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Strengthening of RC Beams Bonded with Acrylic Rubber Latex Modified Ferrocement Laminates

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ABSTRACT

This paper describes the potential of using polymer modified ferrocement as a repairing material with the exhaustive study comprises an experimental and analytical investigation by the influence of preload level on ultimate strength and ductility of polymer modified ferrocement strengthened beams. The beams were reinforced internally with constant amounts of steel and externally with polymer modified ferrocement laminates applied after the concrete had cracked under service loads and were tested under two-point bending. Out of eleven beams tested two were kept as control beams, three were uncracked and laminated; the remaining six beams were preloaded at 70% of the ultimate load with respect to control beam and were rehabilitated. The performance of the strengthened beams was compared to the control beam and the test results revealed that the flexural strengthening of RC beams with polymer modified ferrocement laminates is very effective and allows for significant reduction in concrete strain and mid-span deflection with increase in stiffness. Also, the results of the computational model were in reasonable agreement with the corresponding experimental results.

Keywords : Latex, Mortar, Mesh, Polymer, Volume Fraction

I. INTRODUCTION

Selection of repair material is one of the most important tasks for ensuring durable and trust worthy repair. Though the pre-requisite for a sound repair system is the detailed investigation and determining the exact cause of distress, an understanding of the process of deterioration of the repair materials such as concrete and other auxiliary materials like plastics, resins, under service conditions is vital. Of course, availability of materials by relevance, equipment and skilled labour have to be explored before deciding upon the repair material. Since, cementitious products have a tendency to shrink and hardening with age, it is essential that the repair material for repairing concrete or plaster should be of non shrink type and compatible with parent material. Mineral admixture often has the effect on the brittleness of mortar. In recent years, polymer modified mortars using various polymer dispersions and redispersible polymer powders have widely been used in building construction as finish materials such as repair materials for damage reinforced concrete structures, waterproofing materials, tile adhesives and flooring. The types of polymers generally used in modifying mortars and concretes are either thermoplastic or thermosetting resins which can be classified into three broad groups, namely liquid resins, latexes and water soluble homopolymers and copolymers (Limaye and Kamath 1992). In the preparation of the polymer modified mortars, copolymer latexes are usually employed as cement modifiers to vary mortar properties. Previous studies state that the oxygen diffusion resistance of the polymer modified mortars is superior to that of unmodified mortar with an increase in the polymer cement ratio (Ohama et al 1991). Several studies have been conducted on the use of Ferrocement laminates as flexural strengthening of reinforced concrete beams. Because of its easy application and low cost, especially in developing countries, ferrocement has been used for many years as a repair material for reinforced concrete and masonry elements as an alternative to other expensive ones. It allows rapid construction with no heavy machineries or high-level skilled workers, imposes small additional weight and the cost of construction is low. These unique qualities make the ferrocement as an ideal material for rehabilitation (Khan Mahmud Amanat et al 2007).

Hossain and Awal (2011) observed that the flexural modulus of elasticity of thin cement composite depends on the elastic modulus of mortar and some factor of the difference of elastic modulus of mesh and mortar. For the purpose of improving the flexural behaviour and durability of conventional ferrocement, polymer modified ferrocement has been developed using polymer modified mortars instead of ordinary cement-sand mortars. In seismic areas, ductility is an important factor in design of concrete members under flexure; it is due to the increase in capacity of plastic displacement (Hamid Reza Ashrafi et al 2012). The scope of the work was limited to overloading damage with the study towards strengthening of simply supported reinforced concrete beam attached onto the soffit with polymer modified ferrocement laminate. To evaluate the flexural performance of the strengthened members, it is necessary to study the flexural strength of polymer modified ferrocement strengthened RC members at different stages, such as pre-cracking, post-cracking and post-yielding. Also it has been found that, debonding phenomenon is a major effect for the reduction on the flexural strength. The problem with the surface attaching repairing method is that the repairing sheets or plates tend to be exfoliated from the surface due to bond failure and the material's capacity cannot be fully utilized due to premature debonding (Sang-Kyun Woo et al 2013). By means of this basic the beams were tested to determine the load-deflection and load-strain relationship besides with the ultimate load capacity, showed a considerable increase in ultimate load capacity with good ductility and energy absorption capability.

II. EXPERIMENTAL PROGRAM

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 conform 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 was adopted for plain mortar and 0.3 for the mortars modified with polymer emulsion. A preliminary test program was set up to investigate the mechanical properties of ferrocement with different layers on mesh reinforcement of volume fraction (Vr) towards 3.55%, 5% and 6.43% with influence of polymer modification on the properties of cement mortar. A type of polymer emulsion, acrylic 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. Mortar cubes and cylinders were tested in axial compression for the estimation of mechanical strength using various empirical relationships primarily based on mortar crushing strength. Experimental test were also conducted on mortar plates under two-point flexure with the aim to evaluate the flexure strength. The size of ferrocement specimen and loading setup was designed as in accordance with ACI 549R-97 and the tension test was conducted. The results obtained from the preliminary study on the mechanical properties of polymer modified ferrocement are shown in Table 1. Ultimately to understand the real characteristics of polymer ferrocement composites eleven rectangular RC beams 125mm wide and 250mm deep with a total length measures 3.2m (3m effective) span were casted and tested under static condition with two point loading. The beams were reinforced with 2 nos. of 12mm diameter at tension and 2 nos. of 8 mm diameter at compression side with 22 nos. of 6 mm diameter stirrups spaced 150 mm c/c. The reinforcing bars towards tension and compression had a proof strength of 460 N/mm^2 and 415 N/mm^2 respectively. M20 grade concrete with mix 1: 1.59: 3.12 towards water cement ratio of 0.50 was adopted for all beams. Ordinary Portland cement 43Grade, natural river sand conforming to Zone I and 20 mm size coarse angular aggregate conforming to Zone II (IS 383:1970) were used as ingredients in concrete. The arrangement of beams with their series is shown in Table 2. The principal type of meshes used in the laminate related to their properties is show in Table 3 and the quantity depends on the volume fraction. The arrangement of mesh reinforcement with volume fraction (Vr) of 3.55 percent contributes with 2 layers of welded mesh with 1.51%, 1 layer of woven mesh with 1.44% and 4 layers of twisted mesh with 0.60%. Mesh reinforcement for volume fraction of 5 percent contributes with 2 layers of welded mesh with 1.51%, 2 layers of woven mesh with 2.88% and 4 layers of twisted mesh with 0.60%. Mesh reinforcement for volume fraction 6.43 percent contributes with 2 layers of welded mesh with 1.51%, 3 layers of woven mesh with 4.32% and 4 layers of twisted mesh with 0.60%. Before rehabilitation the original beam was turned upside down to expose its soffit. The surface was then thoroughly cleaned and after surface preparation, the cracks were 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. After curing the beams were subjected to two-point loading. Beams were instrumented with three LVDTs in the testing region to monitor the mid-span and end deflections. The rebars were instrumented with strain gauges to measure rebar deformation. In the testing region, demac gages were bonded to the beam surface, the same level as the longitudinal rebars to measure the crack widths. A microscope was also used to measure the crack width at the rebar location. Load was applied in increments by a hydraulic jack and measured with a load cell. At the end of each load increment, the load was held constant, crack patterns were photographed and near mid-span crack widths were recorded.

Table 1. Mechanical Properties of Polymer Modified Ferrocement

Properties (N/mm^2)	**Volume fraction (V_r)**		
	3.55%	**5%**	**6.43%**
Cube compressive strength	86.22	99.93	93.10
Split tensile strength	7.28	9.70	9.31
Flexural strength	21.21	24.01	23.62
Young's modulus under compression	41349	43982	42198
Young's modulus under tension	39013	41215	42460
Young's modulus for meshes	1.996×10^5	2×10^5	2.032×10^5
Yield strength for meshes	351	352	356

Table 2. Typical Arrangement of Beams on Assessment

Beam code	**Damage level (% P_u)**	**V_r (%)**	**Performance evaluation**
BP1- BP2	-	-	Strength and deformation of perfect beam under static test
ABP1 ABP2 ABP3	- - -	3.55 5 6.43	Effect of uncracked beams strengthened with AR latex modified ferrocement laminates
ABOR1 - ABOR2 ABOR3 - ABOR4 ABOR5 - ABOR6	70 70 70	3.55 5 6.43	Effect on overloading damage of beams rehabilitated with AR latex modified ferrocement laminates

Table 3. Properties of Reinforced Mesh

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

2.1 STATIC BEHAVIOUR OF PERFECT AND REHABILITATED BEAMS

Beam BP1 and BP2 were control beams tested for maximum bearing load under static loading. The test was conducted to establish the load deflection envelope curve as shown in Figure 1, where load was increasing steadily up to failure. Displacements were measured at mid span and at location of applied loads and the cracks were traced at each load increment. The strain was measured at different stages of loading. The crack pattern and failure mode of the beam BP1 and BP2 is shown in Figure 2. The maximum crack width at the yield stage varies between 0.2593mm and 0.443mm for beam BP1 and between 0.263mm and 0.457mm for beam BP2 with the maximum crack spacing of 89mm.

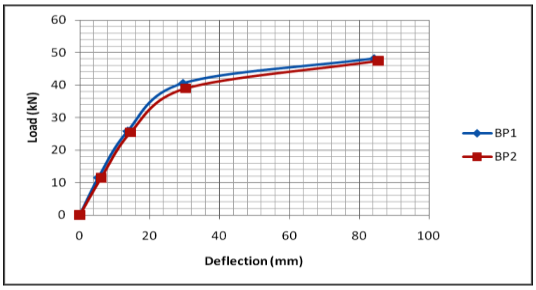

Figure 1 Load-deflection curve for perfect beams

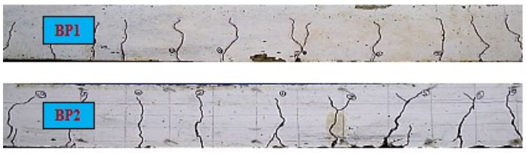

Figure 2 Crack pattern and failure mode of perfect beams

2.2 BEHAVIOUR OF UNCRACKED LAMINATED BEAMS

The uncracked beams ABP1-ABP3 was strengthened with AR latex modified ferrocement laminates to understand their ultimate level in load carrying capacity. A typical set of load deflection curves for these beams along with that of perfect beam BP2 is shown in Figure 3.

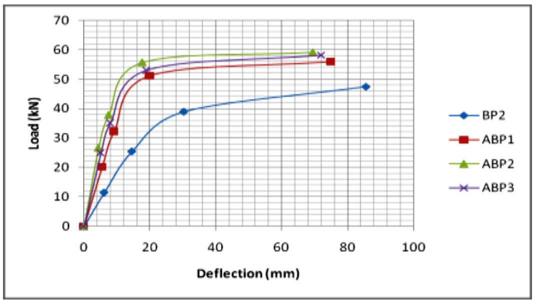

Figure 3 Load-deflection behaviour of uncracked laminated beams

The experimental load deflection curves clearly indicate that bonding of ferrocement laminates to the tension face of the beams have given an improvement in load carrying capacity and reduction in deflection. These responses may be attributed to an increase in lever arm due to bonding of ferrocement laminates and the increase in the composite moment of inertia of the section. The concrete, steel and laminate strains were measured using demec and electrical strain gauges. The load-strain profile for perfect and uncracked AR laminated beams is shown in Figure 4.

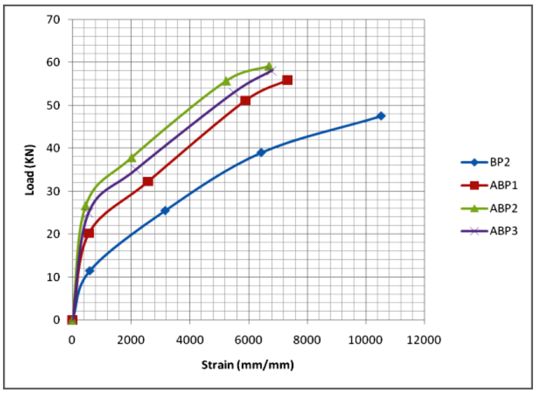

Figure 4 Load-rebar strain profile for perfect and uncracked laminated beams

For uncracked AR latex modified ferrocement laminated beams, the crack width near the yield stage varies between 0.280mm to 0.369mm in the constant bending moment zone. The maximum crack spacing at yield to ultimate stage was found to have 73mm.

2.3 BEHAVIOUR OF PRECRACKED REHABILITATED BEAMS

A typical load deflection plot is as shown in Figure 5 towards load strain plot in Figure 6 for overloaded and rehabilitated beams ABOR1-ABOR6. These precracked beams were bonded with polymer modified ferrocement laminates through three different volume fractions of mesh reinforcements. Overloading of these beams was achieved in terms of ultimate load as obtained with perfect beams (Pu) towards 70% Pu, of the applied level and was tested as per the method adopted on test of the perfect beams.

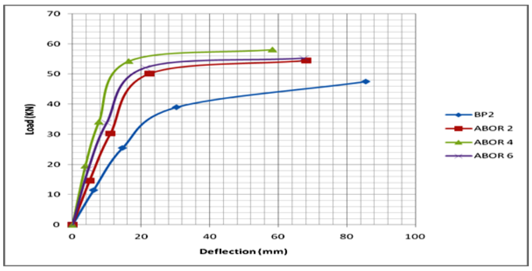

Figure 5 Load-deflection behaviour of precracked rehabilitated beams

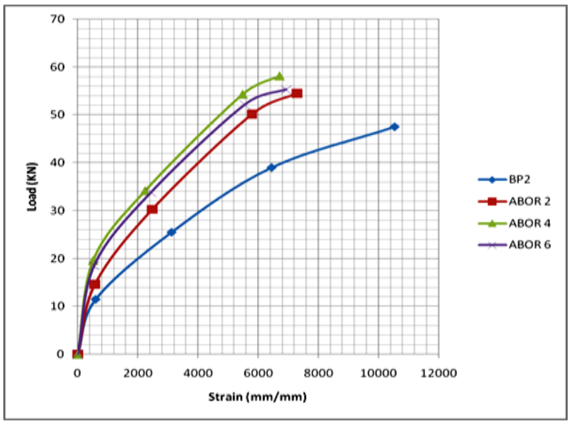

Figure 6 Load-rebar strain profile for perfect and precracked rehabilitated beams

III. NON-LINEAR ANALYSIS

A static non-linear analysis using ANSYS was executed to simulate the behaviour of uncracked and precracked beams strengthened in flexure. An eight-node solid element, Solid65 was used to model the concrete. The solid element has eight nodes with three degrees of freedom at each node, translations in the nodal x, y, and z directions. The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. All the reinforcements were modeled separately using Link 8, a 3D spar element which is a uniaxial tension-compression element. Also, an eight-node solid element, Solid45 was used for the steel plates at the supports in the beam models. The element is defined with eight nodes having three degrees of freedom at each node - translations in the nodal x, y, and z directions.

3.1 ELEMENT FOR POLYMER MODIFIED FERROCEMENT COMPOSITES

A layered solid element, Solid 46 was used to model the polymer ferrocement composites. The element allows for up to 100 different material layers with different orientations and orthotropic material properties in each layer. The element has three degrees of freedom at each node and translations in the nodal x, y, and z directions. The bond between steel reinforcement and concrete was assumed to be perfect and no loss of bond between them was considered in this study. The thickness of the element was modified due to geometric constraints from the other concrete elements in the model. However, the equivalent overall stiffness of this element was maintained by making changes in the elastic module. The geometry and the material properties as adopted during experimentation were used for this study and the analysis was carried out for perfect, uncracked laminated and precracked rehabilitated beams. Figure 7, 8 & 9 show the typical deflected profile of all these beams at various stages of failure.

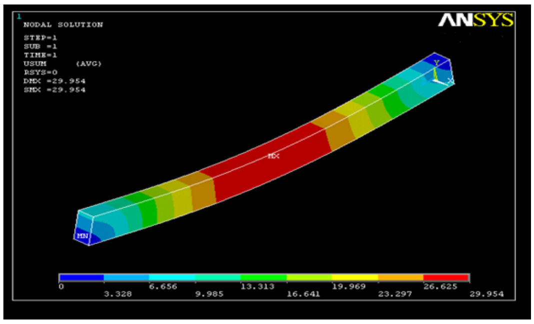

Figure 7 Deflected profile of perfect beam BP2 at yield stage

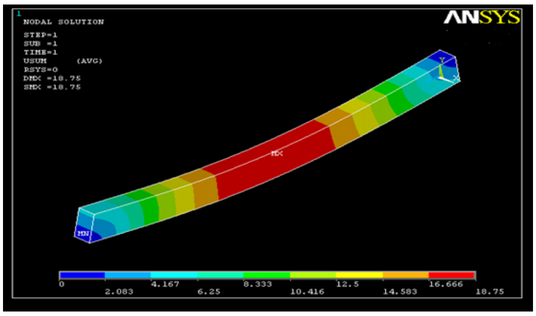

Figure 8 Deflected profile of uncracked laminated beam ABP2 at yield stage

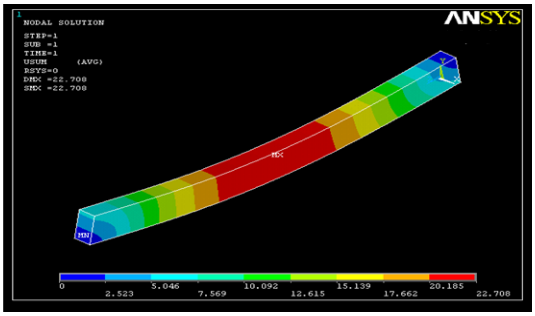

Figure 9 Deflected profile of precracked rehabilitated beam ABOR4 at yield stage

IV. RESULTS AND DISCUSSION

4.1 EFFECT ON BONDING OF POLYMER FERROCEMENT LAMINATES TOWARDS LOAD CARRYING CAPACITY OF UNCRACKED BEAMS

From experimental test results, it is seen that the uncracked beams strengthened by AR latex modified ferrocement laminates of the second series with three different volume fractions exhibit an increase of 76%, 132% and 117% in the initial cracking stage, 27%, 48%

and 38% in the serviceability stage, 31%, 36% and 36% in the yield stage, 18%, 25% and 22% in the ultimate stage towards the load carrying capacity with respect to perfect beam. The experimental results clearly indicate that bonding of polymer ferrocement laminates to the tension face of the RC beams as strengthening material has given an enhancement in load carrying capacity and in particular 5% volume fraction of reinforced laminate performs an outstanding effect.

4.2 EFFECT ON BONDING OF POLYMER FERROCEMENT LAMINATES TOWARDS DEFLECTION OF UNCRACKED BEAMS

Deflection of a beam primarily depends on span, moment of inertia of the section, loading and Young's modulus of concrete. Bonding of polymer ferrocement laminates to the tension face of a beam resulted in an increase in moment of inertia and consequently, the stiffness. From the experimental results, the second series of uncracked beams strengthened with AR latex modified ferrocement laminates of the second series with three different volume fractions exhibit a decrease of 10%, 28% and 17% in the initial cracking stage, 37%, 48% and 45% in the serviceability stage, 34%, 41% and 37% in the yield stage, 13%, 19% and 16% % in the ultimate stage towards deflection with respect to perfect beam.

4.3 EFFECT ON BONDING OF POLYMER FERROCEMENT LAMINATES TOWARDS LOAD CARRYING CAPACITY OF PRECRACKED BEAMS

Test results showed that the load carrying capacities of the beams were higher in the initial cracking stage due to polymer ferrocement mortar strength and thus the restoring effect of the bonded laminates from the initial cracking was clearly seen. The ultimate load level of the rehabilitated beams was greatly improved as towards the bond with polymer ferrocement laminates. The Polymer modified ferrocement laminates with three different volume fractions towards the third series of beams, ABOR1-ABOR6 exhibits an increase of 28%, 70% and 62% in the initial cracking stage, 19%, 34% and 32% in the serviceability stage, 26%, 40% and 34% in the yield stage, 14%, 23% and 16% in the ultimate stage towards the load carrying capacity with respect to perfect beam.

4.4 EFFECT ON BONDING OF POLYMER FERROCEMENT LAMINATES TOWARDS DEFLECTION OF PRECRACKED BEAMS

It may be noticed from the experimental results that the beams repaired and rehabilitated with polymer modified ferrocement laminates with three different volume fractions of reinforcements of the third series ABOR1-ABOR6 exhibit a decrease of 20%, 39% and 25% in the initial cracking stage, 24%, 49% and 33% in the serviceability stage, 27%, 45% and 31% in the yielding stage, 20%, 32% and 22% in the ultimate stage, towards deflection with respect to perfect beam. It was noticed that there is a decrease in deflection with increase load carrying capacity for all the beams tested.

4.5 COMPARISON OF ANALYTICAL AND EXPERIMENTAL LOAD DEFLECTION RESPONSE OF PERFECT, LAMINATED AND REHABILITATED BEAMS

The load deflection plots towards perfect, laminated and rehabilitated beams as obtained analytically were compared with the experimental results to authenticate the study, and are shown in Figures 10, 11 & 12. On the analytical study, the general behaviour of the finite element models represented by the load deflection plots at mid span showed good agreement with the experimental results. However, the finite element models showed slightly more stiffness than the test data ranges. The effects of bond slip in between the concrete and steel reinforcement and also the micro cracks occurring in the actual beams were excluded in the finite element models as they contribute to higher stiffness.

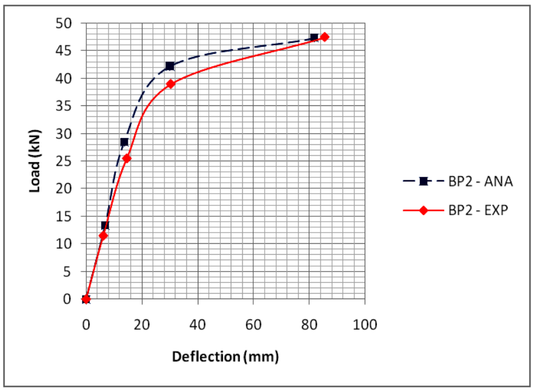

Figure 10 Comparison of analytical and experimental load-deflection response of perfect beam

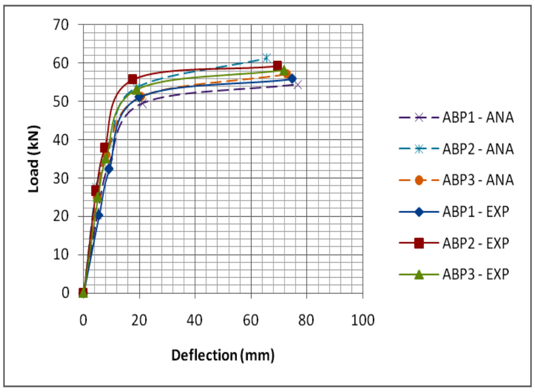

Figure 11 Comparison of analytical and experimental load-deflection response of uncracked laminated beams

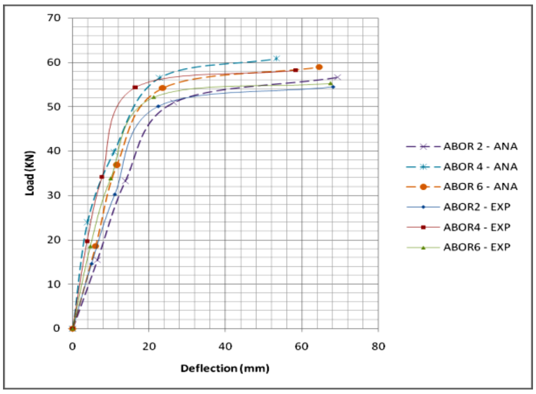

Figure 12 Comparison of analytical and experimental load-deflection behaviour of precracked rehabilitated beams

4.6 DUCTILITY AND ENERGY CAPACITY OF BEAMS

Ductility can be expressed in terms of deformation or energy. The deformation can be measured through deflection, strain or curvature. Generally the ductility of reinforced concrete section may be expressed as the deflection, strain or curvature at ultimate to yield. Energy absorption capacity can be measured under the area of stress-strain curve or through load-deflection curve. Also, the load-deflection showed that repaired and rehabilitated beams by bonding of polymer ferrocement laminates positively influence the overall structural ductility of the beams. The obtained values of ductility and energy absorption capacity for all the beams are presented in Table 4.

Table 4 Performance of Ductility and Energy capacity of Beams

Beam code	Degree of distress	V_r %	Ductility	Energy capacity
BP2	-	-	2.82	4.27
ABP1	-	3.55	3.75	5.33
ABP2	-	5	3.92	5.47
ABP3	-	6.43	3.78	5.41
ABOR1	70% P_u	3.55	3.39	5.28
ABOR2	70% P_u	3.55	3.26	5.22
ABOR3	70% P_u	5	3.84	5.43
ABOR4	70% P_u	5	3.79	5.39
ABOR5	70% P_u	6.43	3.51	5.37
ABOR6	70% P_u	6.43	3.42	5.35

The uncracked laminated beams of the second series ABP1-ABP3 exhibit an increase of 33%, 39% and 34%, the precracked rehabilitated beams of the third series ABOR1-ABOR6 exhibit an increase of 18%, 35% and 23% in ductility with respect to perfect beams. Decrease in ductility was found with an increase of loading in precracked rehabilitated beams. Therefore, the test results confirmed that the beams rehabilitated with polymer ferrocement laminates are extremely ductile. On observing the energy capacity the uncracked and laminated beams of the second series ABP1-ABP3 exhibits an increase of 25%, 28% and 27%, the precracked rehabilitated beams of the third series ABOR1-ABOR6 with an increase of 23%, 27% and 26% in energy capacity with respect to perfect beams. Decrease in energy capacity was found with an increase of overloading in precracked rehabilitated beams.

V. CONCLUSIONS

The experimental results of the RC beams rehabilitated with acrylic latex modified ferrocement as tested in flexure leads to the following conclusions.

1. The beams laminated with acrylic latex modified ferrocement have adequate deformation capacity in spite of their brittle failure modes. Therefore the selection of appropriate types of polymers and volume fraction of reinforcements is the most

important steps in the application of rehabilitation of damaged reinforced concrete beams.

2. Acrylic rubber latex modified ferrocement laminates properly bonded to the tension face of the reinforced concrete beams enhanced the flexural strength substantially with an increase in load carrying capacity and a significant reduction in deflection, rebar strain and crack width as compared to perfect beams.
3. The safe load carrying capacity as well as ductility of these beams with different levels of damage was established. Good ductility and high energy capacity was achieved with total volume fraction of mesh through 5% along with polymer cement ratio of 15%. Further increasing the volume fraction of reinforcement's led to decrease in moment of resistance and an increase in average crack spacing and crack width.
4. The uncracked laminated and precracked rehabilitated beams with polymer modified ferrocement laminates experienced flexural failure. Also it has been noticed that none of the beams exhibit premature failure of the laminate as this helps in preserving a structure from further distress or collapse once the damage parameters are established.

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