

## Performances of SBR Latex Modified Ferrocement for Repairing Reinforced Concrete Beams

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**Abstract:** The use of ferrocement is a promising technology for increasing the flexural strength of deficient reinforced concrete members. The study reported herein investigates the mechanical properties of mortar through difference in polymer content and also by ferrocement with three different volume fractions of mesh reinforcement incorporated by Styrene Butadiene Rubber Latex. Consequently in order to exercise proper quality control from materials point of view, the ferrocement specimens being intended from Ferrocement Model Code and in addition to that the results were checked through the limitations of relevant code. Eight full-size beams, (two control beams and six strengthened beams) tested with different loading conditions and the variables were examined through the flexural test of the rehabilitated beams by the methods of attachment of mesh among various volume fractions with the influence of polymer modification on the properties of cement mortar. Performance of the tested beams and modes of failure are presented and discussed in this paper. The test results confirm that polymer modified ferrocement laminates can be used to significantly increase the flexural capacity of RC beams, with efficiency that varies depending on the tested variables.

**Key words:** ferrocement, polymer, mortar, volume fraction, mechanical properties, cracking.

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### INTRODUCTION

A large number of civil infrastructures around the world are in a state of serious deterioration today due to carbonation, chloride attack, etc. Moreover many civil structures are no longer considered safe due to increase load specifications in the design codes or due to overloading or due to under design of existing structures or due to lack of quality control. In order to maintain efficient serviceability, older structures must be repaired or strengthened so that they meet the same requirements demanded of the structures built today and in future. Ferrocement over the years have gained respect in terms of its superior performance and versatility, and now is being used not only in housing industry but its potentials are being continuously explored for its use in retro-fitting and strengthening of damaged structural members. As per Ferrocement Model Code, ferrocement is a type of reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of relatively small wire diameter mesh. The mesh may be made of metallic or other suitable materials. Thinking ferrocement as a material to be applied to thin walled it is necessary to adjust the material properties to the construction type and acting forces in the structures, to obtain the proper strength, stiffness, cracking control, ductility and impact resistance. Water soluble polymers and aqueous polymer dispersions are often used to improve the properties of mortar. Polymer modified mortars are being used as a popular construction material because of their excellent performance. Polymer-modified mortars are generally superior in the resistance to oxygen diffusion to unmodified mortar. Consequently the use of polymer-modified mortars as repairing and finishing materials can be recommended in order to inhibit the wet corrosion of reinforcing bars in concrete structures (Y.Ohama *et al.* 1991). Even powdered polymer-modified mortars can be used in the same manner as those of aqueous polymer-modified mortar for practical application (Musarrat Ullah Khan Afridi *et al.* 1994). The water retention of the powdered and aqueous polymer-modified mortars increases with a rise in polymer-cement ratio, however the magnitude of the improvement depends upon the types of cement modifiers used, polymer-cement ratio or both (M.U.K. Afridi *et al.* 1995). When the

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cement mixtures are mixed with polymer, a large volume of air voids often forms. Jae-Ho Kim *et al.* 1997 established a technique involves pre-wetting the cement and sand with plain water before adding the polymer solution or dispersion. Another area of interest for possible future research would be to determine whether differences noted with the additives used still apply to mortars mixed to higher flows and what effect saturating specimens, initially dry cured has on the tensile bond strength. Wet cured polymer mortars appear to have lower bond strengths than dry cured polymer mortars, indicating that the curing method has much to do with the strength gain of polymer-modified mortars (James Colville *et al.* 1999). During the hardening of cement, polymer can fill into the micro cracks, pores and cracks (J.M. Gao *et al.* 2002). Also it has been noticed that with increase in the addition of polymer the water absorption decreases remarkably when polymer cement ratio is small. But when polymer cement ratio exceeds 10% the change may become unnoticeable (Ke-Ru Wu, Dong Zhang *et al.* 2002). Besides the studies to meet the requirements of the applications, attention is paid to the mechanism and means of polymer modification. Furthermore, this technique becomes particularly attractive for flexural strengthening in the negative moment regions of beams where external reinforcement would be subjected to mechanical and environmental damage and would require protective cover. Ferrocement laminates with skeletal bar can take significant role in strengthening reinforced concrete beams. For flexural strengthening, the ferrocement laminates were cast onto the soffits (tension face) of the beams without any change in width of the beams. As this technology emerges, the structural behavior of RC elements strengthened with polymer modified ferrocement laminates needs to be fully characterized.

## MATERIALS AND METHODS

### 2.1 Outline of the Study:

Mixes were prepared with locally available coarse aggregates of 20mm maximum size, fine aggregates' passing through 4.75 mm IS sieve and ordinary portland cement conforming to ISI specification. The fineness modulus of the coarse and fine aggregates was 6.73 and 2.5 respectively whereas specific gravities of coarse and fine aggregates were 2.69 and 2.61 respectively. Water cement ratio of 0.4 is adopted for plain mortar and 0.3 for the mortars modified with the different polymer emulsion. A preliminary test program was set up to investigate the mechanical properties of ferrocement by methods of attachment of mesh reinforcement with volume fraction ( $V_r$ ) 3.55%, 5% and 6.43% with influence of polymer modification on the properties of cement mortar. Different parameters were taken into account regards to the polymer cement ratio and volume fraction of reinforcement. A type of polymer emulsion, styrene butadiene rubber latex was chosen and their basic properties were studied. With this polymer emulsion, mortars were prepared with cement sand ratio of 1:2 mixes with polymer cement ratios of 5%, 10 %, 15% and 20% (mass of solid phase of polymer emulsion divided by mass of cement) to attain a fair high strength. To understand the characteristics of polymer ferrocement composites eight beams were cast and tested under static condition with two points loading. Out of eight beams two control beams were tested to attain the ultimate load. The remaining six beams were retrofitted with polymer modified ferrocement laminates with the same volume fraction of mesh reinforcement as adopted during the preliminary study.

### 2.2 Details of Test Beam:

Eight full-scale rectangular RC beams 125 mm wide and 250 mm deep with a total length measures 3.2 m (3m effective) span were cast and tested. The beams were reinforced with 2 nos. of 12mm  $f_t$  at tension and 2 nos. of 8 mm  $f_c$  at compression side with 22 nos. of 6 mm  $f_t$  stirrups spaced 150 mm  $c/c$ . The yield strength of the reinforcing bars measures 415 N/mm<sup>2</sup>. M20 grade concrete with mix 1: 1.59: 3.12 towards water cement ratio 0.50 is adopted for all beams. Out of the eight beams, two beams (BP1 and BP2) were considered as perfect beams and the remaining six beams (BOR1 to BOR6) were damaged subjecting to two different levels of overloading and rehabilitated by polymer ferrocement laminates of different volume fractions. Before rehabilitation the original beam was turned up side down to expose its soffit. Prior to bonding with polymer ferrocement laminates, the soffit of the beams and bonding face of laminates were sandblasted to expose the aggregates and roughen the soffits of the beams so that the distance between the peak and rough of the chipped surface, was approximately 1 mm. The surface was then thoroughly cleaned of debris under an air jet. After surface preparation, the cracks are filled with a low viscous resin named corogROUT EPLV. COROCRETIN IHL-18 is applied to the surfaces using trowel and the ferrocement laminate was assembled.

### 2.3 Reinforcing Mesh:

The mechanical behavior of ferrocement highly depends upon the type, quantity, orientation and strength

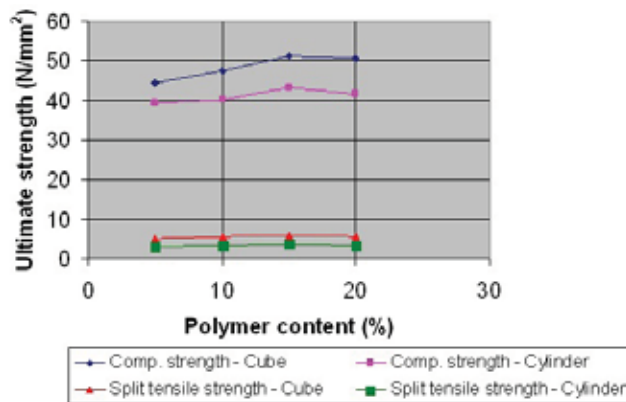
properties of the reinforcing meshes used. To understand this, principal type of meshes used in the laminate related to their properties is shown in Table: 1. Arrangement of mesh reinforcement for volume fraction 3.55% contributes with 2 layers of welded mesh ( $V_r = 1.51\%$ ), 1 layer of woven mesh ( $V_r = 1.44\%$ ) and 4 layers of twisted mesh ( $V_r = 0.60\%$ ). Mesh reinforcement for volume fraction 5% contributes with 2 layers of welded mesh ( $V_r = 1.51\%$ ), 2 layers of woven mesh ( $V_r = 2.88\%$ ) and 4 layers of twisted mesh ( $V_r = 0.60\%$ ). Mesh reinforcement for volume fraction 6.43% contributes with 2 layers of welded mesh ( $V_r = 1.51\%$ ), 3 layers of woven mesh ( $V_r = 4.32\%$ ) and 4 layers of twisted mesh ( $V_r = 0.60\%$ ).

**Table 1:** Properties of reinforcing mesh

Type	Shape	Fabrication mode	Gauge designation	Wire spacing in mm	Wire dia. in mm
Expanded steel meshes	Hexagonal	Twisted	½ No. 22	12.54	0.72
	Square	Woven	½ No. 20	4.23	0.88
	Square	Welded	½ No. 15	15	1.2

**2.4 Test Set up:**

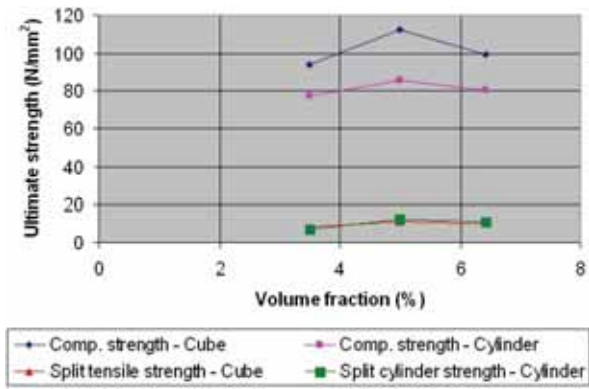
The compressive and split tensile strength of mortar was found by testing 100 mm size cubes as well as 100 x 200 mm cylinders respectively. Its flexural strength is obtained by testing 600 x 100 x 25 mm flexure beams and tensile strength with 100 x 200 x 25mm tensile specimens among mesh reinforcement through volume fraction of 3.55%, 5% and 6.43% in a standard manner. To determine the stress strain behavior beam specimens with strain gauges attached to it were kept vertically under UTM. The strains were measured at regular loading interval and results were tabulated. The 28th day strength presented in Fig: 1, 2, 3, & 4 are mostly the average of the results of three specimens. To study the effect of strength related to damage of the original beams prior to repair, perfect beams BP1 and BP2 was tested under static loading. The remaining six beams BOR1 to BOR6 were damaged by subjecting the beams to a pre-loading corresponding to 70% of the ultimate load capacity of the perfect beams and were rehabilitated by three different volume fractions of mesh reinforcement together with addition of 15% SBR in the polymer modified ferrocement laminates, two beams for each category of rehabilitation. All beams were tested under two point loading over a span of 3000 mm and also instrumented for the measurement of mid-span deflections and concrete strains for difference positions at the middle of the span. Typical test set up is shown in Fig: 5. Crack widths and cracks spacing along the entire length at the soffit level of the original beams were also measured. Linear displacement transducer with a transverse of 50 mm was used to measure the mid-span deflection of the beams. The reading of the deflections was recorded by portable data logger.



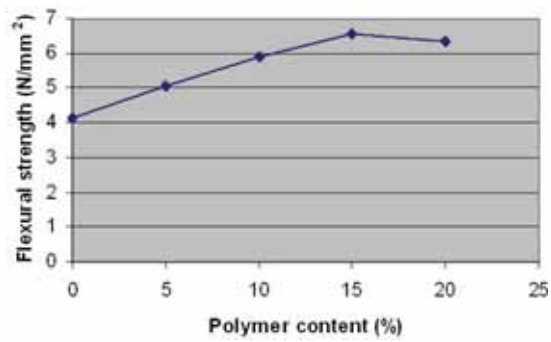
**Fig. 1:** Polymer content versus strength of SBR mortar specimens

**2.5 Young’s Modulus for Ferrocement under Compression:**

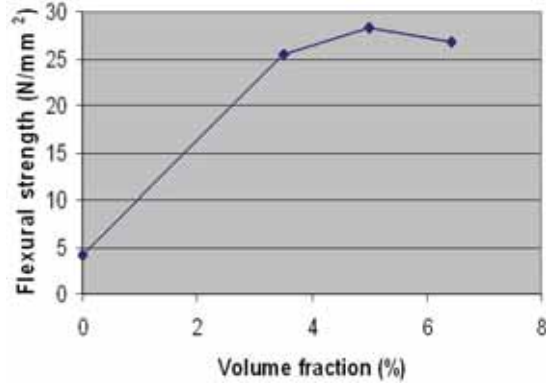
Cylinder specimens were used to find the values of Young’s modulus under compression as shown in Table:2. The deformation of cylinder specimen’s was measured with electrical strain gauges and deflectometers. According to IS 456 – 2000, young’s modulus is given as  $E = 5000 \sqrt{f_{cu}}$ . In this mode, unlike tension, the matrix contributes directly the ferrocement strength in proportion to its cross sectional area. The strength and amount of reinforcement are most appropriately defined in terms of stress and volume fraction of reinforcements.



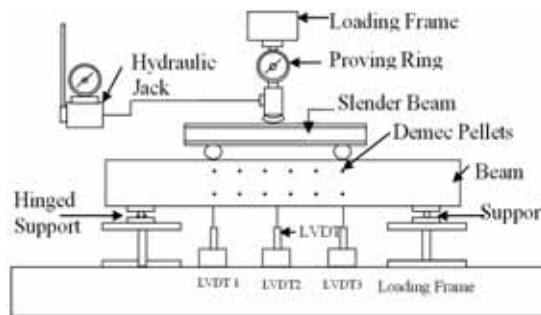
**Fig. 2:** Volume fraction of mesh versus strength of SBR ferrocement specimens



**Fig. 3:** Polymer content versus flexural strength of SBR mortar specimens



**Fig. 4:** Volume fraction of mesh versus flexural strength of SBR ferrocement specimens



**Fig. 5:** Typical set up for beam test

**Table 2:** Young's Modulus for ferrocement specimens under compression

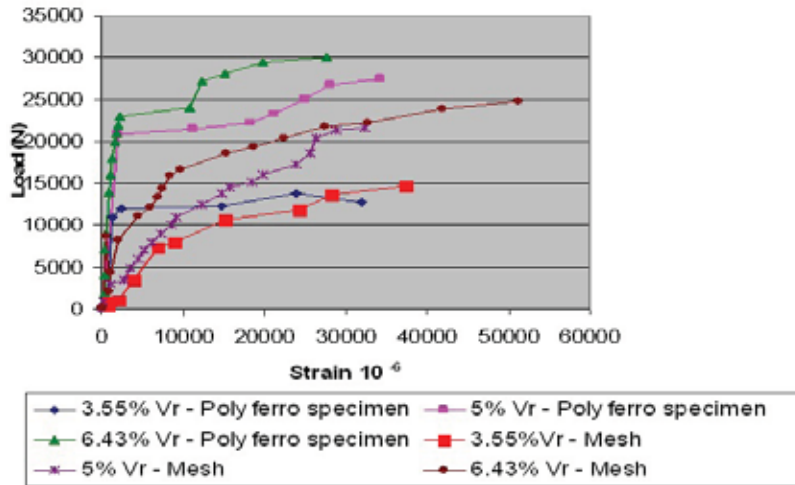
Specimen	Ec (N/mm <sup>2</sup> )	
	Theoretical	Experimental
3.55% Vr	28228	27964
3.55% Vr + SBR	29013	28184
5% Vr	31556	32165
5% Vr + SBR	32215	32436
6.43% SBR	31328	30825
6.43% Vr + SBR	30963	31068

**2.6 Behaviour of Ferrocement under Tension:**

Ferrocement is a highly ductile material and its behaviour in tension is contributed by mortar and also by mesh reinforcement. Results obtained from the tension test on steel mesh reinforcement with different volume fraction are shown in Table: 3. The size of ferrocement specimen and loading setup is designed as in accordance with ACI committee 549. The test conducted for ferrocement with load-strain profile is shown in fig: 6.

**Table 3:** Tension test on steel mesh reinforcement

Vr(%)	Yield stress ( $\sigma_y$ ) N/mm <sup>2</sup>	Ultimate stress ( $\sigma_u$ ) N/mm <sup>2</sup>	Youngs modulus (E <sub>s</sub> ) N/mm <sup>2</sup>
3.55	352	683.42	1.842 x 10 <sup>5</sup>
5	366	698.80	2 x 10 <sup>5</sup>
6.43	354	689.42	1.993 x 10 <sup>5</sup>



**Fig. 6:** Load – Strain profile for SBR ferrocement specimens and meshes

Three stages of behaviour were observed when the ferrocement elements have been subjected to tensile loads.

1. Elastic stage
2. Multiple cracking stage
3. Ultimate stage

In the elastic stage, moduli of elasticity (E<sub>c</sub>) is expressed as

$$E_c = E_m (1-V_r) + E_r V_r$$

Where

E<sub>m</sub> - moduli of elasticity of mortar

E<sub>r</sub> - moduli of elasticity of reinforcement

V<sub>r</sub> - volume fraction of reinforcement

The empirical formula to predict the first crack stress  $\sigma_{cr}$  of ferrocement is

$$\sigma_{cr} = \sigma_{mu} = 25 S_r \text{ (N/mm}^2\text{)}$$

where

$\sigma_{mu}$  – ultimate strength of mortar

$S_r$  – specific surface (mm<sup>2</sup>/mm<sup>3</sup>) in the direction of loading

At this stage, strain  $\epsilon_{cr} = \sigma_{cr} / E_c$

During the multiple cracking stages the contribution of mortar to the stiffness of composite decreases progressively. At this stage the youngs modulus of composite is

$$E_{cy} = E_r V_r$$

Cracking behavior is mainly depending on the volume and dispersion of reinforcement.

$$\sigma_{cy} = \sigma_{ry} \times V_r$$

$$\epsilon_{cy} = \{(\sigma_{cy} - \sigma_{cr}) / E_{cy}\} + \epsilon_{cr}$$

At ultimate stage the load is carried by the mesh reinforcement in the direction of loading. The ultimate strength can be found as

$$\sigma_{cu} = \sigma_{ry} \times V_r$$

where

$\sigma_{ry}$  – yield stress of reinforcement

By use of the above expressions the theoretical values for three stages under tension for three different volume fractions of mesh reinforcement for ferrocement specimens were arrived. Further the experimental results checked for precise with the theoretical values as shown in Table: 4.

**Table 4:** Young's Modulus of ferrocement under tension

Specimen	Ec (N/mm <sup>2</sup> )	
	Theoretical	Experimental
3.55%V <sub>r</sub>	33195	29838
3.55%V <sub>r</sub> + SBR	32619	30024
5%V <sub>r</sub>	35196	31567
5%V <sub>r</sub> + SBR	34628	33226
6.43%V <sub>r</sub>	36927	34446
6.43%V <sub>r</sub> + SBR	36364	35271

**2.7 Crack Spacing and Crack Width of Ferrocement Specimens:**

Cracking behavior is mainly dependent on the volume fraction and distribution of reinforcement. In tensile behavior the crack width is a function of specific surface of the reinforcement, where as in the flexural behavior, the crack width depends on the tensile strain in the extreme layer. Based on observations, the average crack spacing and crack width is calculated using the relation given in BS 8110: Part 2, 1985 as follows:

$$(\Delta_1) = (\theta/\eta) \times l / S_r$$

$$w_{max} = 3500/E_r \text{ for } (\sigma_r \leq 345 S_r)$$

$$w_{max} = 20/ E_r [175 + 3.69(\sigma_r - 345 S_r)] \text{ for } (\sigma_r > 345 S_r)$$

Here  $\Delta_1$  refers to crack spacing,  $S_r$  is the specific surface in the loading direction in mm<sup>-1</sup>,  $w_{max}$  is the maximum crack width in mm,  $\sigma_r$  is the steel stress under service load in N/mm<sup>2</sup>,  $\theta$  is a factor relating average crack spacing to maximum crack spacing and  $\eta$  the ratio of bond strength to matrix tensile strength. (For wire meshes  $\theta/\eta$  was found empirically approximate to unity)

Table 5: shows the theoretical crack width and spacing compared with the experimental results.

**Table 5:** Crack spacing and crack width of ferrocement specimens

Specimen	Crack spacing (mm)		Crack width		No of Cracks
	Theo.	Exp.	Theo.	Exp.	
3.55% Vr	17.97	18.2	0.094	0.132	5
3.55% Vr + SBR	14.87	15.14	0.086	0.091	3
5% Vr	11.32	12.2	0.079	0.083	3
5% Vr + SBR	10.15	10.75	0.071	0.079	2
6.43% Vr	13.24	14.32	0.085	0.087	4
6.43% Vr + SBR	13.95	14.45	0.082	0.091	3

**2.8 Ultimate Strength:**

ACI Committee 549 on ferrocement recommends that theory of conventional reinforced concrete analysis can be used for ultimate strength calculations of ferrocement. The principle of equilibrium and compatibility can be used. Since reinforcement is distributed evenly across the cross section, the analysis is quiet tedious because of the trial and error method. A simplified approach was proposed by P. Paramasivam *et al.* (1998), to compute the ultimate moment by plastic analysis.

$$C = \sigma_{cu} b x$$

$$T = \sigma_{tu} h (h - x)$$

$$\sigma_{tu} = A_s f_y / b h$$

$$T = C \text{ then } Mu = \sigma_{tu} b (h - x) h / 2$$

Using the above analysis, the theoretical Moment – Curvature relations for three different volume fraction of ferrocement specimens was calculated as shown in Fig: 7(a), (b) and (c).

**2.9 Deflection Calculation:**

Experimental Load – Deflection curve of the ferrocement elements show that they can be represented approximately by a tri – linear relation. Accordingly the short term deflection  $\delta$  of the ferrocement element is

$$\delta_{cr} = ( 23 / 216 ) L^2 / \phi_{cr}$$

$$\delta = KML^2 / ( E_c I_g )$$

If  $M < M_{cr}$

$$\delta = KM_{cr} L^2 / ( E_c I_g ) + K (M - M_{cr})L^2 / \alpha E_c I_{cr}$$

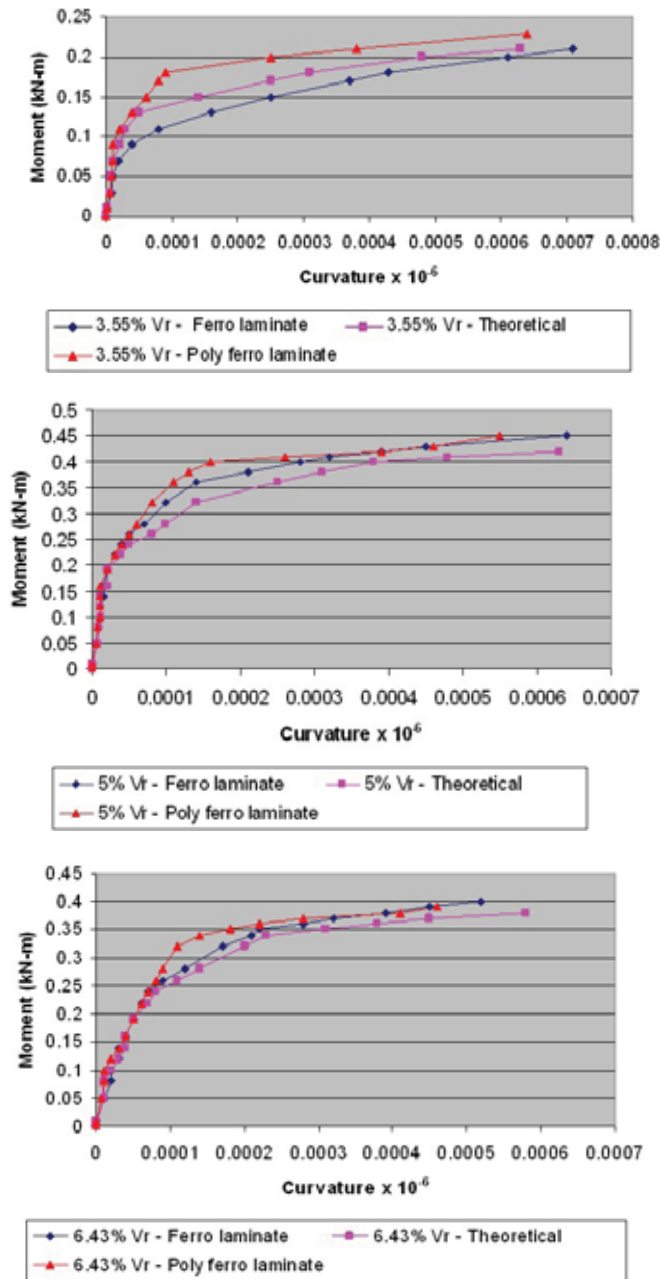
If  $M > M_{cr}$

where M is the applied moment, L is the effective span,  $I_g$  is the moment of inertia of the gross transformed section or gross section,  $I_{cr}$  is the moment of inertia of the cracked section, K is a constant depending on loading and boundary conditions,  $\alpha$  is a constant and  $E_c$  is the modulus of elasticity of mortar ie  $5000\sqrt{f_{cu}}$ . Using this formula, theoretical deflections are calculated for different loading levels and can be compared with experimental values as shown in Fig: 8 (a), (b) and (c).

**RESULTS AND DISCUSSION**

**3.1 Behaviour of Precracked and Rehabilitated Beams:**

The load and deflection due to static load for beams up to failure were recorded and the crack pattern observed for the perfect and the rehabilitated beams are shown in Fig: 9 & 10. The cumulative load deflection curves for rehabilitated beams pertain to precracking of 70% of ultimate load along with perfect beams are shown in Fig: 11. The maximum crack width at the yield stage varied from 0.204 mm to 0.223mm. Of the perfect beams tested the maximum crack spacing was found to be 112mm. For the rehabilitated beams the maximum crack width during the yielding stage varied from 0.132mm to 0.254mm with spacing ranged from 74mm to 96mm at the zone of constant bending moment. The results show that the flexural strength of the beams improved after strengthening by about 13% to 24%. The upper bound correspond to beams with sustained composite action, (BOR3 and BOR4) while the lower values were reported for beams, with early loss of composite action (BOR1 and BOR2). The low level of damage caused to beam prior to repair does not seem to affect its ultimate strength after strengthening. A reduction in the volume fraction of reinforcement (3.55% Vr) in the ferrocement laminate reduced the flexural strength correspondingly.



**Fig. 7:** (a), (b) & (c) Moment curvature relation for SBR ferrocement specimens

**3.2 Evaluation of Overall Performance:**

The overall performance of the rehabilitated beams has been evaluated by considering the equivalent elastic forces using energy and deflection approaches. The effectiveness factors were evaluated using energy ( $F_1$ ) and deflection ( $F_2$ ) approach for the beams as shown in Table: 6.

The equivalent elastic forces  $P_{e1}$  and  $P_{e2}$  are computed as

$$P_{e1} = \sqrt{[2A_e P_y] / \delta_y}$$

$$P_{e2} = P_y [\delta_u / \delta_y]$$

$$F_1 = P_{e1 \text{ (rehabilitated)}} / P_{e2 \text{ (conventional)}}$$

$$F_2 = P_{e2 \text{ (rehabilitated)}} / P_{e2 \text{ (conventional)}}$$

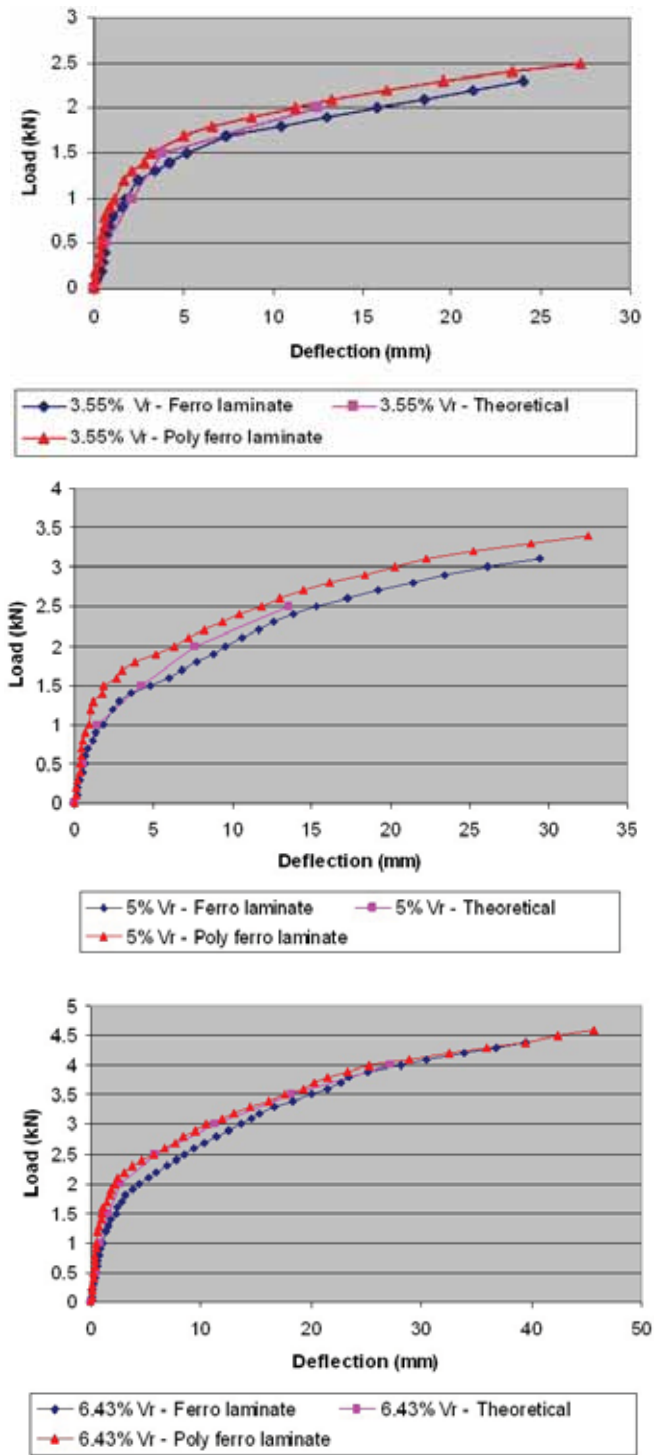


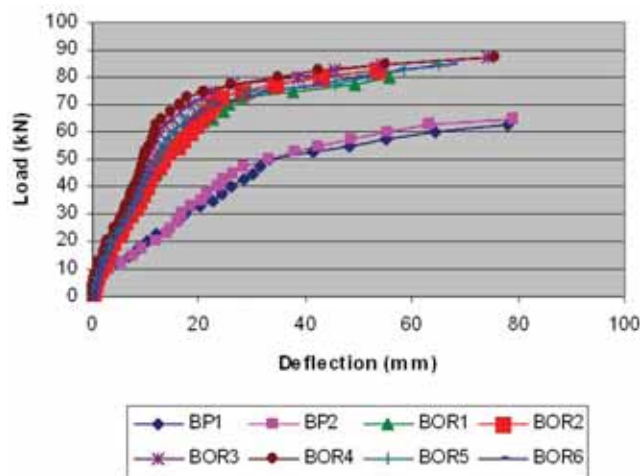
Fig. 8: (a), (b) & (c) Load deflection performances of SBR ferrocement specimens



**Fig. 9:** Typical crack pattern of a perfect beam



**Fig. 10:** Typical crack pattern of strengthened beam after failure



**Fig. 11:** Load deflection behaviours of perfect and rehabilitated beams

The effectiveness factor  $F_1$  for rehabilitated beams varies between 1.15 and 1.58 and  $F_2$  varies between 1.18 and 1.85. It was found that polymer ferrocement with 5% volume fraction exhibits superior performance than the other laminates.

**Table 6:** Effectiveness factor for rehabilitated beams

Beam designation	$P_{y(kN)}$	$P_u(kN)$	$\delta_y(mm)$	$\delta_u(mm)$	$A_{e(mm^2)}$	$P_{e1(kN)}$	$P_{e2(kN)}$	$F_1$	$F_2$
BP1	50	62.5	33.12	78.15	3035.52	95.73	117.98	1.00	1.00
BP2	52.5	65	33.18	78.96	3010.47	97.60	124.94	1.00	1.00
BOR1	72.5	80	28.10	55.75	2410.15	111.52	143.84	1.15	1.18
BOR2	75	82.5	28.05	53.40	2342.54	111.92	142.78	1.16	1.17
BOR3	77.5	87.5	26.20	74.40	3964.55	153.15	220.08	1.58	1.81
BOR4	77.5	87.5	26.10	75.80	3768.69	149.60	225.08	1.55	1.85
BOR5	75	82.5	29.45	65.13	3310.45	129.85	165.86	1.34	1.36
BOR6	72.5	85	29.30	67.52	3390.48	129.53	167.09	1.33	1.37

$P_y$ - load on perfect beam at yield stage,  $P_u$ - load on perfect beam at ultimate stage,  $\delta_y$ - deflection of perfect beam at yield stage,  $\delta_u$ - deflection of perfect beam at ultimate stage,  $P_{e1}$ - equivalent elastic force using energy approach,  $P_{e2}$ - equivalent elastic force using deflection approach,  $A_e$ - equivalent area,  $F_1$ - effectiveness factor using energy approach,  $F_2$ - effectiveness factor using deflection approach.

#### 4. Conclusion:

The variations in compressive strength, split tensile strength and tensile strength of polymer modified mortar among mesh reinforcement with different volume fractions through the above investigations facilitate for rehabilitation of damaged RC beams and on the analysis of the test results leads to the following conclusions:

Better strength can be achieved by adding up 15% of SBR through 5% volume fraction of mesh reinforcement in the polymer ferrocement specimens. The flexural and compressive strength of polymer modified mortars are generally improved over unmodified mortar. While noticing the tensile strength establishes the fact that all the chosen volume fractions of mesh reinforcement hold best results. From this it is clear that, the strength properties are based on the provision of percentage of polymer, volume fraction and the arrangement of reinforcement.

Young's modulus under tension is greater than the value of Young's modulus under compression. Polymer modified ferrocement with 5% volume fraction of reinforcement was higher in its Young's modulus under compression and 6.43% volume fraction of reinforcement being higher under tension. Hence mortar contributes in it's towards the cracking stage and the steel towards the multiple cracking and ultimate stage.

Based on the other properties of ferrocement it has been concluded that it is a low cost and good material to restoring the load carrying capacity of the member. Hence it can be used as a rehabilitation material especially for beams without skeletal steel.

Result from the test program shows that by incorporation of polymers, the mesh reinforcement with volume fraction 5% appropriate for compressive as well as flexural members and 6.43% precise for tensile members.

The performance of the strengthened beams was compared to the control beams with respect to cracking, deflection and ultimate strength. The result show that all the strengthened beams exhibited higher ultimate capacity. A decreased in the volume fraction of reinforcement of the polymer modified ferrocement laminates from 5% to 3.55% resulted in a reduction in strength. The presence of these laminates has an inhibiting effect on the tensile cracks so as the crack spacing and crack width were reduced after strengthening. The deflections, the rebar strains and the crack width in the rehabilitated beams have reduced significantly compared to the perfect beams. Rehabilitated beams exhibit an increase of 85% in its overall performance compared to the perfect beams.

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