

Retrofitting of RC Beams with Externally Bonded Laminates- A Comparative Study

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ABSTRACT: The cost of civil infrastructure constitutes a major portion of the national wealth. The rapid deterioration of reinforced concrete structures has thus created an urgent need for the development of cost-effective methods for repair, retrofit and new construction. In this report, experimental study concerning the flexural strengthening of RC beams using externally bonded laminates and with ferro cement were done. A total of five reinforced concrete beams were casted and tested in the laboratory over an effective span of 500mm. Four beams were retrofitted with externally bonded SIFCON, Polypropylene, HFRC laminates and Ferro cement under virgin condition and tested until failure. The remaining one beam was used as control specimen. Static responses of all the beams were evaluated in terms of flexural strength. Comparison was made between the Control specimen and retrofitted beams.

KEYWORDS: RCC, Retrofitting, Ferro cement, SIFCON, Polypropylene fibres, Flexural strength.

I. INTRODUCTION

Retrofitting means structural strengthening of a building to a pre-defined performance level, whether or not an earthquake has occurred. The seismic performance of a retrofitted building is aimed higher than that of the original building. [8]. Due to the variety of structural condition of building, it is hard to develop typical rules for retrofitting. Each building has different approaches depending on the structural deficiencies. Hence, engineers are needed to prepare and design the retrofitting approach [4]. The methodology adopted for these should be simple in execution, offer better performance even when handled by less experienced workers, must involve materials which are readily available and yet durable, strong and economical. And hence the choice of the strengthening system depends on the specific performance requirement [6]. This project deals with retrofitting RC beams with three materials such as steel fibre, polypropylene fibre and ferro cement and comparing their flexural strength. SIFCON is a high performance, high strength material containing relatively high volume percent of fibres compared to steel fibre reinforced concrete [2]. In SIFCON, fibres are placed in the mould and infiltrated with cement based slurry [3]. Ferro cement is a composite material consisting of rich cement mortar matrix uniformly reinforced with one or more layer of very thin wire mesh with or without supporting skeletal steel [10]. With the distribution of small diameter wire mesh reinforcement over the entire surface, a very high resistance to cracking is obtained and other properties such as toughness, fatigue resistance, impermeability also get improved [9]. Polypropylene is a synthetic hydrocarbon polymer, the fibre of which is made using extrusion processes by hot-drawing the material through a die [7]. Polypropylene is more effective in the tension than compressive strength due to the adhesive and friction forces between concrete paste and Polypropylene fibres [5].

II. MATERIALS USED

II.A Cement

Ordinary Portland cement of 43 grade with brand name ULTRATECH cement was used. The properties of cement like specific gravity, initial setting time and normal consistency was found to be 3.14, 126 minutes and 31% respectively.

II.B Aggregates

II.B.a Fine aggregate

Locally available M-sand was used as fine aggregate. The specific gravity of fine aggregate was found to be 2.46.

II.B.b Coarse Aggregate

Machine crushed angular shaped, maximum 12mm size aggregate was used. The specific gravity of coarse aggregate was found to be 2.4 and its water absorption was 0.55%.

II.C Water

Water used in concrete and cement slurry is clean and free from oils, acids, alkalis, salts and other organic materials. Potable water with pH value not less than 6 is generally considered to be satisfactory for mixing concrete.

II.D Admixtures

The admixtures used in cement slurry for SIFCON and polypropylene laminates were CONPLAS and micro silica. CONPLAS is used for improving the workability with reduced water cement ratio and to have adequate fluidity in order to facilitate the construction of specimens. Micro silica or silica fume is an excellent admixture for concrete as it leads to better engineering properties. It reduces thermal cracking, improves durability and strength.

II.E Steel bars

Fe415 steel bars were used for reinforcing the beams of size 50cmx10cmx10cm. Bars of 8mm and 6mm diameter were used for all the beams. 8mm diameter bars were used as tension reinforcement and compression reinforcement while 6mm diameter bars were used as shear stirrups.

II.F Fibres

II.F.a Steel Fibres

Crimped steel fibres of 0.5mm diameter with aspect ratio (L/D) 60 were used in the study. The density of the fibre was 7850 kg/m³. The fibres used for the study is shown in Fig 1.

II.F.b Polypropylene fibres

Polypropylene fibres are readily available in the market in the standard dimensions. Fiber of length 12mm with specific gravity 0.92 and density 930 kg/m³ was used. The fibres used for the study is shown in Fig 2.



Fig.1 Crimped steel fibres



Fig.2 Polypropylene fibres



Fig.3 Square mesh

II.G Meshes

Square meshes of opening 16mm x 16 mm was used in ferro cement for retrofitting the RC beam as shown in Fig 3. Each wire of the mesh has 0.8 mm diameter.

III. EXPERIMENTAL WORKS

As the main aim of this project is to increase the serviceability of an ordinary beam by retrofitting it with the above mentioned techniques, initially an ordinary beam is tested in flexural testing apparatus to determine its ultimate load and flexural strength. The test specimens were subjected to a safe percentage of ultimate load of standard specimen. Then the test specimens were retrofitted with above mentioned materials in order to verify the increase in load carrying capacity.

III.A Casting of RC Beams

Five reinforced concrete beams of 50cmx10cmx10cm were used for the study. The concrete ingredients were proportioned as per M20 concrete mix ie; 1:1.5:3 with water cement ratio 0.5. The cement, fine aggregate and coarse aggregate were first mixed in dry pan. Water proof wooden moulds were used to cast all the beams. Before placing the concrete in the mould, its interior surface and the base plate were oiled. Steel reinforcement cages were placed inside

the wooden frame (Fe 415 steel with two 8mm diameter bars each at compression and tension face and 6mm diameter stirrups for shear reinforcement). Concrete was placed in layers and adequate compaction was carried out. After 24 hours the beam specimens were de-moulded and cured for a period of 28 days.

III.B Casting of Laminates

SIFCON laminates of size 50cmx10cmx2cm were casted for the bottom face. Steel fibres were used for this purpose and fibre volume was 8%. The cement sand ratio and water cement ratio was 0.5 and 0.3 respectively. Micro silica was used as super plasticizer with its cement ratio 0.025. Wooden moulds of required size were made to cast the laminates. Initially moulds are coated with oil for the easy removal of specimen. The fibres were placed inside the mould manually and the cement sand slurry prepared in the meantime was then poured into the mould evenly above the preplaced fibres. The specimen is removed from mould after 24 hours of casting and was allowed to cure for a period of 28 days.

Polypropylene and HFRC laminates of size 50cmx10cmx2cm was also casted in the same way as SIFCON laminates. Polypropylene fibres were used instead of steel fibres in polypropylene laminates. In HFRC laminates both steel fibres and polypropylene fibres were mixed simultaneously in equal proportion. Finished laminates were kept for 28 days curing.



Fig. 4 Casted Beams



Fig.5 Placing steel fibers



Fig.6 Casted Laminates.

III.C Loading of RC Beams

In most field applications, beams are subjected to bending stress, at least partially. Hence, the behaviour under flexural loading plays an important role in field applications. The following procedure is adopted to conduct the flexural strength test.

- The size of the casted specimen was 50cmx10cmx10cm. The beam was cleaned and placed on the flexural testing machine.
- The square bearing plates were placed on the beam and adjusted to a certain distance by means of guide plates.
- A stripe of leather or similar material was placed under bearing plate to assist in load distribution.
- A contact is established between the plunger and ball on the bearing bar, and set the initial dial gauge reading as zero.
- Two point load was applied to the beam specimen until it breaks and the failure load was noted.

Computation of flexural strength is as follows,

$$\text{Flexural strength} = \frac{FL}{BD^2}$$

where, P = Load in kN; L = Effective length of beam = 400 mm; B = Width of the beam = 100 mm; D = Depth of the beam = 100 mm

The breaking load of control specimen was 43kN. The other four beams were stressed with 80% of the safe load obtained from the testing of control beam. And then the distressed beams were retrofitted with the 20mm thick ferrocement jackets and laminates.

III.D Retrofitting

III.D.a Retrofitting with Ferro Cement

A rough layer of mortar was applied on bottom and two sides of beam. Square wire mesh was wrapped around the beam in "U" shape. Mortar matrix with cement sand ratio 1:2 and water cement ratio 0.4 was applied on the three faces of beam with wire mesh covering. The thickness of mortar was 20mm. After 24 hours the specimen was cured for 28 days.



Fig .7 Applying mortar over wire mesh

III.D.b Retrofitting with laminates

After 28 days of curing all the laminates were bonded to the tension face of distressed beams using Araldite, a strong bonding agent. A bond line of 2.0mm thickness was kept constant for all specimens. After bonding leave the beams undisturbed for 7-14 days to ensure maximum bonding.



Fig.8 Araldite applied at the bottom face of distressed beam

III.E Testing of Retrofitted Beams

The retrofitted beams were tested with the same procedure as adopted during the testing of control beams to calculate the ultimate load and the corresponding flexural strength. Fig (9), (10), (11) and (12) shows the crack developed on beams retrofitted with ferro cement, SIFCON, polypropylene and HFRC respectively after testing.



Fig. 9 Crack developed on Ferrocement after testing



Fig. 10 Crack developed on beam retrofitted with SIFCON Laminate



Fig.11 Crack developed on beam retrofitted with Polypropylene Laminate



Fig .12 Crack developed on beam retrofitted with HFRC Laminate

IV. RESULTS AND DISCUSSIONS

The overall results of flexural strength of beams retrofitted with different materials are shown in Table .1.

- Concrete beam retrofitted with Ferrocement yields higher flexural strength than ordinary beam and the percentage increase in flexural strength compared with beam without retrofitting is found to be 93.02%.

Table. 1 Overall result of Flexural Strength

| Retrofitting techniques | Flexural strength (MPa) | Percentage increase of flexural strength with respect to the beam without retrofitting |
|--|-------------------------|--|
| Beam without retrofitting | 17.2 | 0 |
| Beam retrofitted with SIFCON | 26.4 | 53.48 |
| Beam retrofitted with Ferrocement | 33.2 | 93.02 |
| Beam retrofitted with Polypropylene fibers | 24.2 | 40.69 |
| Beams retrofitted with HFRC | 25.6 | 48.83 |

- Concrete beam retrofitted with SIFCON yields higher flexural strength than ordinary beam and the percentage increase in flexural strength compared with beam without retrofitting is found to be 53.48%.
- Concrete beam retrofitted with Polypropylene laminate yields higher flexural strength than ordinary beam and the percentage increase in flexural strength compared with beam without retrofitting is found to be 40.69%.
- Concrete beam retrofitted with HFRC laminate yields higher flexural strength than ordinary beam and the percentage increase in flexural strength compared with beam without retrofitting is found to be 48.83%.

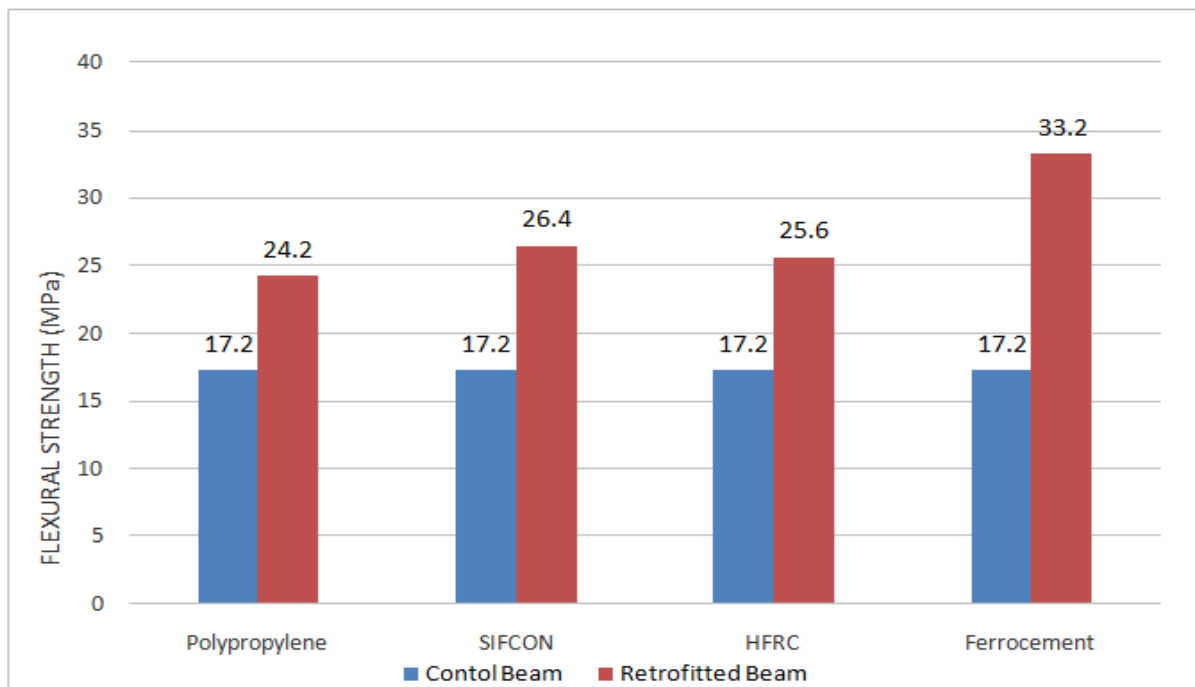


Fig.13 Variation in Flexural Strength for different Retrofitting Techniques

V. CONCLUSION

From the experimental study conducted, it can be concluded that retrofitting with materials such as SIFCON, polypropylene fibres, HFRC and ferro cement significantly increases the flexural strength of distressed beams. In RCC beam, failure was followed by the development of a single main crack which propagates from bottom to top and it is found that by the addition of small, closely spaced and uniformly distributed fibres in laminates, cracks can be arrested to a great extent and also uniform reinforcement in ferro cement helps in developing multiple cracks and thus increasing the yielding of the specimen.

Among the various techniques adopted, retrofitting with ferro cement shows high flexural strength compared to other materials. This is because by the application of varying intensity load, ferro cement behaves as a linearly elastic material in the initial stages and further increase in load creates multiple cracks within the specimen and this continues until the wire mesh get yielded. With the yielding of mesh the crack width starts increasing and finally the specimen fails. In case of SIFCON, varying intensity load was found to bear by the bridging of steel fibres. Even though it has high ductility the failure of composite is mainly due to fibre pull out rather than fibre yielding.

The composite of two fibres i.e.HFRC shows an intermediate result of SIFCON and polypropylene fibres. Polypropylene fibres due to its low modulus of elasticity than steel fibres show a reduction in the flexural strength.

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