Retrofitting of RC Beams using FC Laminates

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***Abstract*: This paper presents the results of experimental investigations done for the flexural strengthening of RC beams using externally bonded ferrocement laminates. A total of twelve beams, belonging to four groups each consisting of three beams, were cast and loaded under two point loading until failure. One group of beams was used as control specimen and the remaining three groups were strengthened using ferrocement laminates. Among the strengthened groups of beams, the reinforcement for ferrocement was chicken mesh for one group. Expanded mesh and welded mesh were used as reinforcements in remaining groups of strengthened beams. Response of all beams were evaluated in terms of strength, stiffness and associated failure modes. The results showed that the strengthened beams exhibited increased flexural strength and enhanced flexural stiffness. The best retrofitting effects were observed when welded mesh reinforcement was used. Expanded mesh reinforcement was observed to be better compared to chicken mesh reinforcement in strength and stiffness point of view.**

Keywords— Retrofitting, Epoxy, external bonding, chicken mesh, expanded mesh, welded mesh.

I. INTRODUCTION

The development of civil infrastructure is one of the main factors that uses the national wealth in the form of money as well as resources. The structures being constructed are required to be long lasting for the sustainable development of a nation. Unless the resources are properly used to design and develop infrastructural systems, it will create negative impact on the economy. In present days new techniques and methods are experimented in the civil engineering field to have better infrastructure. But the rapid deterioration of existing structures has created an urgent need for the development of novel, long-lasting and cost-effective methods for repairing and strengthening [1]. Always complete replacement of buildings is much expensive and will result in the wastage of natural resources, which may be saved or used for other purposes, if the building is more durable. This is why upgrading or strengthening of various structural elements has got much importance. Strengthening means enhancing the structural performance of an existing structure. By strengthening some selected elements, the life of the whole structure may be extended [2]. Strengthening of a structural element can be done by adding some technology, accessory, component or feature to it. This process is termed as retrofitting.

Retrofitting is required for strengthening the components when there is excess loads due to new combination of loads. For example, if a new machinery is installed in the building and the building comes under an instance when imposed load exceeds maximum expected loadings, then there is a possibility of bending failure. In such situations, strengthening is essential for safety. Further, in situations when cracks are formed in the beams, life extension can be achieved through retrofitting [3]. Loading, shrinkage of concrete and micro crack formation at the time of setting etc. are the factors leading to faster deterioration and larger crack formation in concrete members.

The family of reinforced concrete beams is the biggest among the structural element families in a structure in terms of number of members. So the retrofitting of reinforced concrete beams got much importance. Beams are usually retrofitted for shear or flexure strengthening [4]. This study is planned for the flexural strengthening of reinforced concrete beams by retrofitting done at the tension face. Materials having high tensile strength and superior cracking performance can serve the purpose. Materials like steel, fiber reinforced polymers etc. can be used. But these are lacking the fire resisting power. Cementitious composites having better fire resistance may be a solution for that problem. Ferrocement is such a composite which has the properties desired for a flexural strengthening material [5]. This study is aimed to determine the level of strengthening achieved when a ferrocement laminate of small thickness is retrofitted to the tension face of an old beam.

In ferrocement, cement mortar matrix is reinforced with layers of continuous and relatively small diameter wire meshes. While the mortar provides the mass, the wire mesh imparts tensile strength and ductility to the material [6]. In terms of structural behavior ferrocement exhibits very high tensile strength to weight ratio and superior cracking performance. It has many other engineering properties, such as hardness, resistance, impermeability etc.

In this study, three types of reinforcements were used in the ferrocement laminates so as to find the better one among them. A total of twelve beams, belonging to four groups each consisting of three beams, were cast and loaded under two point loading until failure. One group of beams was used as control specimen and the remaining three groups were strengthened using ferrocement laminates. Among the strengthened group of beams, the reinforcement for ferrocement was chicken mesh for one group. Expanded mesh and welded mesh were used as reinforcements in remaining group of laminates.

II. EXPERIMENTAL INVESTIGATION

M_{20} grade concrete mix was selected and designed as per standard design procedure using the properties of materials found. The water-cement ratio used in the design was 0.5. The mix was designed to get a slump value of 100 mm. The mix proportion of material comes out to be 1:2.21:3.81 (cement: sand: aggregate) and compressive strength of the mix obtained by testing cubes after 7 days and 28 days of water curing were 17.62 MPa and 26.58 MPa respectively. Super plasticizer Conplast SP430 was used for better workability of the concrete. A concrete mixer machine was used to produce each batch of concrete.

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RCC beams for the experimental study was designed using M_{20} grade concrete and Fe_{415} Metcon TMT bars. It was designed using limit state method considering it to be an under-reinforced section. The beam was designed as having 2 steel bars of 8mm diameter at both compression face and tension face. The stirrups used were of 6mm diameter, provided at a spacing of 300 mm center to center. The dimension of the beam were fixed to 150mm x 150mm x 1000mm overall. The reinforcement details of the designed beam section is shown in fig. 1.

All the twelve beams were casted in moulds having inner dimensions 150mm x 150mm x 1000 mm. The moulds were prepared out of 8mm thick plywood pieces. First of all the entire beam mould was oiled so that the beam may be easily removed from the mould after the desired period. Spacers of size 25 mm were used to provide uniform cover to the reinforcement. Concrete mix was poured into the mould after the bars have been placed in position. Then vibrations were given using a needle vibrator until the mould was completely filled. Level the concrete in the mould and finish the surface. The beam was then removed from the mould after 24 hours. Then demoulding was done and the beam was cured for 28 days in the water tank. After curing period, the beams was taken out. It was kept exposed to the atmosphere so that the surface become dry.

Ferrocement laminates were prepared by adding cement mortar mix to the multiple layers of wire meshes placed in the pre-prepared moulds. The meshes used were welded square mesh, expanded mesh and hexagonal chicken mesh. The number of layers of meshes used depends on the volume fractions to be provided. Welded meshes were provided in eight layers and the number of layers of expanded meshes and chicken meshes were 13 and 15 respectively. The overall size of the laminates were fixed to 150 x 25 x 850mm. The meshes obtained in rolls of mat were cut into required dimensions using a cutting machine. The desired number of layers were tied using binding wire. After oiling, the multi layered meshes were kept in the mould and mortar of high fluidity was filled in it. The proportion of cement – sand mortar used for the ferrocement sheets was 1:2 (cement: sand) and the water-cement ratio for mortar taken was 0.40. 2% superplasticizer was added to ensure the fluidity of the mortar. After 48 hours, the moulds were removed and the laminates are kept under water in the curing tanks for 28 days of curing.

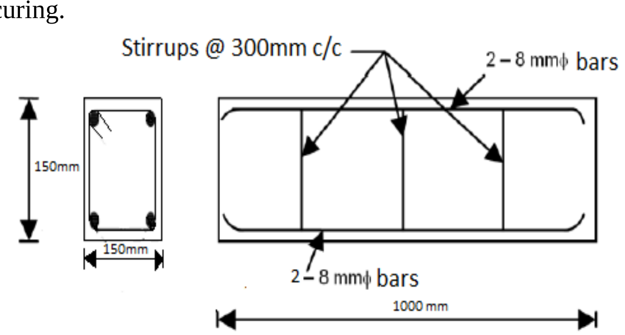

Fig. 1: Reinforcement Details

Usually retrofitting was done on a beam existing in an old building. Such a beam may or may not contain some sort of cracks. But it must have been applied with certain amount of loads. In the experimental case, the beams were freshly prepared and they were not applied with any type of loads. If such beams were used, the experimental results would have shown some variations from the actual effects of retrofitting. Thus to make the fresh beams prepared to resemble the preloading conditions of an older beam to be strengthened, a preloading was applied on the fresh beams casted. The magnitude of preloading applied was taken as equal to 90% of the design load for all the casted beams, which might not be applied under the service conditions of the actual beam. The loading was done for all the beams using a universal testing machine. Two point loading was used to preload the beams casted. Before placing the beam on the machine, clear span of 900mm was set up on the machine. Markings were done to fix the position of the supports and load points on the beam. The beam loading details of the beams are shown in fig. 2. After the application of the initial loads, the slightly cracked beams were unloaded. Then it was observed that the cracks formed were not seen well on the beam surface. So to get a better view of the crack profile formed on the beams, the side faces of the beams were cleaned and painted to white.

The next step was retrofitting. It was done by the help of an epoxy binder named 'Nitobond EP', which was a product of forsoc chemicals. It was a two part epoxy, for which to impart the binding property, two components were required to be mixed thoroughly. The components were base material of white colour and hardener of brown colour. Hardener was added to base material, mixed well to form a uniform paste of green colour. This paste was to be applied on the prepared beam surface using a brush, as shown in fig. 3.

Surface preparation was required to have a better bond between the beam and laminate. For that, the binding surface of beam as well as laminate was roughened using some sharp edge tool. The roughened surface was cleaned and washed well to remove the dust and oil particles from the surface. Then the surface was allowed to get dried. After surface preparation, the adhesive paste prepared was applied to the surface using a painting brush. Care was given to use optimum quantity of adhesive. The application of excess and lesser quantities of the epoxy could have resulted in inefficient bonds. Laminates already cast and surface prepared were placed over the beam and held in position by dead weights. Care was given to avoid the trapping of air bubbles along the bond line. A curing time of seven days was necessary to get the components bonded.

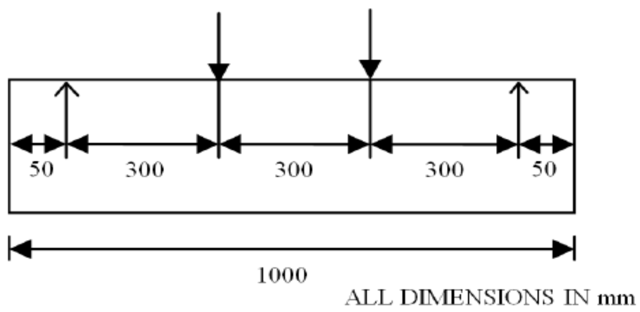

Fig. 2: Loading Details

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Fig. 3: Epoxy Pasting

Testing of beams was done by using universal testing machine. The loading applied was two point loading. Four set of beams, each set consisting of three beams were tested. One set was control specimens and the remaining three sets were consisting of strengthened beams. The testing setup used for the loading of control beams and strengthened beams are as shown in fig. 4 and fig. 5 respectively.

A clear span of 900mm was set up on the machine. Markings were made on the beam at 50mm distance away from both ends to fix the position of the supports and 300mm away from the supports to fix the position of the loading points. Control beams as well as strengthened beams were loaded to failure. The deflection of the beam under the loading was recorded by using a dial gauge at mid span for each 10kN increase in load. The crack formation, ultimate loads and mode of failure were observed. The values recorded were tabulated to arrive at appropriate results and conclusions.

The mode of failure of control beams was observed to be flexural failure as shown in fig. 6, while the mode of failure of the retrofitted beams was observed to be a combination of flexural and de-bonding failure for laminates using welded mesh and expanded mesh as shown in fig. 7. And mode of failure was observed to be flexural failure for laminates using chicken mesh as reinforcement as shown in fig. 8.

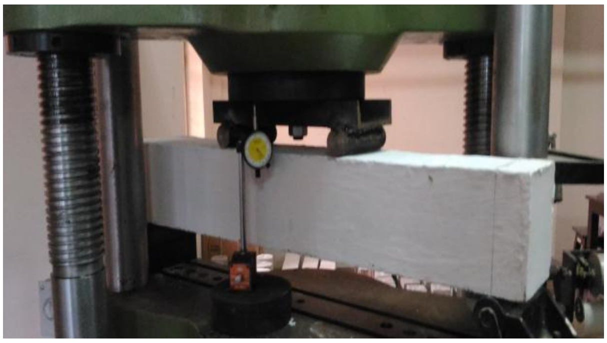

Fig. 4: Testing Setup for Control Beams

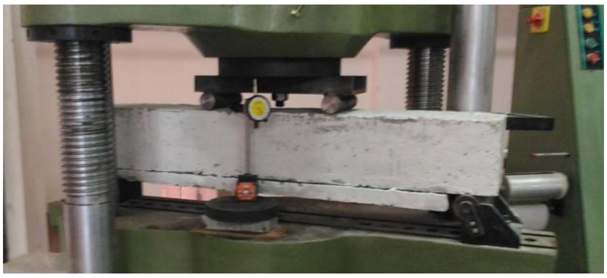

Fig. 5: Testing Setup for Strengthened Beams

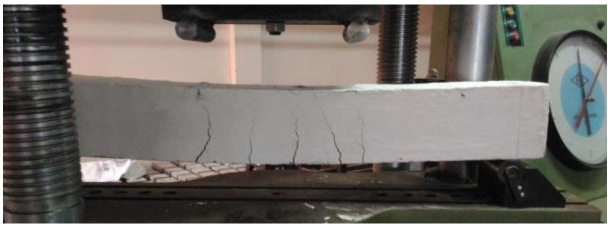

Fig. 6: Bending Failure of Control Beams

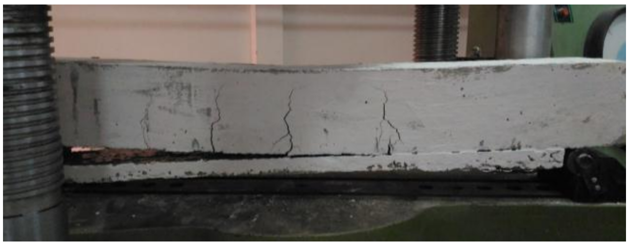

Fig. 7: Combined Bending & De-bonding Failure

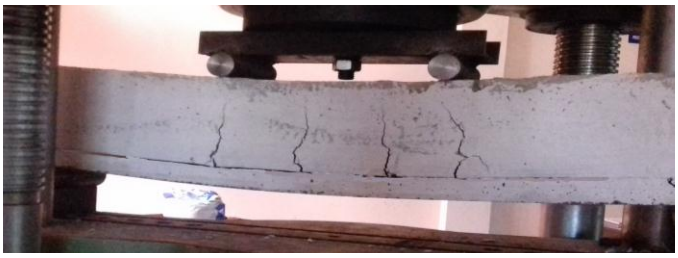

Fig. 8: Bending Failure of Strengthened Beam

III. RESULTS

The dial gauge readings for each beams in a set were recorded and deflections were computed. This procedure was followed for all the four sets of beams and the average values were tabulated as shown in the table I. The average value of ultimate loads obtained were also included in the same table. The load-deflection graphs for each set was drawn for the average deflections obtained. The comparison of the slope-deflection curve in the four cases are shown in the fig. 9. The terms A1, A2, A3 and A4 in the table and graph represents the average deflection values of control beams, chicken mesh laminated beams, expanded mesh laminated beams and welded mesh laminated beams respectively. The steepness of the curve represents the stiffness of the beams.

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TABLE I. AVG. DEFLECTION VALUES

Load(kN)	A1(mm)	A2(mm)	A3(mm)	A4(mm)
10	0.020	0.010	0.010	0.010
20	0.263	0.036	0.030	0.013
30	1.236	0.816	0.390	0.326
40	3.143	1.836	0.816	0.643
50	5.560	3.456	1.906	1.680
60	-	4.866	2.986	2.786
70	-	6.543	3.820	3.633
80	-	-	4.830	4.613
Avg. Ultimate Load (kN)	52.33	74.33	80.33	84.33

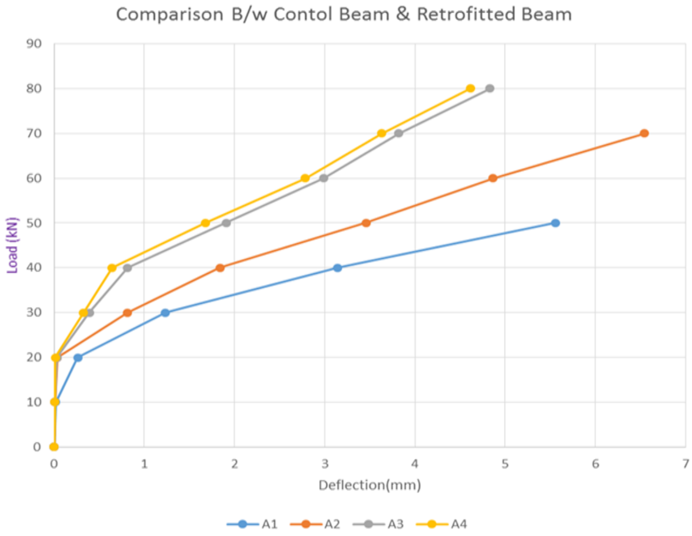

Fig. 9: Load – Deflection Comparison

From the graphs, it is clear that stiffness is improved in a best manner in the case of welded mesh laminated beams, although all reinforcements were found to be useful in increasing the stiffness. Expanded mesh was found to be better when compared with chicken mesh retrofitting. From the observations of the ultimate loads, it was clear that all the techniques were useful in the strengthening point of view. Welded mesh reinforcement was found to be the best. Expanded mesh was found to be better compared to chicken mesh. So it can be concluded that the retrofitting of simply supported reinforced concrete beams using externally bonded ferrocement laminates is a good method for the RC beam strengthening.

IV. CONCLUSIONS

- Ferrocement laminates can be successfully used to strengthen reinforced concrete beams in flexure.
- Among the laminates used, laminates using welded mesh has given better performance against load and deflection. Usage of expanded mesh reinforcement was found to be more dependable compared to usage of chicken mesh reinforcement.
- 61% improvement in ultimate strength was observed when welded mesh was used. Strength improvement achieved when expanded mesh and chicken mesh reinforcements used were 53.5% and 42% respectively
- At any given load level, the deflections are reduced significantly and thereby increasing the stiffness for the retrofitted beams. Maximum stiffness was achieved on using welded mesh reinforcements.
- Expanded mesh reinforcement was found to be better than chicken mesh reinforcement in terms of strength and stiffness.

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