where σ = stress at the outer fiber.

F = the load (force) at the fracture point (N)

L = the length of the support span (mm)

b = width (mm) and d = is thickness (mm)

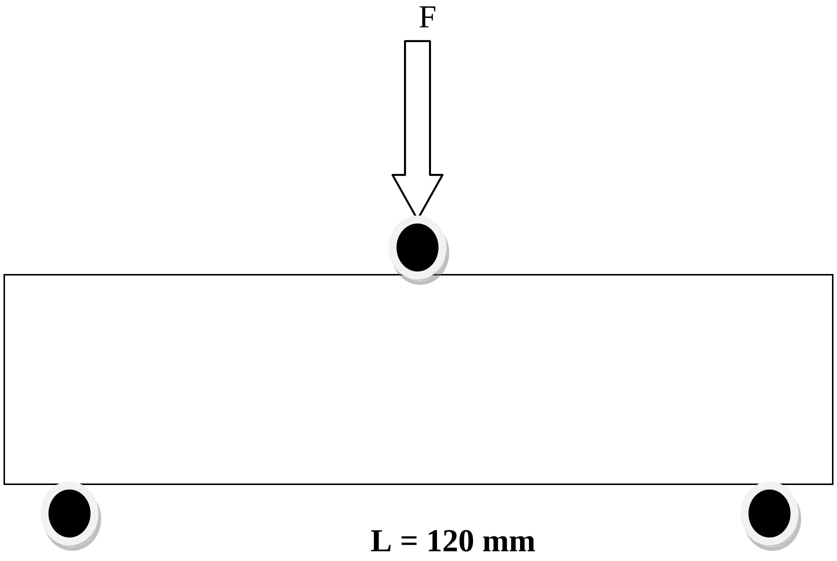

Fig: 3.2 a) Schematic Diagram for three point loading

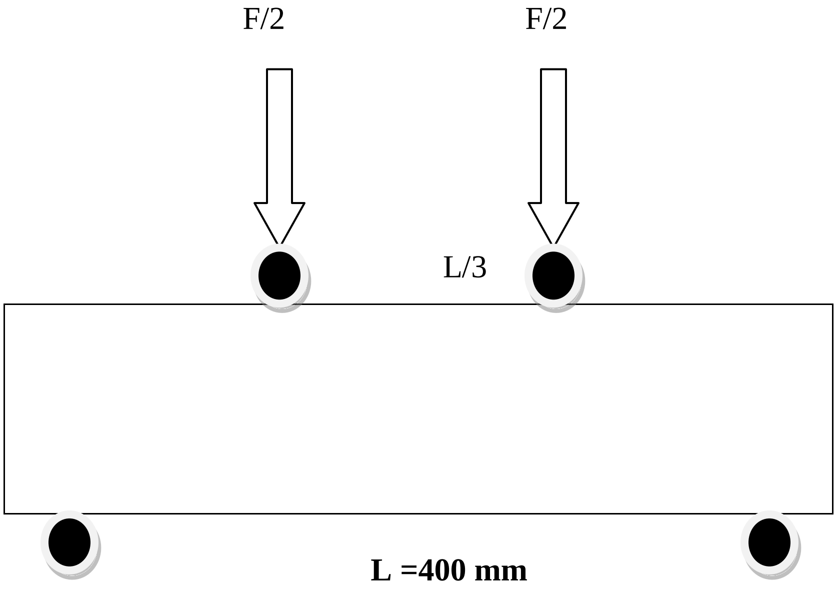

Fig: 3.2 b) Schematic Diagram for third point loading.

Figure : 3.3 Compressive Strength test in progress.

Fig : 3.4 flexure Strength test in progress.

3.7.2 Modulus Of Elasticity

ASTM C 469, the "Standard Test Method for Static Modulus of Elasticity," describes modulus of elasticity as a stress to strain ratio value. The Standard also states that the modulus of elasticity is applicable with the customary working stress range of 0 to 40% of the ultimate concrete strength. The modulus of elasticity is often used in sizing reinforced and non-reinforced structural members, establishing the quantity of reinforcement, computing stress for observed Strain.

An **elastic modulus**, or **modulus of elasticity**, is the mathematical description of an object or substance's tendency to be deformed elastically (i.e., non-permanently) when a force is applied to it. The elastic modulus of an object is defined as the slope of its stress strain the elastic deformation region. As such, a stiffer material will have a higher elastic modulus.

$$\lambda = \text{Stress/ Strain}$$

where lambda (λ) is the elastic modulus

Twenty seven cylinders of size 100 * 200 mm diameter were casted. Three for controlled value and the remaining for each fixed value of polymer at varied w/c ratio. The cylinders were demolded after 24 hours and were kept in curing tank for curing. After 28 days the cylinders were kept out before 20 to 30 minutes of testing. If the surface of the cylinder is not flat or smooth the grinder was used to make smooth. The load was given up to 40 % of the ultimate value of the cylinder in compression. The stress vs strain curves are drawn for each sample. The slope of the graph gives the modulus of elasticity of that sample.

As per ASTM C-469, Calculate the modulus of elasticity, to the nearest 50 000 psi (344.74 MPa) as follows:

$$E = (S_2 - S_1)/(€_2 - 0.000050)$$

E = chord modulus of elasticity, psi,

$S2$ = stress corresponding to 40 % of ultimate load,

$S1$ = stress corresponding to a longitudinal strain, $€_1$, of 50 millionths, psi, and

$€_2$ = longitudinal strain produced by stress $S2$.

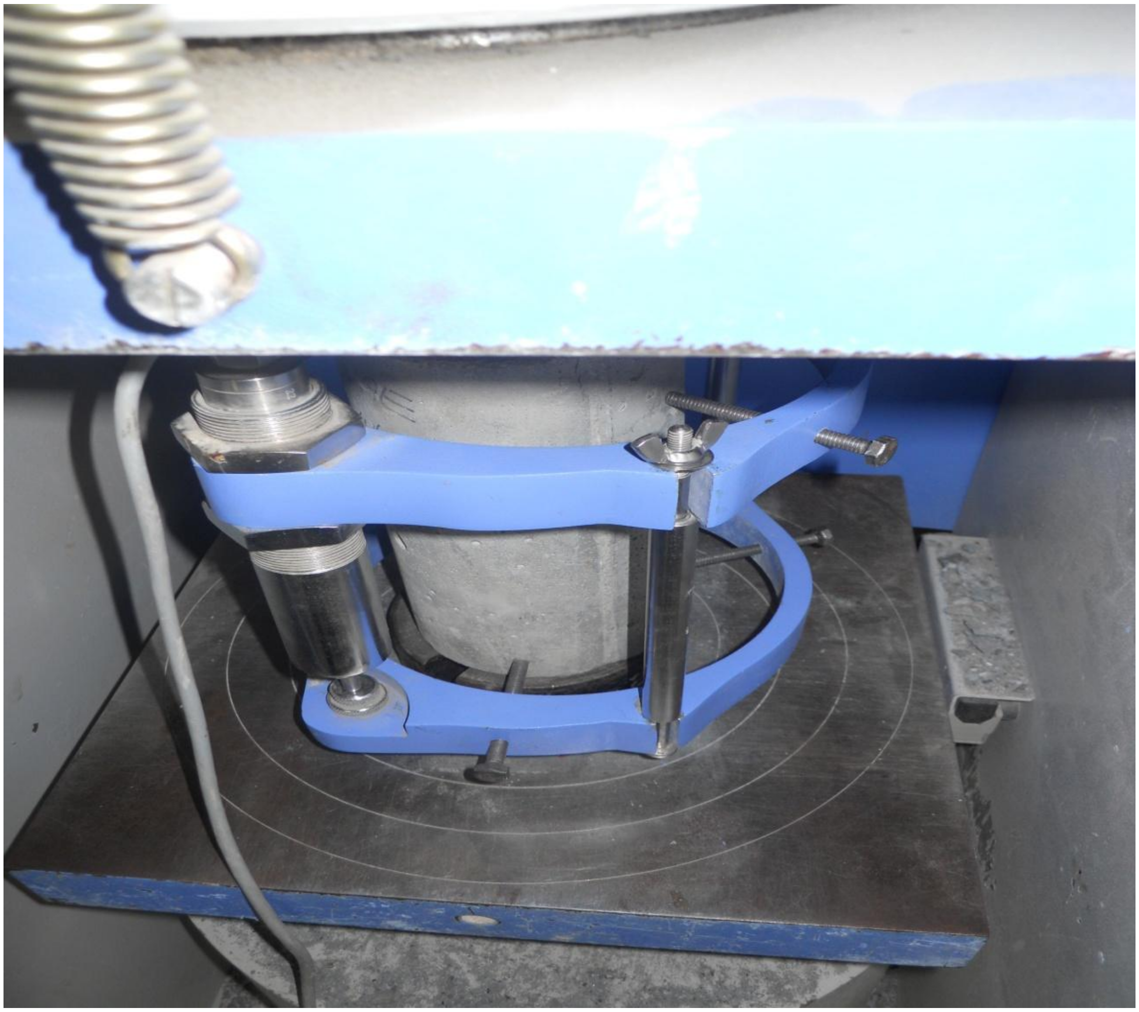

Figure: 3.5 Cylinder during testing for modulus of elasticity.

3.8 PHASE III

3.8.1 Flexural Strength Of Ferrocement Beams

The research program encompasses the investigation characteristic of polymer modified ferrocement elements. The tests include determination of load and deflection characteristics when subjected to static flexure. The structural properties of ferrocement were determined from the test specimens, 100 mm x 500 mm x 20 mm, reinforced with 2 and 3 layer of square mesh of diameter 0.48 mm and opening 7. 98 mm. A four-point loading was used over a simply supported span of 400 mm to determine the load-deflection properties. The samples were demoulded after 24 hours and then cured in water for 28 days. The ferrocement specimens were tested at to the ages of 28 days. The flexural test was conducted on UTM as shown in fig. The specimen was subjected to a static load at the loading points. In the middle of the tensile face of ferrocement specimen dial gauge were also used to measure the static deflection at the centre.

Figure **:** 3.6 a) Polymer modified ferrocement Beams after demoulding

Figure **:** 3.6 b) Polymer modified ferrocement beams before demoulding.

The minimum spacing between bottom phase of beam and wire mesh was kept 5 mm as shown in Figure : 3.7

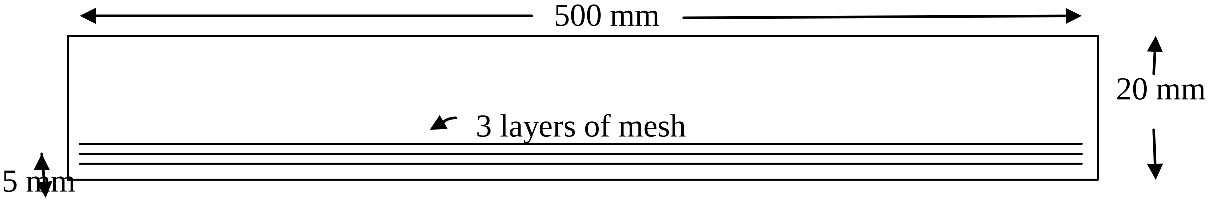

Fig: 3.7 Dimensions for polymer modified ferrocement beams.

Figure : 3.8 Test performance for third point loading ferrocement beams.

3.8.2 Tensile Test On Ferrocement Beams

Tensile strength measures the force required to pull the member or a structural beam to the point where it breaks. The test include determination of load and elongation characteristics when subjected to axial force. The 500 x 100 x 20 mm beams with 2 and 3 layers of ferrocement at the bottom phase were casted to cover the tensile properties of the polymer modified mortar samples. The samples were tested in UTM machine. The sample was put into the jaw of the UTM machine. Then the tensile force was applied by gripping its edges properly. It was found that the breaking of the sample take place from the middle portion of the beam because the maximum stresses developed at the centre of the beam.

The load elongation curve was plotted. The curve shows the linear variation first and then the elongation starts increasing. The results shows that when the beam have same polymer i.e either

VAE or SBR, the elongation in the two layered beams were found more as compared to the three layered ferrocement beams. The samples for tensile test are shown in Fig: 3.9

Figure : 3.9 Samples casted for tensile test.

Figure : 3.10 Breaking and crack patterns during tensile test.

3.8.3 Tensile Properties Of Mesh

The mesh used in the beam to increase its strength in flexure. Two and three layers of the mesh were used at a 5 mm spacing from the bottom phase of the beam. The polymer modified mortar makes high strength bond as compared to the conventional mortar. The mesh was tested in UTM as per the specification ASTM - 549. The properties of wire mesh are shown in Table: 3.3 as under.

Table: 3.3 Properties of wire mesh

Dia of wire	0.48mm-0.49mm
Quality of wire	wire drawn from 14G hot dip GI wire.
Zinc Coating	wire drawn from 14G hot dip GI wire.
UTS of wire	95kg/mm^2
Mesh size	36 mesh per 12" horizontally and 34 to 36 mesh per 12" vertically
spacing between wires	7.98 mm

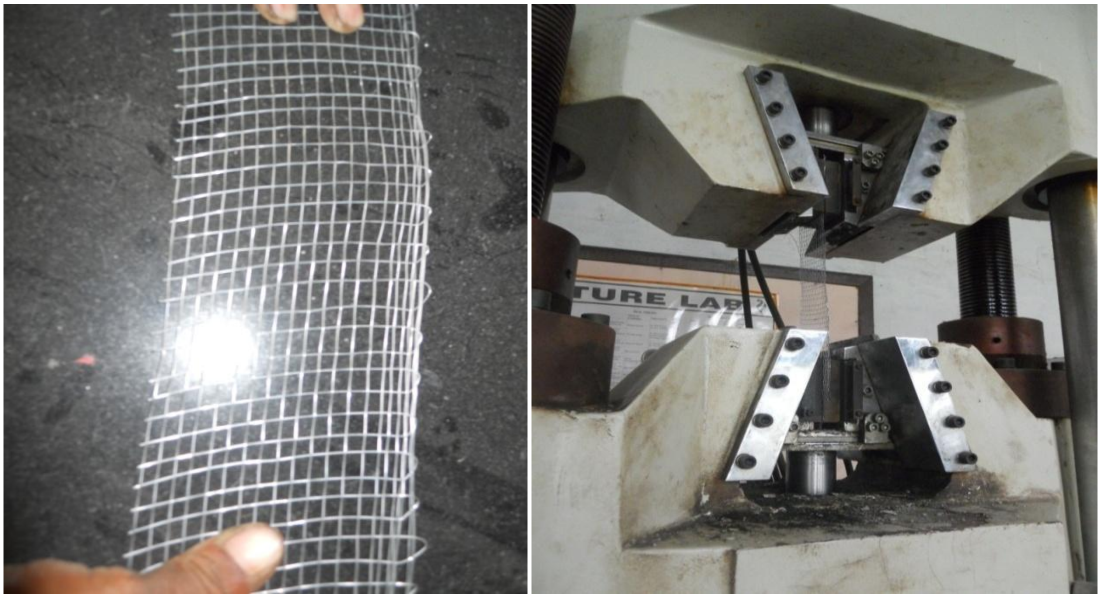

Figure : 3.11 Tensile test on mesh sample.

CHAPTER : 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

The chapter deals with the results obtained for compressive strength, flexure strength, and modulus of elasticity of the of the polymer modified mortar and load deflection characteristics of the of the polymer modified ferrocement samples. the results obtained are discussed below.

4.2 WORKABILITY OF THE POLYMER MODIFIED MORTAR:

Latex-modified mortar provide a good workability over conventional cement mortar. The flow of the latex modified mortars increases with increasing water-cement ratio and polymer cement ratio. The workability of mortar increases about 1.65 times for 20 % addition of the VAE polymer and approximately 2 times with addition of 20 % SBR at constant water cement ratio. This is mainly interpreted in terms of improved consistency due to the ball bearing action of polymer particles and entrained air and the dispersing effect of surfactants in the latexes. The results are discussed in the Table: 4.1 and plotted on the graph as under.

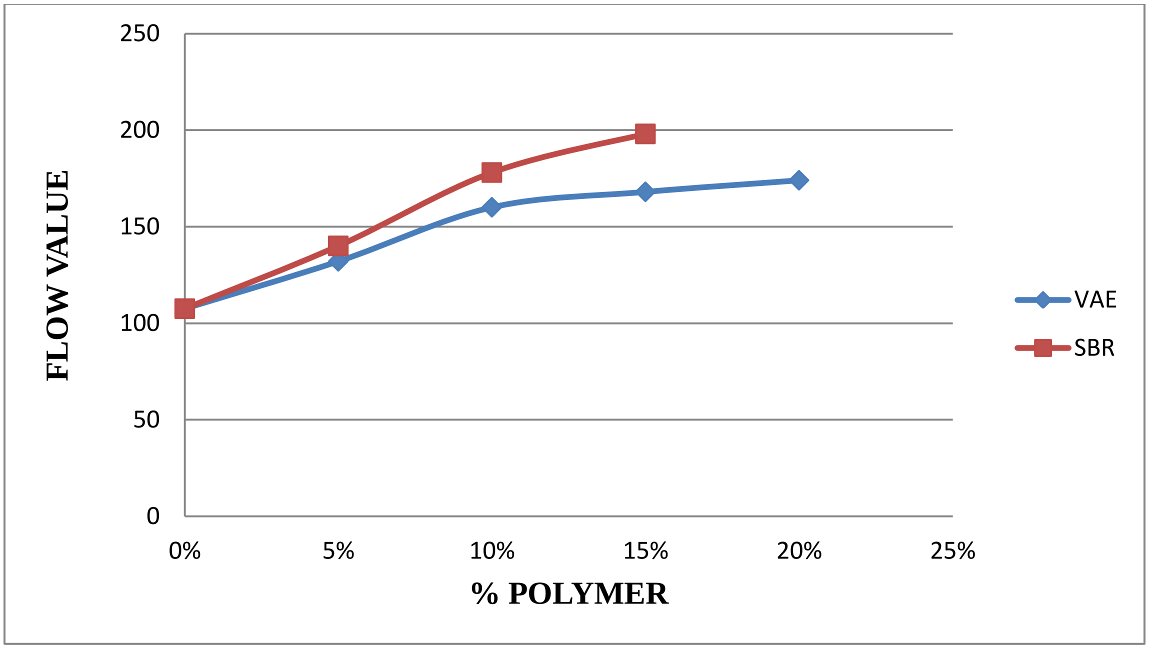

Figure : 4.1 Flow Value Vs Percentage Polymer at constant water cement ratio.

4.3 COMPRESSIVE STRENGTH OF POLYMER MODIFIED MORTAR

The compressive strength of both VAE and SBR polymer modified mortar decreases at constant water cement ratio. The compressive strength of the VAE still decreases to some extent at the varied water cement ratio but the compressive strength of the SBR modified mortar increases. This is due to the decrease in the water content at varied w/c ratio as compared to the constant w/c ratio. Due to decreases in w/c ratio the density of mortar increases. Hence the compressive strength of the polymer modified mortar is more for varied w/c ratio as compared to the constant w/c ratio. The values of the compressive strength for both constant and varied w/c ratio are given below in Table 4.2.

4.3.1 Compressive strength after 7 and 28 days at constant w/c ratio

The compressive strength of the conventional mortar is 13.56 N/mm^2 at constant water cement ratio. The compressive strength of the VAE polymer mortar decreases linearly with increase in polymer cement ratio.The compressive strength of the SBR polymer mortar decreases linearly upto 5 %. From 5 % to 10 % the compressive strength does not vary too much but after 10 % it again decrease linearly up to 20%. After 28 days the compressive strength of both VAE and SBR polymer mortar decreases cement ratio the compressive strength of controlled samples found more as compared to the polymer modified mortar samples. At 15 % the strength of each modified mortar is nearly equal but decreases continuously.

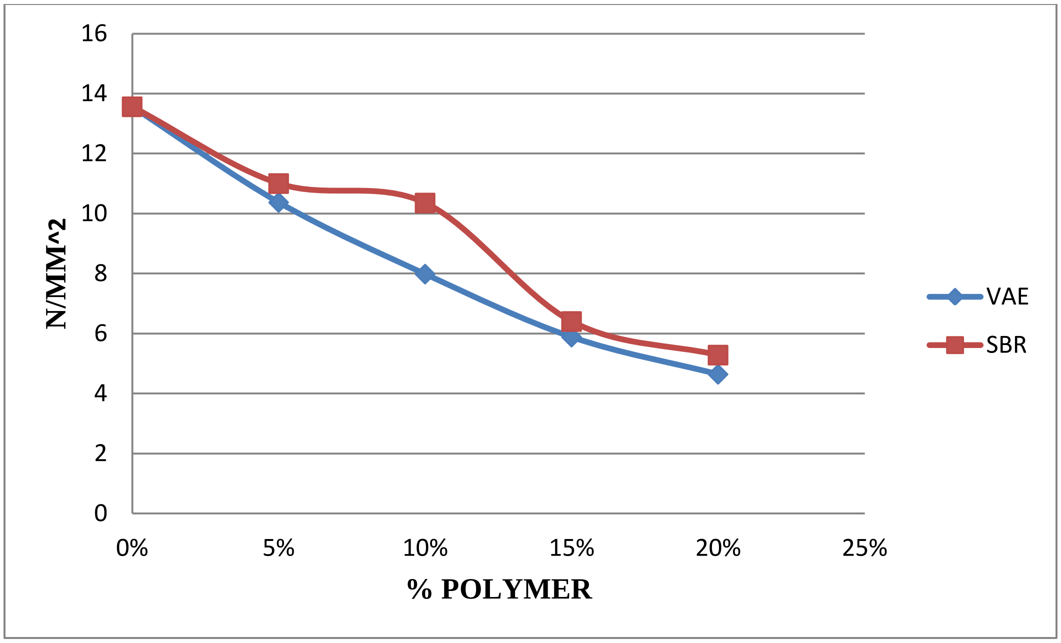

Figure: 4.2 Compressive Strength Vs % Polymer after 7 days at constant w/c ratio.

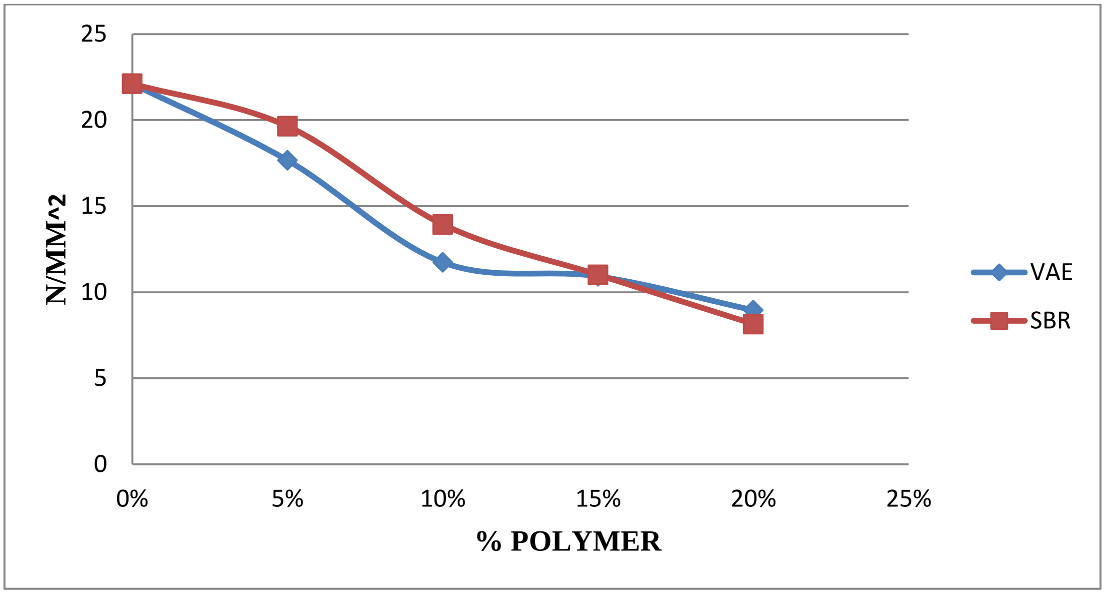

Figure : 4.3 Compressive Strength Vs % Polymer at constant w/c ratio after 28 days**.**

4.3.2 Compressive strength after 7 and 28 days at varied w/c ratio or constant flow.

Compressive strength of SBR modified mortar increases with increase in polymer cement ratio up to 10 %. After 10 % the compressive strength starts decreasing up to 15 % of polymer cement ratio. After 15 % addition of SBR, there is no such effect of polymer addition in mortar and the curve becomes straight up to 20 %. After 28 days the behavior of VAE polymer modified mortar remains similar as after 7 days. The behavior of SBR modified mortar is concave upward up to 15 % but the behavior of VAE modified mortar is concave downward up to 20 %. SBR shows more compressive strength than VAE at varied water cement ratio. The graph and results for both VAE and SBR modified mortars is shown in Figure : 4.4 and Table: 4.6

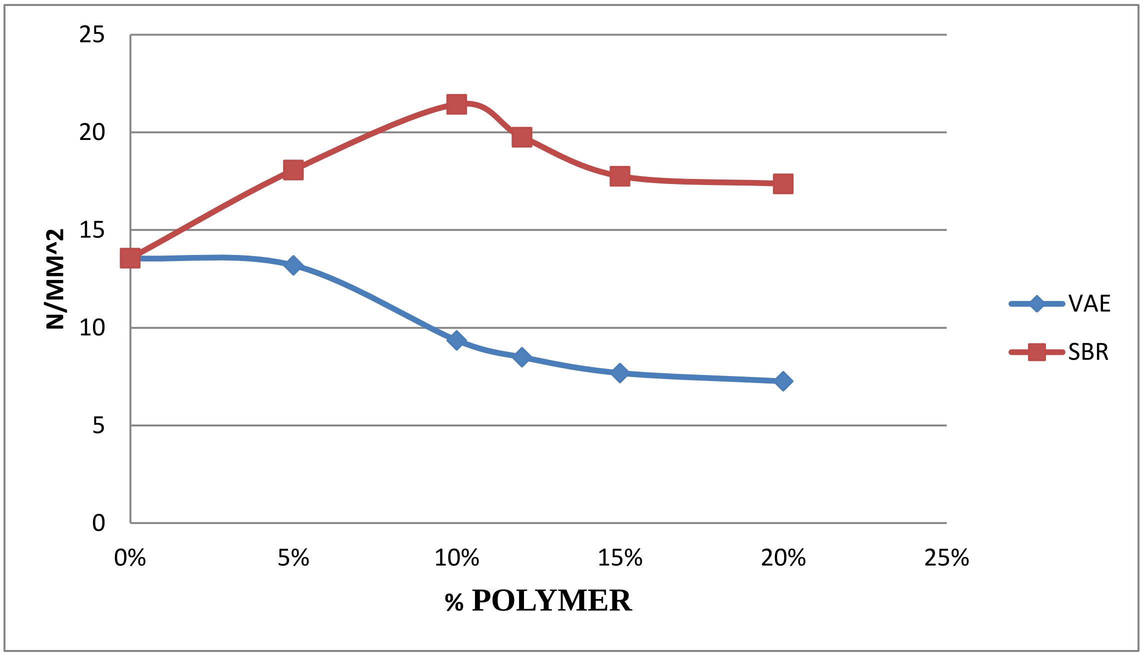

Figure : 4.4 Compressive Strength Vs % Polymer after 7 days at constant flow value.

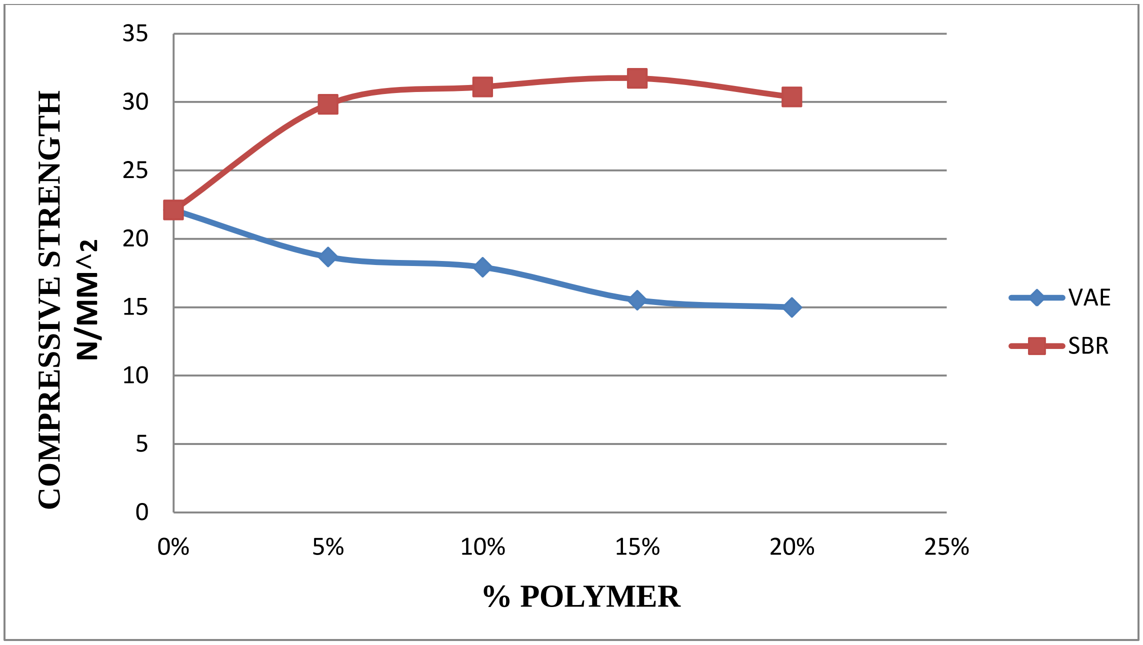

Figure : 4.5 Compressive Strength Vs % Polymer after 28 days at constant flow value.

Table:4.1 Mix at constant w/c ratio for VAE polymer

Sr. No.	**Mix designation**	**p/c ratio**	**w/c ratio**	**Flow value**
1.	Con	0	0.58	107.5
2.	V11	5	0.58	132
3.	V21	10	0.58	160
4.	V31	15	0.58	168
5.	V41	20	0.58	174

Table : 4. 2 Compressive Strength Of VAE Polymer modified mortar after7 and 28 days at constant water cement ratio.

Mix designation	**Compressive Strength (after 7 days water curing) N/mm^2**	**Compressive Strength (after 28 days water curing) N/mm^2**
Con	13.56	22.11
V11	10.37	17.66

V21	7.98	11.73
V31	5.88	10.92
V41	4.64	8.95

Curing Conditions:

C1 = 7 days water curing

C2 = 28 days water curing

Table:4.3 Mix at constant w/c ratio for SBR polymer

Sr. No.	Mix designation	p/c ratio	w/c ratio	Flow value
1.	Con	0	0.58	107.5
2.	S11	5	0.58	140
3.	S21	10	0.58	178
4.	S31	15	0.58	198
5.	S41	20	0.58	--

Table: 4.4 Compressive Strength of SBR polymer modified mortar after 7 and 28 days at constant water cement ratio.

Mix designation	(C1) Compressive Strength (after 7 days water curing) N/mm^2	(C2) Compressive Strength (after 28 days water curing) N/mm^2
Con	13.56	22.11
S1	11	19.64
S2	10.35	13.93
S3	6.40	11
S4	5.28	8.14

Curing Conditions: -

C1 = 7 days water curing

C2 = 28 days water curing

Table: 4.5 Mix at constant flow value for VAE polymer

Sr. No.	Mix designation	p/c ratio	w/c ratio	Flow value
1.	Con	0	0.58	107
2.	V11	5	0.52	109
3.	V21	10	0.49	109
4.	V31	15	0.47	106
5.	V41	20	0.44	105

Table : 4. 6 Compressive and Flexure Strength of VAE Polymer modified mortar after 7 and 28 days at constant flow

Mix designation	Compressive Strength (after 7 days water curing) N/mm^2	Compressive Strength (after 28 days water curing) N/mm^2	Flexural Strength (after 28 days water curing) N/mm^2
Con	13.56	22.11	4.70
V11	13.19	18.67	5.37
V21	9.34	17.92	5.63
V31	7.68	15.51	6.15
V41	7.26	14.98	5.30

Curing Conditions: -

C1 = 7 days water curing

C2 = 28 days water curing

Table: 4.7 Mix at constant flow value for SBR polymer

Sr. No.	Mix designation	p/c ratio	w/c ratio	Flow value
1.	Con	0	0.58	107
2.	S11	5	0.47	106
3.	S21	10	0.42	111
4.	S31	15	0.39	107
5.	S41	20	0.36	106

Table: 4.8 Compressive and Flexure Strength of VAE polymer modified mortar after 7 and 28 days at constant flow value.

Mix designation	(C1) Compressive Strength (after 7 days water curing) N/mm^2	(C2) Compressive Strength (after 28 days water curing) N/mm^2	(C2) Flexural Strength (after 28 days water curing) N/mm^2
Con	13.56	22.11	4.70
S1	18.07	29.83	6.46
S2	21.43	31.10	6.98
S3	17.75	31.73	7.26
S4	17.36	30.37	7.20

Curing Conditions: -

C1 = 7 days water curing

C2 = 28 days water curing

4.4 EFFECT OF POLYMER ON FLEXURE STRENGTH OF MORTAR

The flexure strength and the further research is based on the constant flow value. The flexure strength of both VAE and SBR mortar increases up to 15 % addition of polymer. Both VAE and SBR shows the flexural strength graph convave upward up to 15% and then it starts decreasing.mThe strengths of SBR-modified mortar increase with a rise in the bound styrene content. A film of the bound styrene content is formed in the SBR modified mortar. The flexure strength of the dry films made from SBR latexes increases sharply due to the bound styrene content, and there is a positive correlation between the strength of the films and the flexural strength of SBR-modified mortars with polymer-cement ratios above 5 %. (Ohama, y et al. 1995).

Addition of both VAE and SBR Up to 15 % act to strengthen the mortar microstructure but a further increase in the polymer content ratio leads to discontinuities in the microstructure which reduces the flexure strength further. As a result the flexure strength of the polymer modified mortar increased up to 15 % and then starts decreasing. The results shown in Table: 4.7- 4.8 and The diagram is shown in Figure : 4.6..

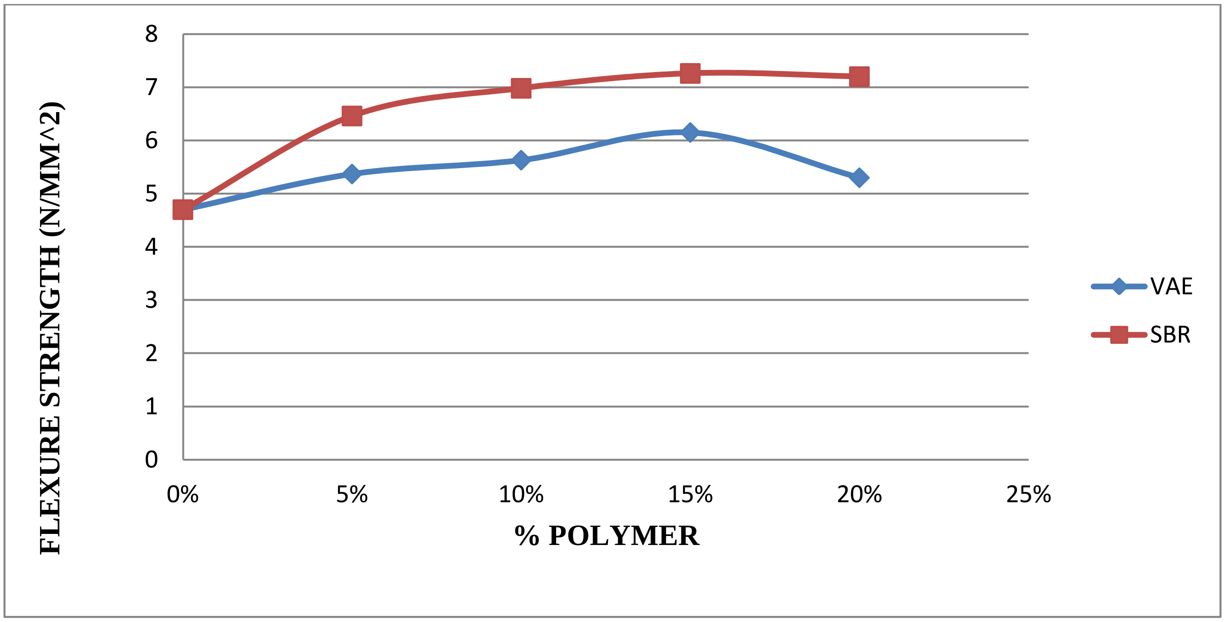

Fig: 4.6 Flexure Strength Vs % Polymer at constant flow.

4.5 MODULUS OF ELASTICITY OF MORTAR

Modulus of elasticity of SBR modified mortars increases with increase in the polymer – cement ratio. Modulus of elasticity is maximum at 10 % SBR modified mortars and then it again starts decreasing but always more than M.O.E of ordinary mortar. Modulus of elasticity for SBR modified mortars at 20 % is increased 1.05 times than the ordinary mortars.

Modulus of elasticity of VAE modified mortar decreases sharply than the modulus of elasticity of ordinary mortars. The results and graphs are shown in Table: 4.9 and Figure: 4.7 as under.

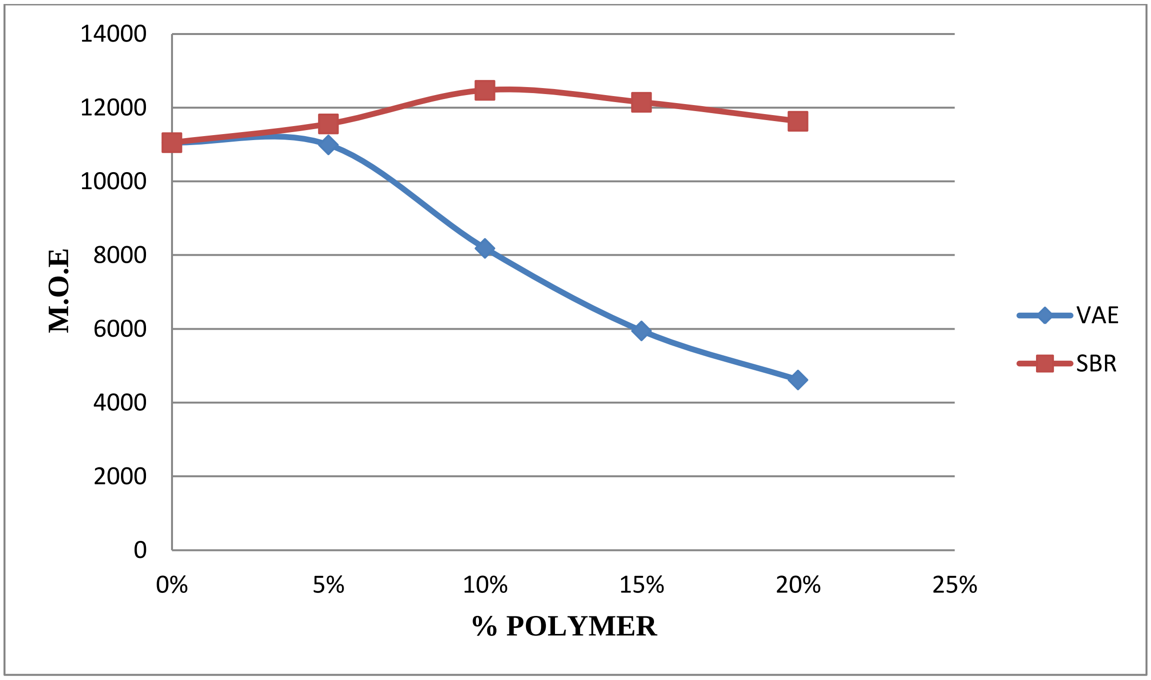

Figure: 4.7 Modulus Of Elasticity Vs % Polymer

Table: 4.9 Modulus Of Elasticity Vs Percentage Polymer of VAE and SBR modified mortar.

POLYMER	VAE	SBR
% POLYMER	M.O.E (N/mm²)	M.O.E(N/mm²)
0 %	11.053×10^3	11.053×10^3
5 %	10.992×10^3	11.561×10^3

10 %	8.186×10^3	12.472×10^3
15 %	5.948×10^3	12.147×10^3
20 %	4.617×10^3	11.633×10^3

4.6 EFFECT OF POLYMER ON POLYMER MODIFIED FERROCEMENT SAMPLES

The flexure strength of polymer modified ferrocement samples increases up to 15 %. This is due to the dry films made from VAE and SBR latexes increases sharply due to the bound acetate styrene content, and there is a positive correlation between the strength of the films and the flexural strength of SBR-modified mortars with polymer-cement ratios. (Ohama y et al. 1995)

After 15 % the flexure strength of ferrocement samples decreases up to 20%. Both VAE and SBR Up to 15 % act to strengthen the mortar microstructure but a further increase in the polymer content ratio leads to discontinuities in the microstructure which reduces the flexure strength further.The deflection in the P.M.F beams increases with increase in load at the member. The results shows that the increase of polymer cement ratio up to 15 % increases the capacity of the member to take more load.

The flexure and tensile strength of mortar increases due to both cement hydration and polymer phase formation (coalescence of polymer particles and the polymerization of monomers) proceed well to yield a monolithic matrix phase with a network structure in which the hydrated cement phase and polymer phase interpenetrate. In the polymer-modified mortar and concrete structures, aggregates are bound by such a co-matrix phase, resulting in the superior properties of polymer-modified mortar and concrete compared to conventional. (Ohama Y et al, (1995)).

4.6.1 Flexure Test Results

The results for both load deflection and flexure strength vs deflection are explained as under:

Table : 4.10 Flexure Load Vs Deflection Vs Percentage Polymer

2- LAYER			3 – LAYER	
Particular	**Load (KN)**	**Deflection(mm)**	**load(KN)**	**deflection(mm)**
Controlled	0.776	6.58	1.05	7.15
5 % SBR	0.91	7.43	1.381	8.89
10 % SBR	1.06	8.61	1.50	9.50
15 % SBR	1.295	8.95	1.64	10.35
20 % SBR	1.127	9.13	1.54	10.91
5 % VAE	0.86	7.14	1.27	7.97
10% VAE	0.995	8.47	1.40	8.84
15 % VAE	1.176	8.60	1.45	9.79
20 % VAE	1.015	9.03	1.42	10.32

Table: 4.11 Flexure Strength Vs % Polymer vs Deflection

2- LAYER			3 – LAYER	
Particular	**Flexure strength(N/mm²)**	**Deflection(mm)**	**Flexure strength(N/mm²)**	**deflection(mm)**
Controlled	7.76	6.58	10.50	7.15
5 % SBR	9.10	7.43	13.81	8.89
10 % SBR	10.60	8.61	15.05	9.50
15 % SBR	12.95	8.95	16.01	10.35
20 % SBR	13.05	9.13	16.48	10.69
5 % VAE	8.60	7.14	12.70	8.84
10% VAE	9.95	8.47	14	9.27
15 % VAE	11.76	8.60	14.46	9.98
20 % VAE	11.65	9.03	14.23	10.32

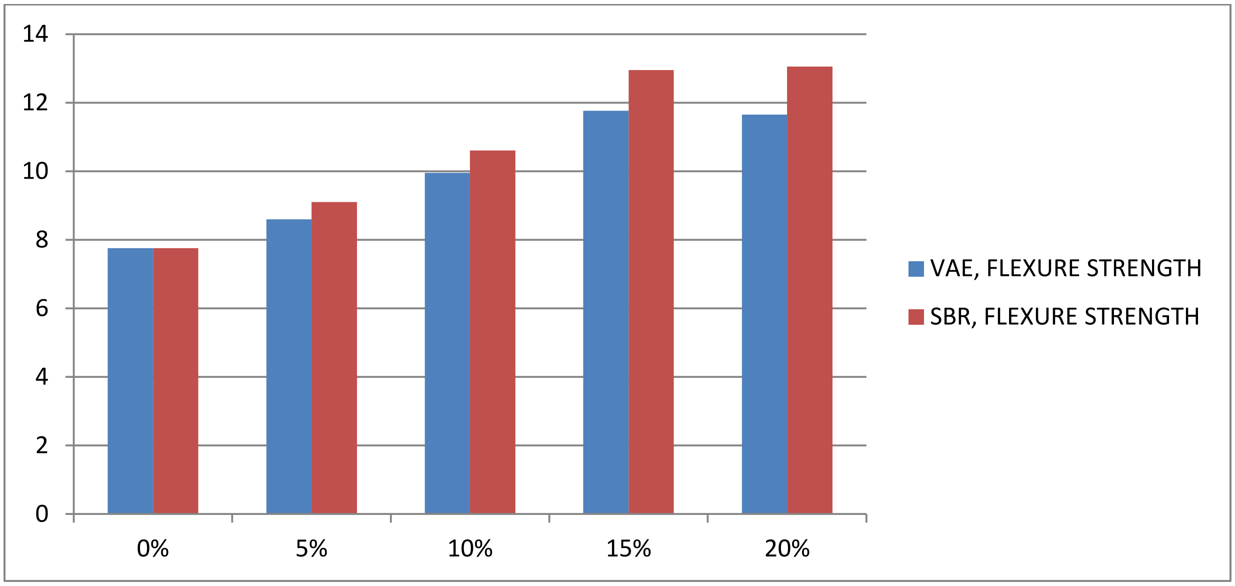

Figure:4.8 Flexure Strength Vs % Polymer for two layered mesh Samples.

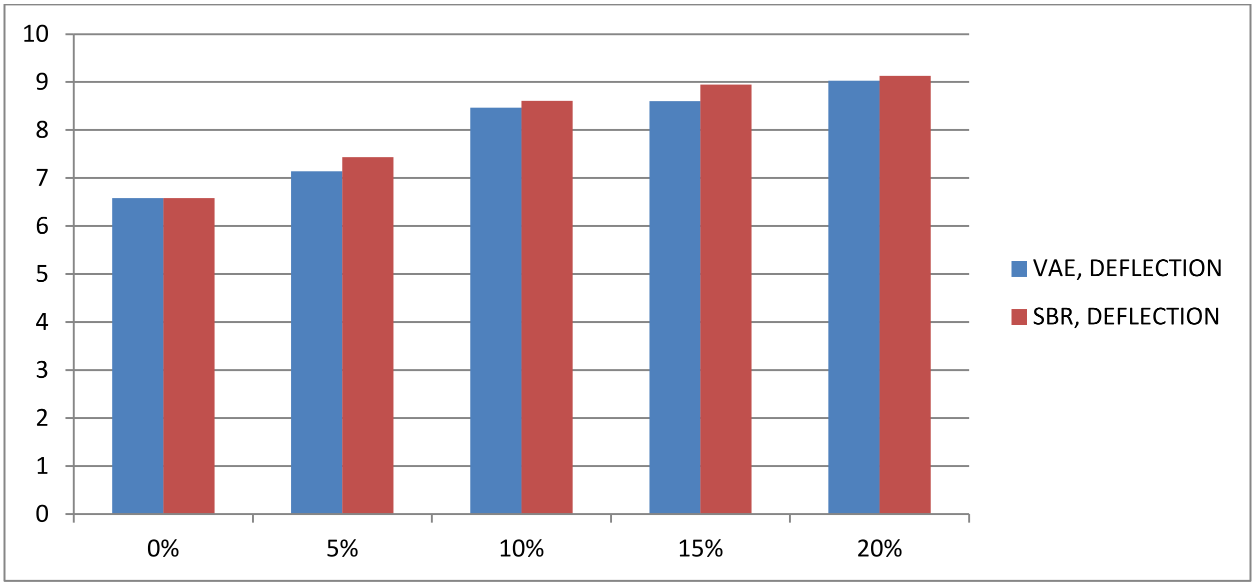

Figure: 4.9 Deflection Vs % Polymer for two layered mesh Samples

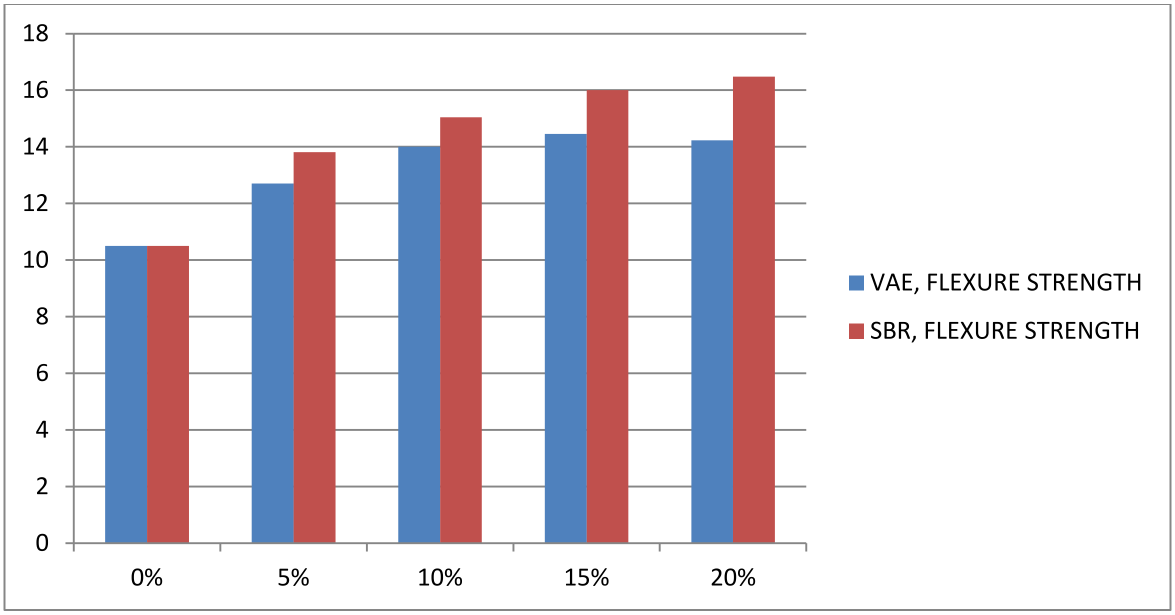

Figure: 4.10 Flexure Strength Vs % Polymer for three layer mesh samples

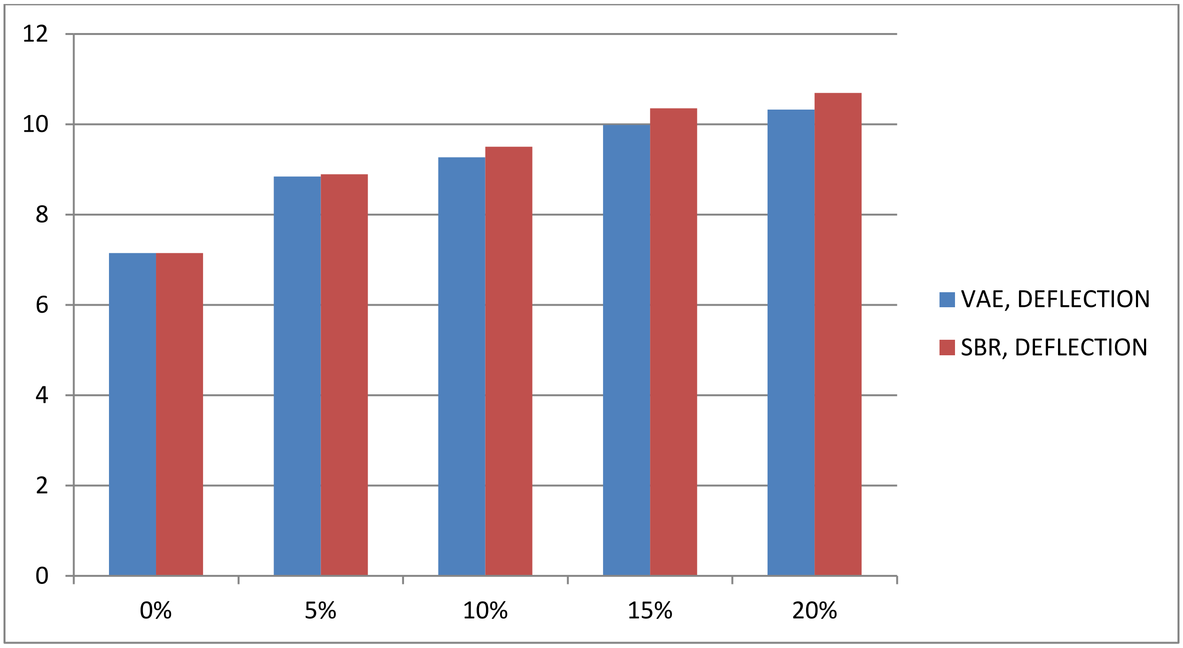

Figure: 4.11 Deflection Vs % Polymer for three layered mesh Samples

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4.7 TENSILE PROPERTIES OF POLYMER MODIFIED FERROCEMENT

There is an increase in the elongation of the ferrocement beam with increase in the content of the polymer. Although there is a little change in the elongation at 5 % addition of polymer over controlled samples. The maximum difference in the elongation for the two layered polymer modified mortar and the unmodified controlled sample is 1.22 mm in SBR addition. The maximum difference in the elongation for the three layered polymer modified mortar and the unmodified controlled sample is 1.32 mm in SBR addition. SBR shows more elongation and load due to its more complex matrix formation with the cement. Due to increase in the percentage of reinforcement in three layered mesh rather than two layered , beams shows more load vs elongation at constant polymer content. It may be due to the more complex bonding of the mesh with the mortar.There is slight decrease in the axial load after 15 % to 20 % polymer content but the elongation increases continuously.. The results are mentioned in Table : 4.12 and the diagrams are shown in Figure: 4.10 to 4.13.

Table : 4.12 Load- Deflection values for different % of Polymer.

2- LAYER			3 – LAYER	
Particular	**Load (N)**	**elongation(mm)**	**load(N)**	**elongation(mm)**
Controlled	6873	6.53	8355	6.69
5 % SBR	8415	6.98	10026	7.01
10 % SBR	8972	7.35	11039	7.48
15 % SBR	9446	7.64	11651	7.89
20 % SBR	9526	7.75	11546	8.01
5 % VAE	7825	6.75	9554	6.91
10% VAE	8572	6.95	10436	7.20
15 % VAE	9125	7.25	10895	7.53
20 % VAE	9024	7.49	11005	7.78

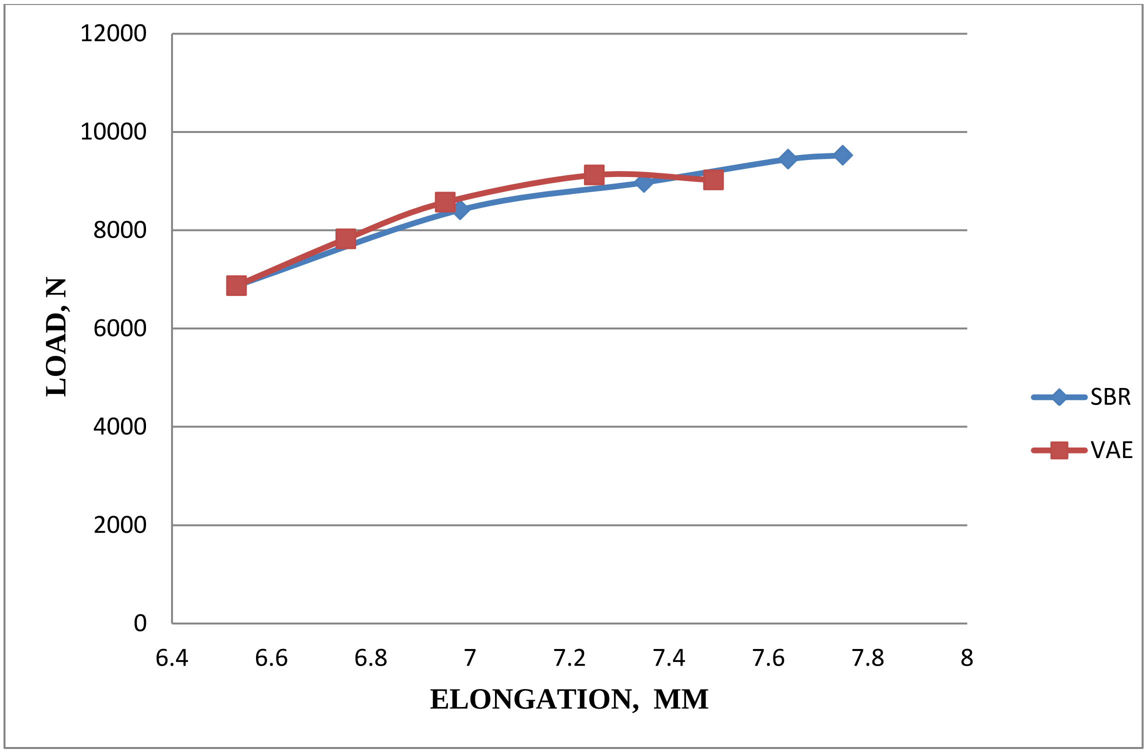

Figure : 4.12 Load Vs Elongation for 2 layered polymer modified ferrocement beams.

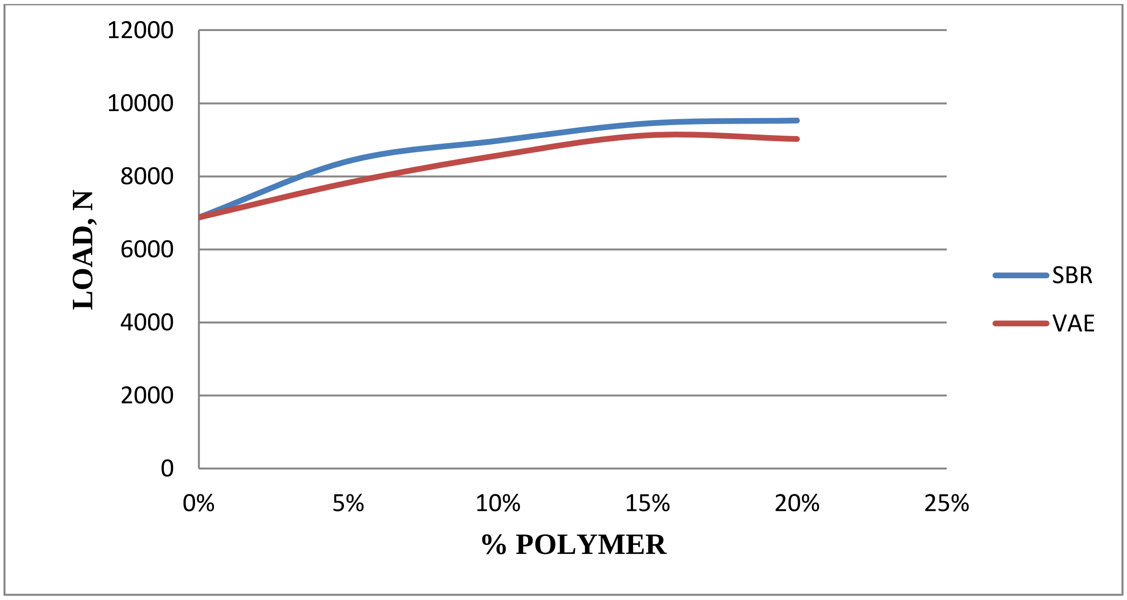

Figure : 4.13 Load Vs Percentage Polymer for 2 layered polymer modified ferrocement beams.

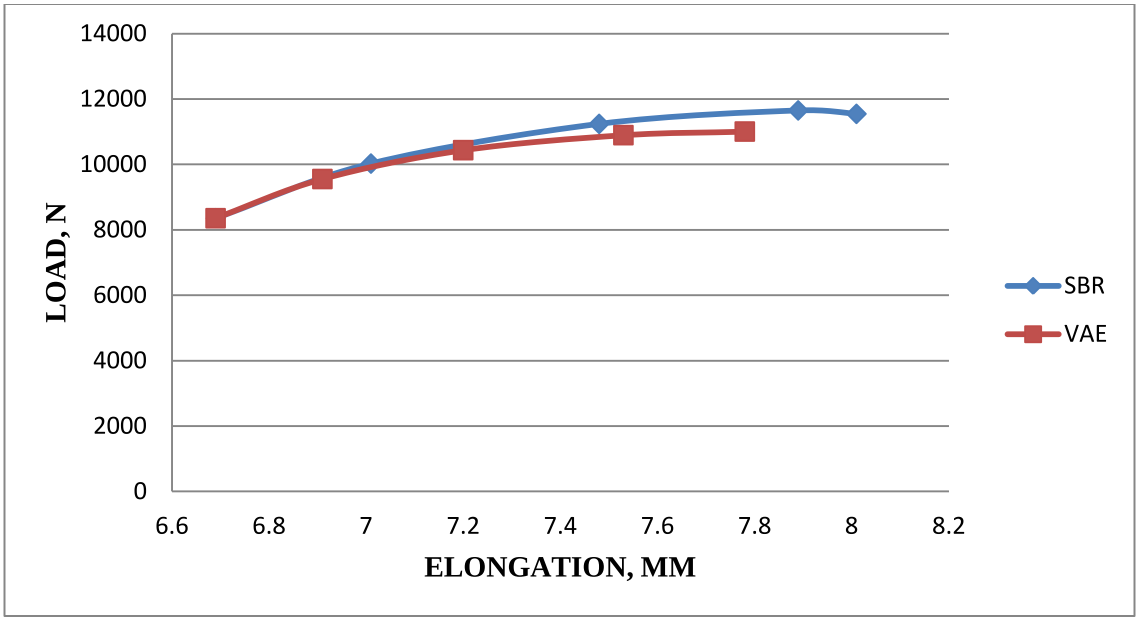

Figure : 4.14 Load Vs Elongation for 3 layered polymer modified ferrocement beams.

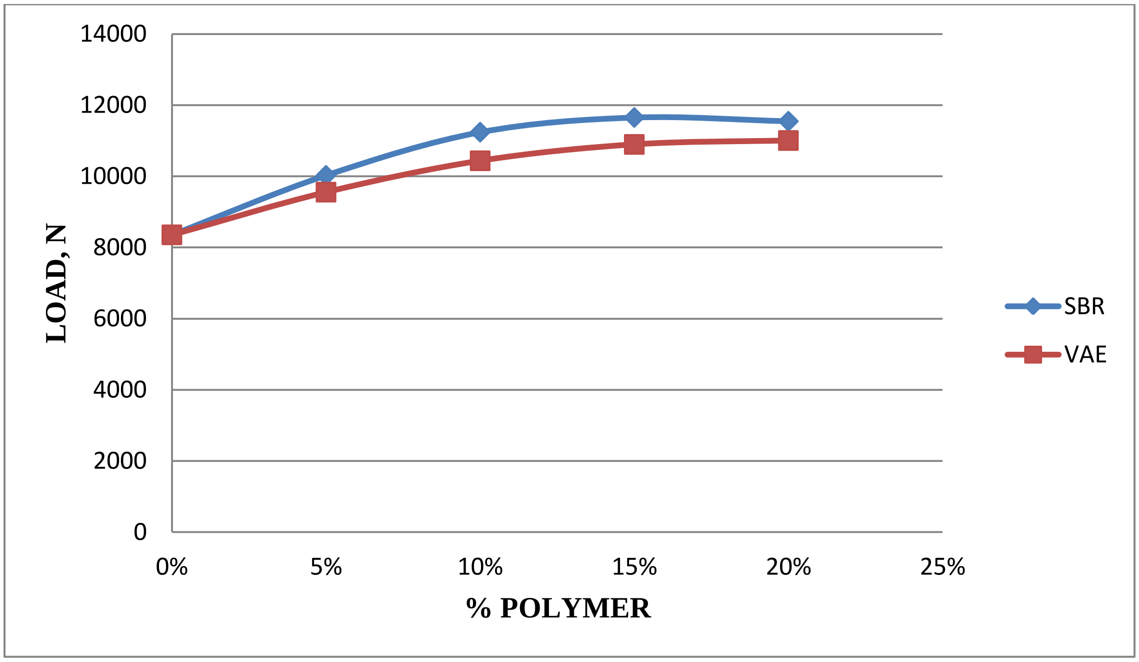

Figure : 4.15 Load Vs Percentage Polymer for 3 layered polymer modified ferrocement beams.

CHAPTER : 5

CONCLUSIONS

- The addition of VAE and SBR polymer in mortar increases the workability. At constant water cement ratio the workability can be increased up to 1.84 times at 15 to 20 % SBR addition.
- The compressive strength of polymer modified cement decreases at constant water cement ratio. But at varied water cement ratio the compressive strength of polymer modified cement increases up to 10 % and then starts decreasing after 7 days.
- At varied water cement ratio the compressive strength of VAE modified mortars decreases but the compressive strength of SBR modified mortars increases both after 7 and 28 days..
- The flexure strength of both VAE and SBR modified mortars increases but after 15 % the flexure strength of VAE modified mortars starts decreasing.
- Modulus of elasticity of SBR modified mortars increases with increasing in polymer content upto 10 % and then starts decreasing but modulus of elasticity of VAE modified mortars decreases with increase in polymer content in mortar.
- The tensile strength of both VAE and SBR modified ferrocement samples increases with increase in polymer content. The elongation and load of three layered polymer modified ferrocement found more than the two layered.
- SBR modified ferrocement beams take more load than VAE for both flexure and tensile strength.

REFERENCES

- Afridi, M.U.K., Ohama, Y., et al (2002) "Development of polymer films by the coalescence of polymer particles in powdered and aqueous polymer-modified mortars" cement and concrete research 33 (2003) 1715- 1721.
- Zulkarnain ,F., and Suleiman M.Z., (2008) " Properties of latex ferrocement in flexure", 2nd international conference(ICBEDC 2008).
- Barluenga, G. and Olivares, A.F. (2003) " SBR latex modified mortar rheology and mechanical behavior", cement and concrete research 34(2004) 527-535.
- Ali, S. Ahmad., Jawad, S.H., (2012) " Improvement the properties of cement mortar by using Styrene Butadyne Rubber polymer", journal of engineering and development, vol. 16, no. 3, sep. 2012.
- Wang, R., Wang, P.M., and Li, X.G (2004) " Physical And Mechanical properties of styrene – butadiene rubber emulsion modified cement mortars", cement and concrete research 35 (2005) 900-906.
- Bhikshma, V., Ravandekishore and Srinivas, R., (2011) "Durability of Polymer and Fly Ash Modified Ferro Cement Elements", Procedia Engineering 14 (2011) 2642–2649.
- Wang, R., Wang, P.M., and Li, X.G (2013) "Polymer-modified mortar with a gradient polymer distribution: Preparation, permeability, and mechanical behavior" construction and building materials 38 (2013) 195-203.
- Wang, R., Wang, P.M., and Li, X.G (2012) "Effect of redispersible vinyl acetate and versatate copolymer powder on flexibility of cement mortar" construction and building materials 27 (2012) 259- 262.
- Zhao, F.Z., Hao, Li., et al (2011) "Preparation and properties of an environment friendly polymer-modified waterproof mortar" construction and building materials 25 (2011) 2635- 2638.
- Schulze, J (1999) " Influence of water-cement ratio and cement content on the properties of polymer-modified mortars" cement and concrete research 29 (1999) 909-915.

- Jenni, A., Zurbriggen, R., et al (2005) “Changes in microstructures and physical properties of polymer-modified mortars during wet storage” cement and concrete research 36 (2006) 79-90.
- Ramli, M., and Tabassi, A.A (2012) “Effects of polymer modification on the permeability of cement mortars under different curing conditions: A correlational study that includes pore distributions, water absorption and compressive strength” cement and concrete research 28 (2012) 561-570.
- Wang, R., and Wang, P.M., (2011) “ Action of redispersible vinyl acetate and versatste copolymer powder in cement mortar”. Construction and building materials 25 (2011) 4210-4214.
- Chen, J., Zhang, S., et al (2011) “ Prepration And Properties of cement mortar modified by VAE latex” Advanced materials research vols.306-307(2011) pp 913-916.
- Wang, R., and Wang, P.M (2011) “ Application of styrene- butadiene rubber in cement-based materials”. Advanced materials research vols. 306-307(2011) pp 588-593.
- ACI 549.1R-93 (1999) “Guide for design, construction and repair of ferrocement”.
- Ohama, Y (1995) “handbook of polymer-modified concrete and mortars”.
- Ramli, M., and Tabassi, A,A (2012) “ Mechanical behavior of polymer- modified ferrocement under different exposure conditions: An experimental study” Composites: part B 43 (2012) 447-456.
- Bansal, P.P., Maneek.K., Kaushik, S.K., “ Effect of Type of Wire Mesh on Strength of Beams Retrofitted Using Ferrocement Jackets”, NBM&CW,Vol. 14, Issue -1 July 2008 P.P 272-282.
- Bansal,P.P., Kumar,M.,Tomar,A., Kaushik, S.K “ Retrofitting of shear Deficient RC Using Ferrocement Laminates”, International Conference on Recent Developments in Structural Engineering (RDSE-2007), 30 August- 1 September 2007, pp 1255-1262.
- Namaan, A.E., Robertson, R.E (1999) “Structure and properties of poly vinyl modified mortar concrete” Cement and concrete Research, vol. 29, 1999, pp. 407-415.
- Naaman A.E., et al (2000), , "Ferrocement and Laminated Cementitious Composites,".