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ENHANCEMENT OF FLEXURAL STRENGTH ON REINFORCED CONCRETE BEAMS WRAPPED WITH GLASS FIBRE REINFORCED POLYMER

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ABSTRACT
Reinforced Concrete (RC) structures are designed for a particular load carrying capacity and they are expected to function safely during their service life. Several strengthening methods are being adopted to extend the service life of damaged structures. Plate bonding technique using Fibre Reinforced Polymer (FRP) shows a better choice of strengthening method of RC structural elements. Glass Fibre Reinforced Polymer (GFRP) Sheet offers a viable alternative in repair and strengthening of RC structures. The objective of this investigation is to study the effectiveness of the retrofitting beams by fixing GFRP sheet at the tension zone (soffit of beam) for increasing the flexural strength of RC beams. Two point bending flexural tests were conducted up to failure on reinforced concrete beams retrofitted and control beams.

KEYWORDS: RC Structures, Glass Fiber Reinforced Polymer, Flexural Strength.

INTRODUCTION
Concrete, steel and masonry materials are the common materials used for housing, office buildings, bridges, power plant structures and these structures are being deteriorated with age. The deterioration of the structures is due to the design deficiency, materials deficiency, poor workmanship and extreme loads. As long as the structural integrity of the building exists, the deterioration of the structure can be rectified. Structures are designed to withstand safely a particular predetermined load during their life period. Generally, RC structures can suffer varying degrees of damage due to several reasons including material deterioration, construction technique adopted, poor workmanship, overloading, aggressive environments, fatigue and corrosion of steel reinforcement embedded in concrete. Repair and rehabilitation mean restoring the damaged structures to make them fit for serviceability condition whereas retrofitting means strengthening of undamaged and new structures. Durable repair can be done only by matching the properties of the base concrete with those of the repair material intended for use (Neelamegam, 2001). Rehabilitation of structurally deteriorated RC structures is one of the major tasks for the construction industries worldwide. Use of properly selected materials can solve this tough task. Retrofitting, upgraded the structural elements for its load carrying capacity by using techniques like plate bonding. Sharif et al (1994) demonstrated the feasibility of strengthening structurally deteriorated concrete beams using externally bonded GFRP plates. Their primary interest was the achievement of the full flexural capacity of the strengthened beams. They formulated theoretical analysis for predicting the flexural strength and the plate separation load and compared them with the experimental results. Tom Norris et al (1997) studied the behaviour of retrofitted RC beams with CFRP sheet by experimental and analytical investigations. The strength and stiffness of beam was found for different CFRP sheets fibre orientation with the axis of the beam. The stiffness and strength were increased to a greater extent when the CFRP fibres were placed perpendicular to the crack of beams.

FLEXURAL STRENGTHENING OF BEAMS
Fibre reinforced polymers were developed and used in the form of thin laminates. They are constructed of high performance fibres such as carbon, aramid or glass, which are placed in a resin matrix. The GFRP sheets are being widely used for flexural strengthening because of their excellent properties. Moreover, bonding of GFRP sheet does

not need expensive scaffolding. Many researchers have done experiments on RC beams strengthened with externally bonded GFRP sheets to the tension face to exhibit ultimate flexural strength greater than their original/damaged beams.

CASTING OF BEAMS

The concrete mix ratio is 1: 1.77: 3.04 with water cement ratio of 0.50. The concrete mix is designed by IS method to attain the mean strength of 20 N/mm^2. The average strength of concrete obtained is 28.40 N/mm^2. The modulus of elasticity and Poisson's ratio of concrete are obtained as 2.51 x10^4 N/mm^2 and 0.186 respectively. The split tensile strength of cube is obtained as 3.98 N/mm^2. The flexural strength of concrete prism of size 100 x 100 x 500 mm is obtained as 3.65 N/mm^2. A total of four beams are cast and out of which one is control beam (CB) and remaining three beams (RB1, RB2, RB3) retrofitted with single, double and triple layers of GFRP sheets. The size of beams is 150 x 250 x 3200 mm length and designed as the beams of under reinforced section as per IS: 456 – 2000. The casting of beams is shown in Figure 1.

Figure 1 Casting of Beams

BONDING OF GFRP SHEET

The GFRP fabric (Figure 2) of 0.3 mm thickness is kept tight and wrinkles free. The tension face of the concrete surface is made rough to a coarse sand paper texture by scarifying with a toothed grinder and cleaned with an air blower. The concrete surface is made free all apparent moisture. A two component epoxy primer is mixed thoroughly and applied (Figure 3), to the concrete surface and is allowed to dry for thirty minutes. A very thin coat of putty is applied on primer coat to get smoothened over the surface so that it fills small voids, holes and uneven surfaces. Putty is prepared by mixing these three components thoroughly and applied on primer coat as shown in Figure 4. After the application of putty, the surface is smoothened then it is ready for the application of epoxy.

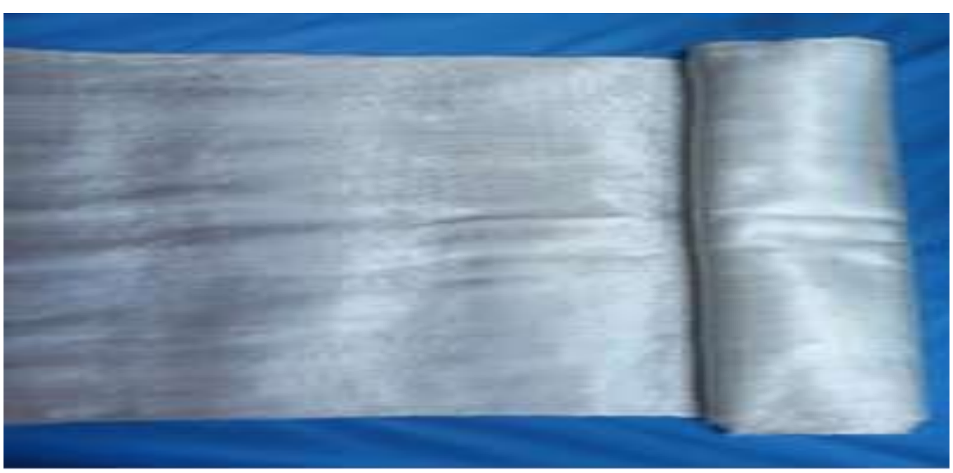

Figure 2 GFRP Sheet

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Figure 3 Primer Application

Figure 4 Application of Putty

A thick layer of two component saturating epoxy is applied over this concrete surface using a paint roller (Figure 5). This rolled on the concrete surface, and pressed in to place at the centre and moved towards each end. The GFRP fabric cut to size of 125 x 3000mm is placed on soffit of the beam which is parallel to beam axis and uniform pressing were done by grip roller head (Figure 6). The GFRP sheet is fixed with epoxy bonded coating with single layers and again the epoxy is applied on the beam for the double layer and the same process is held for the triple layer. The concrete beams strengthened with GFRP fabric are allowed to cure for seven days at room temperature.

Figure 5 Application of Epoxy Resin

Figure 6 CFRP Retrofitted Beams

TESTING OF BEAMS

The beams were loaded with simply supported boundary condition subjected to two equal point loads, one each at the one-third span as shown in Figure 7. The test specimen is mounted in a beam testing frame of 300 kN capacity. Dial gauges of 0.001 mm least count is used for measuring the deflections under the load points and at mid span for measuring the deflection. The dial gauge readings are recorded at different loads. The strain in concrete is measured using a demec gauge. An automatic data acquisition unit is used to collect the data during test. The load is applied at intervals of 25 kN. The first crack loads are obtained by visual examination. Fifty ton capacity hydraulic jack and fifty ton proving ring were used. The loading was done in increments with recording of the deflection and strain reading. Observations like the ultimate load carried by the beam, the load at first crack, maximum crack width, and maximum deflection were made. It is found that the control beams failed in flexure. As the load increased, the crack started to widen and propagated towards the location of loading.

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Figure 7 Testing of Beam

The specimens are to be kept on the loading frame and two dial gauges are to be kept below the loading point and one dial gauge at the center of the beam. The specimens are tested under monotonically increasing load until failure. As the load increased, beam started to deflect and flexural cracks developed along the middle span of the beams. Eventually, all beams failed in a typical flexure mode. While testing the load deflection behaviour of control beams at initial stage of loading, the concrete behaves in a linear elastic manner. When the load increases, the extreme fibre stresses in bending increase up to the tensile strength of concrete and the first crack appears in the middle of constant bending moment region. Then several flexural cracks develop with the increasing of load on the beam. The tension steel reinforcement carries the maximum amount of bending moment and at the same time rotation of beams increases further causing increase in steel stress. Due to the stress in steel reaches yield value, the overall stiffness of beam gets reduced. Further, flexural cracks extend vertically upwards with increasing crack width. Then, cracks appear in the support reaction in inclined direction. The final failure of the beam takes place with increasing in deflection with constant ultimate load. The crack pattern of control and retrofitted beams are shown Figure 8.

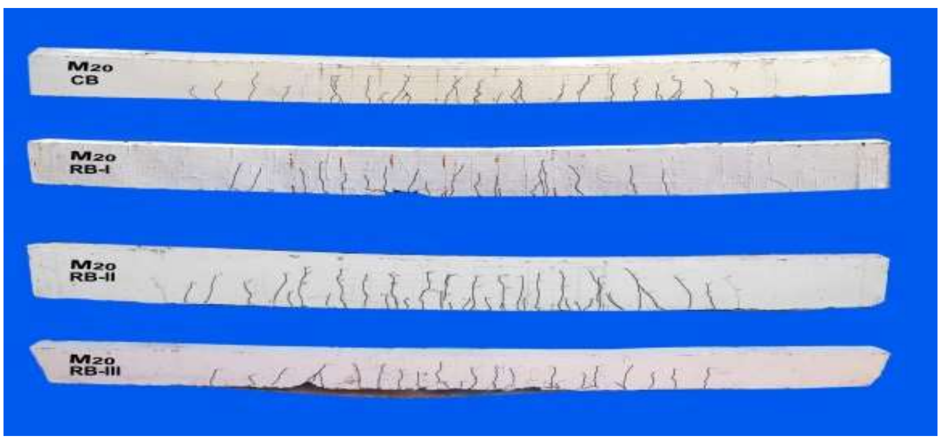

Figure 8 Control GFRP Sheet Strengthened RC Beams

It clearly indicates that the bonding of GFRP sheet to the tension face of the beams by cast in situ bonding technique has given good improvement in load carry capacity. There is a reduction in deflection of beams when compared to control beam. This response may be attributed to increase in liver arm due to bonding.

RESULT AND DISCUSSION

The summary of test results is given Table 1. The load deflection curves of control and retrofitted beams are shown in Figure 9.

Table.1 Summary of Test Results in Control and Retrofitted Beams

Beam Code	**Ist Crack Load (kN)**	**Yield Load (kN)**	**Ultimate Load (kN)**	**Max. Deflection (mm)**
CB	10.00	32.00	37.50	73.00
RB1	15.00	46.00	57.50	58.00
RB2	20.00	52.00	75.00	53.00
RB3	25.00	60.00	80.00	47.00

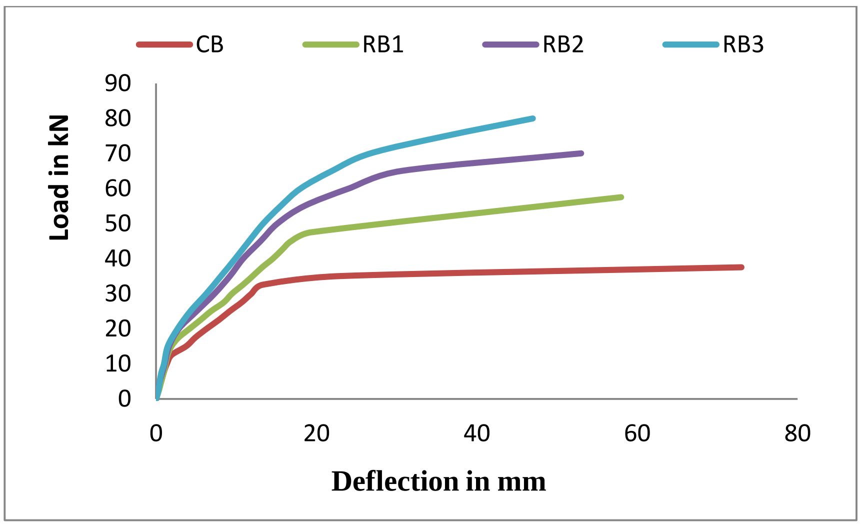

Figure 9 Load Deflection Curves of Beams

From the test results, it is seen that the retrofitted beams with FRP sheets show an increase of load carrying capacity of beams. In the first category, M 20 grade RC beams strengthened with single layer GFRP sheet show 43.75% increase in load carrying capacity at yield stage and 53.33% increase with ultimate load stage when compared to control beam. The RC beams strengthened with double layer of GFRP sheet show 62.5% and 100% increase at yield and ultimate load stage when compared to control beam. The RC beams strengthened with triple layer of GFRP sheet show 87.5% and 113.3% increase at yield and ultimate stage when compared to control beams. The deflection at retrofitted beam increased in first crack and yield load but decreased in ultimate load in all the retrofitted beams of all grades of concrete compared to corresponding control beams. The deflection in retrofitted beams increase at yielding stage and at the same time it is reduced at the ultimate loading stage in all the grade of concrete beams. The M 20 grade RC beams strengthened with single layer GFRP sheet show 15.38% increase in deflection at yield stage and 20.55% decrease at ultimate load stage when compared to control beams. The RC beams strengthened with double layer of GFRP sheet show 23.07% increase and 27.40% decrease at yield and ultimate load stage respectively when compared to control beams. The RC beams strengthened with triple layer of GFRP sheet show 38.46% increase and 35.62% decrease at yield and ultimate stage respectively when compared to control beams. For M 20 grade retrofitted beams with single, double and triple layers show a decrease of 12.5% to 37.5% in the initial crack stage, a decrease of 8.70% to 39.135% in the yield stage and a decrease of 13.64% to 38.64% in the ultimate stage of loading when compared to control beams. For M 20 grade concrete beams retrofitted with single, double, triple layer of GFRP sheets have increased load capacity of about 53.3% to 113.3 % over that of control beams, but its ductility index is only 47% to 69% of control beam based on deflection and 43% to 68% of control beam based on energy stored.

CONCLUSION
From the presence study, it is derived that strengthen of RC beams with GFRP sheets can enhance the load carrying capacity of beams and at the same time deflections up to yield stage of loading is increased and further the deflections are reduced up to ultimate stage of loading. The RC beams strengthened with GFRP sheets show a marked reduction in crack width at all stages of loading and substantial delay in the formation of first crack. The cracks distribution indicates that the size and density of crack are lower in the GFRP strengthened beams than in the control beams.

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