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Experimental Study on Reinforced Concrete Beam Strengthened & Retrofitted with GFRP Sandwich Panels

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Abstract

This paper presents the flexural behavior of strengthened and retrofitted reinforced concrete beam by providing the GFRP sandwich panels at the soffit of the beam. Totally three sets of beam with each two numbers were cast and tested for the performance of flexural behavior. In the first set of beams, control and strengthened beam (bonded with GFRP sandwich panels) were compared for the performance of flexural behavior. In the second set of beams, control and retrofitted beam (bolted with GFRP sandwich panels) were compared for the performance of flexural behavior. In the third set of beams, control and strengthened beam (bonded & bolted with GFRP sandwich panels) were compared for the performance of the flexural behavior. The experimental results indicated that the load carrying capacity of the beams were increased by 15.65%, 5% and 24.39% for the strengthened beam in first set, retrofitted beam in second set & strengthened beam in third set respectively on comparison with their respective control beams.

Keywords: GFRP sandwich panels, flexural behavior, strengthening, soffit

INTRODUCTION

The IS codes used for designing the building elements were proposed for a life span of 50 or 100 years. It has been observed that the functioning of the structural members in the past few decades were not able to provide a suitable serviceability to the occupants inside the building till the design life period. The member was getting deteriorated due to environmental exposure, overloading, usage of low quality materials, quality of workmanship etc. Due to the defect of a single or various elements in the structure, entire building cannot be demolished and a new building cannot be constructed which will be uneconomical in that case the defective member has to be retrofitted (Bruhwiler, 2012) by adding an additional member to the existing member. Earlier steel jacketing was done for strengthening the member and after the existence of composite materials, steel jacketing was replaced by the composite materials which were less in self-weight and economical when compared with the traditional method. In this paper the strengthening of RC beam was done with GFRP composite sandwich panels in which the skin is rigid and core is flexible. The GFRP sandwich panels can also be used for reducing the beam depths while designing the beam since nowadays Architects were restricting the beam depths for the aesthetical purposes of the building.

The GFRP composite sandwich panels were placed at the soffit of the beam. On applying the load to the concrete beyond the yield point, the bottom portion starts yielding leading to the formation of cracks. If the bottom portion is unable to restrain the tension which it indirectly means that the beam is overloaded. In order to reduce the crack propagation and for retrofitting of the beam the GFRP sandwich panels will be provided at the soffit as they are strong in tension. The GFRP is economical when compared to CFRP. There are two types of beam strengthening with FRP composites (i) Externally bonded (Mosallam et al, 2000 & 2007) & (ii) near surface mounted (Almusallam TH et al, 2012) techniques. In this paper the beam was strengthened by externally bonded technique.

EXPERIMENTAL WORKS

Materials used for GFRP sandwich panels

Releasing Agent :

The releasing agent used for laminating the GFRP laminates is Mansion Wax polish for easy removal of GFRP laminates from the mould after the curing period of the laminates.

Glass Fibre :

For GFRP laminates, bidirectional E glass fibre were used for laminating the GFRP sheets. The thickness of E glass fibre is 0.5mm and the density for the same is 600gm per square metre. The GFRP laminates were used as rigid materials at top and bottom layers of the GFRP sandwich panels.

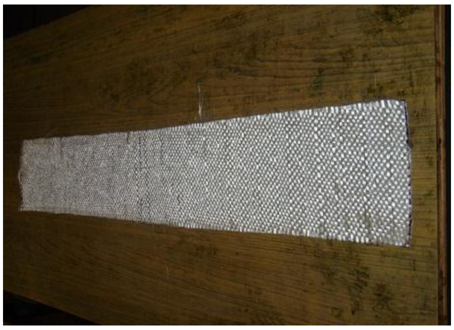

Figure 2. Glass Fibre

Polyester Resin:

For laminating the E glass fibres, polyester resin was used along with cobalt naphthalene & Methyl ethyl ketone peroxide which were used as a catalyst and accelerator respectively. As per the manufacturer's specification, for 1 part of resin, 0.1 part of catalyst & accelerator were used.

Foam:

The centre core material used for the GFRP sandwich panels was foam of 10mm thick. Polyester resin is used for bonding the top and bottom of the foam to the laminates for the arrangement of GFRP sandwich panels.

Fabrication of GFRP Laminates

The GFRP laminates were fabricated using the hand layup process. Two layers of E glass fibres were used for the laminates. The releasing agent is applied at the bottom of the surface for the easy removal of laminates from the surface. Over the releasing agent, resin was poured equal to the weight of the glass fibre and the glass fibre was placed over the resin. The similar procedure was used for the second layer as well. Finally the laminate was removed after the setting of the resin in the fibres. Table 1 shows the details of materials used for the fabrication of laminates for beams.

Material Testing

The material testing for the GFRP sandwich panels were carried out to determine the mechanical properties of the same. The laminates were cut to the size of 250 x 25mm and foam was placed in between top and bottom laminates. The testing was done as per the method followed by the modifications of Moody & Anthony to determine the material properties of the GFRP sandwich panels (Ayman Mosallam et al, 2015). Yield stress, tensile strength & young's modulus were determined for the GFRP sandwich panels. Five samples were tested in Composite technology center located at Indian Institute of Technology, Madras. The samples were shown in figure 3.

Figure 3. Samples for material testing

The samples were tested in Composite universal testing machine and the test setup for material testing of GFRP sandwich panel is shown in figure 4.

Figure 4. Test setup for material testing

The Yield stress, tensile strength & young's modulus determined from the testing of the samples were tabulated in the table 2

Casting of beams

A total of six beams were cast for investigating the flexural load carrying capacity. Based on the material properties of cement, sand & coarse aggregate the design mix was done for the M30 grade concrete as per ACI 211 for casting all the beams. Based on the availability of resources in the laboratory, the beams were cast in the dimension of 150mm width, 200mm depth & 1200mm length. Reinforcement provided for the beams were two numbers of 12mm diameter at the bottom as a main bars & two numbers of 10mm at the top as a hanger bars. Stirrups were provided at a spacing of 100mm centre to centre throughout the beam. The beams were cast in such a way that maximum strain value of steel should reach prior to the maximum strain value of concrete.

Table 1. GFRP Fabrication details

Laminates for	**Weight of fibre (1st layer) in (grams)**	**Weight of fibre (2nd layer) in (grams)**	**Resin for each layer in (grams)**	**Catalyst for each layer in (grams)**	**Accelerator for each layer in (grams)**
Material Property Testing	121.65	116.28	121.65	12.16	12.16
Beam B1 for top	97.28	96.71	97.28	9.73	9.73
Beam B1 for bottom	95.72	95.56	95.72	9.57	9.57
Beam B4 for top	96.46	89.01	96.46	9.65	9.65
Beam B4 for bottom	97.78	95.04	97.78	9.78	9.78
Beam B6 for top	98.93	97.24	98.93	9.89	9.89
Beam B6 for bottom	99.23	92.07	99.23	9.92	9.92

Table 2. Mechanical Properties of GFRP sandwich panels

Sample Labels	Yield Stress (Mpa)	Tensile Strength (Mpa)	Young's Modulus (Mpa)
GFRP 1	18	23	2747.25
GFRP 2	17	19	2747.25
GFRP 3	12	18	915.75
GFRP 4	17	20	2747.25
GFRP 5	19	23	2747.25

The grade of steel used for reinforcement is Fe415.The cross section of the beam were shown in figure 5

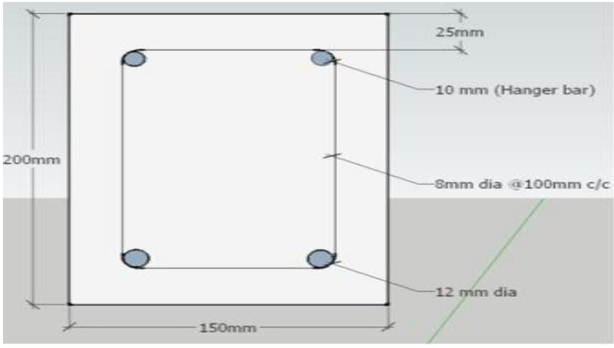

Figure 5. Cross section of beam

Installation of GFRP sandwich panels

The installation of GFRP sandwich panels were done by externally bonding & bolting to the soffit of the beam. In the first set of strengthened beam B1, the GFRP sandwich panels were only externally bonded to the soffit of the beam using Polyester resin. In the second set of beam B4, load was applied till the yield load & then the GFRP sandwich panels were externally bolted in zigzag manner to the soffit of the beam using screw and washer (P.Saravana Kumar et al, 2014). In the third set of strengthened beam B6, GFRP sandwich panel was externally bonded and bolted to the soffit of the beam (Mosallam AS, 1994). The GFRP sandwich panels were placed at 50mm offset from the support since the foam may get compressed if it is placed throughout the beam.

Figure 6. GFRP sandwich panel bonded to the soffit of the beam using polyester resin

Figure 7. GFRP sandwich panel bolted to the soffit of the beam using screws & washers

Experimental setup

The flexural strength of the beam for control and strengthened beams were tested for two point loading or four point bending tests. The experimental setup used for determining the same is shown in figure 8. The beams were placed in the testing frame as shown in the figure 8. The maximum capacity of the loading frame is 1000 kN. The total length of the beam is 1200 mm; beam is placed with the one end as a fixed & other end as a roller support. A 100mm offset is left from both end support for the safety point of view.

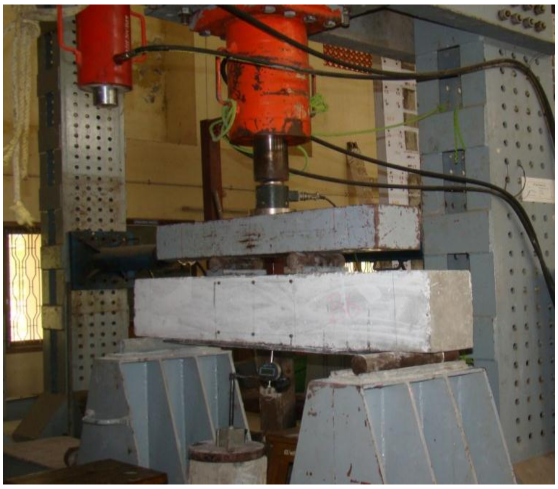

Figure 8. Experimental setup

The load cells were placed at the centre of the beam and it is distributed by means of spandrel beams for two point loading. The load was applied at a one third distance from both ends. Dial gauge was placed at the centre to the soffit of the beam to measure the deflection magnitude. Pellets were pasted at 30mm from the bottom of the beam & Demec gauge was used to measure the tensile strain. The load was applied at the rate of increment of 0.5 Tonnes and the corresponding deflection & strain readings were determined from dial gauge & demec gauge respectively.

RESULTS & DISCUSSIONS

Experimental Results

The results of maximum stress, strain, deflection, ultimate load carrying capacity & initial crack formation for each beam obtained by two point load method were tabulated in table 3. The load carrying capacity of the strengthened beam B1 using bonding alone was found to increase by 15.65% on comparison with the control beam B2. Load carrying capacity of the retrofitted beam B4 using bolting alone was found to increase by 5% on comparison with the control beam B3 and the load carrying capacity of the strengthened beam B6 using both bonding & bolting was found to increase by 24.39% on comparison with the control beam B5.The yield load for the beam B1 was observed in the range of 50 to 55 kN whereas in the case of control beam B2 yield load was between 40 to 45 kN. The yield load for Beam B4 was observed at the range of 70 to 75 kN. But for the control beam B3, yield load was observed at the range of 35 to 40 kN. The yield load for the Beam B6 was at the range of 50 to 55 kN and in the control beam B5, the yield load was observed at the range of 35 to 40 kN. This clearly shows that the tension developed at the bottom was initially bear by the GFRP sandwich panels in the case of the strengthened beams of B1,B4 & B6 so that the initial crack formation were delayed by 25%,100% & 42.86% when compared with the control beams of B2,B3 & B5 respectively

Load – Deflection

The comparison of load – deflection plot for strengthened beam B1 & control beam B2 was shown in figure 9. Figure 10 shows the comparison of load – deflection plot for retrofitted beam B4 with control beam B3 & Figure 11 shows the comparison of load – deflection plot for strengthened beam B6 with the control beam B5.

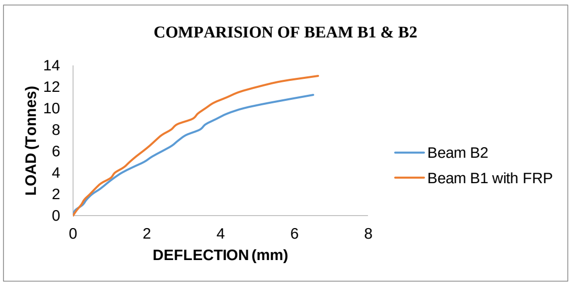

Figure 9. Load Deflection for B1 & B2

From the above figure 9, deflection at the ultimate load for the strengthened beam B1 was found nearly same as compared with the deflection of control beam B2 at the ultimate load point. But the ultimate load carrying capacity of the strengthened beam increased by 15.65%

From the below figure 10, deflection at the ultimate load point for the strengthened beam B3 was found greater than the deflection of control beam B2 at the ultimate load point and the ultimate load carrying capacity of the retrofitted beam increased by 5%. From the below figure 11, the deflection at the ultimate load point for the strengthened beam B6 was found greater than the deflection of control beam B5 at the ultimate load point & the ultimate load carrying capacity of the strengthened beam is 24.39%. This clearly shows the enhancement of ductility behaviour of beams B4 & B6 due to installation of GFRP sandwich panels at the soffit of the beams (Kumatha Rathinam et al, 2016.

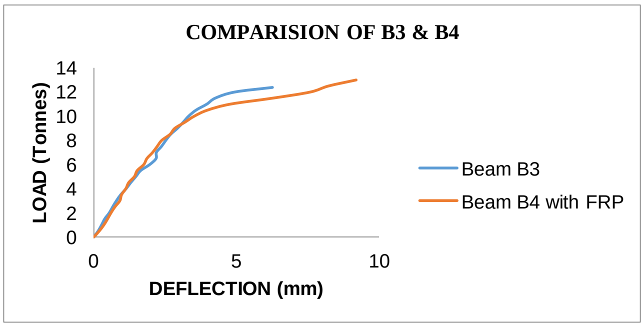

Figure 10. Load Deflection for B3 & B4

Table 3. Experimental Observation

Set No	Details	Maximum Stress (N/mm^2)	Maximum Strain	Maximum Deflection (mm)	Ultimate Load Carrying capacity (kN)	Yield Load (kN)
1	Strengthened beam B1 (Bonding Only)	51.84	0.011	6.65	130.00	50 - 55
	Beam B2 control beam	44.83	0.013	6.52	112.40	40 - 45
2	Beam B3 control beam	49.37	0.011	6.26	123.80	35 - 40
	Retrofitted beam B4 (Bolting only)	51.84	0.014	9.2	130.00	70 - 75
3	Beam B5 control beam	47.74	0.012	7.23	119.70	35 - 40
	Strengthened beam B6 (Bonding & Bolting)	59.38	0.012	9.71	148.90	50 - 55

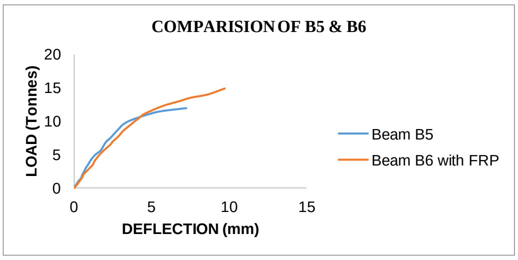

Figure 11. Load deflection for B5 & B6

In figure 14, the stress-strain plot for strengthened beam B6 was compared with the control beam B5. The strain value was lesser for the strengthened beam for a higher stress in the beam. This clearly shows that 1st and 3rd set of strengthened beam tension were majorly carried by GFRP sandwich panels and hence the strain values were lesser compared to the control beam.

Failure modes

The failure patterns for the strengthened beam were shown in the Figure 15, 16 & 17. In Figure 15, failure pattern of the strengthened beam B1 with GFRP sandwich panel placed at the soffit of the beam by using polyester resin alone. The bonding between the surface of the concrete and GFRP sandwich panels were not found adequate so while the GFRP sandwich panels had got delaminated and the concrete was not able to carry the load beyond this point. If the delamination did not happen, the ultimate load carrying capacity would have been increased.

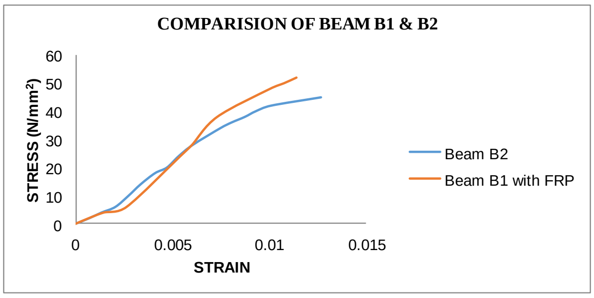

Figure 12. Stress Strain for B1 & B2

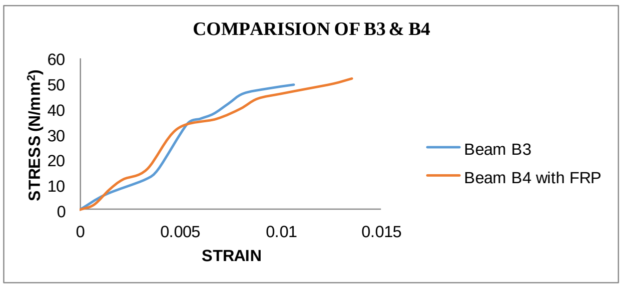

Figure 13. Stress Strain for B3 & B4

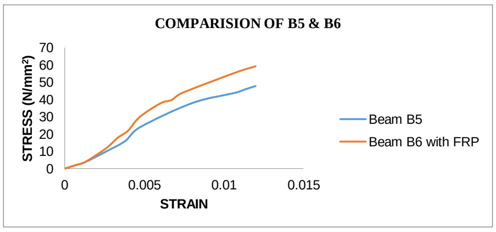

Figure 14. Stress Strain for B5 & B6

Figure 15. Failure of Beam B1

In the figure 16 failure of the retrofitted beam B4 is shown, since the GFRP sandwich panel was fixed to the soffit of the beam by means of screws and washer in a zigzag manner & the failure of GFRP sandwich panels due to delamination is avoided. The GFRP sandwich panel was placed after the yield load of the beam is achieved, the crack propagation was retained and the beam has failed due to the maximum value of strain in compression zone is reached earlier than maximum value of strain in tension zone & percentage increase of ultimate load carrying capacity of the retrofitted beam is less but the crack formation is delayed. The figure 17 shows the failure of strengthened beam B6 as the beam B6 was strengthened with GFRP sandwich panels using Polyester resin & screws. The ultimate load carrying capacity of the beam was increased when compared to the beam B5 and the initial crack formation was delayed.

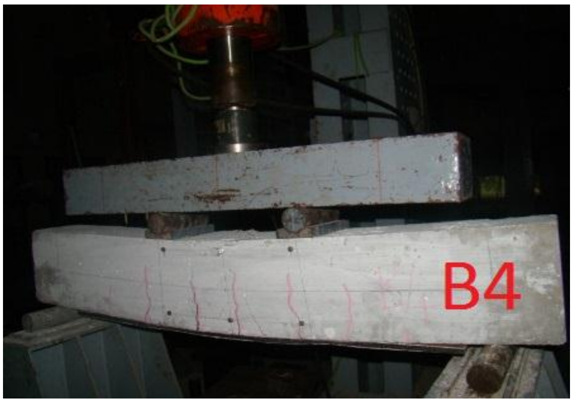

Figure 16. Failure of Beam B4

Figure 17. Failure of Beam B4

CONCLUSIONS

Based on the experimental investigation the below conclusions were made

1. The load carrying capacity of the strengthened beam with externally bonded GFRP sandwich panel is increased by 15.65% when compared with the control beam.
2. The load carrying capacity of the retrofitted beam with externally bolted GFRP sandwich panels is increased by 5% when compared with the control beam.
3. The load carrying capacity of the strengthened beam with externally bonded & bolted to GFRP sandwich panels is increased by 24.39% when compared with the control beam.
4. The delamination of GFRP sandwich panel was avoided in the case of externally bolted & externally bonded/bolted beams.
5. The initial crack formation for the strengthened beams was delayed since the bottom tension was taken by the GFRP sandwich panels.
6. The cost of installation of GFRP sandwich panels is very less when compared to the traditional method of retrofitting and wrapping the entire element with GFRP composites.
7. Below are the scope of works can be carried out with the extension of this paper
   - (i) The percentage of steel in the beam shall be reduced and the beam shall be strengthened using GFRP sandwich panels
   - (ii) The depth of the beam shall be reduced & the same shall be strengthened using GFRP sandwich panels
   - (iii) Instead of providing the sandwich panels over the entire span, the GFRP sandwich panels shall be provided in between the loading points at the soffit of the beam.

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