# Flexural Behaviour of Reinforced Concrete Beams Retrofitted With Fibre Reinforced Polymer Sheets

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**Abstract -** *This paper presents the experimental studies on Reinforced Concrete (RC) beams retrofitted with hybrid Fiber Reinforced Polymer (FRP) sheets consisting Carbon FRP (CFRP) and Glass FRP (GFRP). The objective of this study is to examine the effect of hybrid FRPs on structural behavior of retrofitted RC beams and to investigate if different sequences of CFRP and GFRP sheets of the hybrid FRPs have influences on improvement of strengthening RC beams. For this, 36 RC beams were fabricated and retrofitted with hybrid FRPs having different combinations of CFRP and GFRP sheets. The main test variables are sequences of attaching hybrid FRP layers. Under loaded condition, beams were retrofitted with two or three layers of hybrid FRPs, then the load increases until the beams reach failure. Test results conclude that strengthening effects of hybrid FRPs on ultimate strength and ductility of RC beams depend on orders of FRP layers.*

***Key Words*:** Reinforced concrete, Fibre reinforced polymer, Carbon fibre, Glass fibre, Retrofitted beams, Hybrid fibre reinforced polymer, Flexural behavior.

## 1.INTRODUCTION

Structures deteriorate due to problems associated with reinforced concrete. Natural disasters like earthquakes have repeatedly demonstrated the susceptibility of existing structures to seismic effect and hence implements like retrofitting and rehabilitation of deteriorated structures are important in high seismic regions. Thus retrofitting and strengthening of existing reinforced concrete structures has become one of the most important challenges in Civil engineering. Engineers often face problems associated with retrofitting and strength enhancement of existing structures. Commonly encountered engineering challenges such as increase in service loads, changes in use of the structure, design and/or construction errors, degradation problems, changes in design code regulations, and seismic retrofits are some of the causes that lead to the need for rehabilitation & retrofitting of existing structures. Complete replacement of an existing structure may not be a cost-effective solution and it is likely to become an increased financial burden if upgrading is a viable alternative. In such occasions, repair and rehabilitation are most commonly used solutions.

Reinforcement corrosion and structural deterioration in RC structures are common and prompted many researchers to seek alternative materials and rehabilitation techniques. While many solutions have been investigated over the past decades, there is always a demand to search for use of new technologies and materials to upgrade the deficient structures. In this context, strengthening with FRP composite materials in the form of external reinforcement is of great interest to the Civil engineering community. The conventional strengthening methods of reinforced concrete structures attempt to compensate the lost strength by adding more material around the existing sections. Thus retrofitting and rehabilitation of structures can be concluded to be the best alternative.

Externally bonded, FRP sheets are currently being studied and applied around the world for the repair and strengthening of structural concrete members. FRP composite materials are of great interest because of their superior properties such as high stiffness and strength as well as ease of installation when compared to other repair materials. Also, the non-corrosive and non-magnetic nature of the materials along with its resistance to chemicals makes FRP an excellent option for external reinforcement. The addition of externally bonded FRP sheets to improve the flexural and shear performance of RC beams has been actively pursued during the recent years. Research reveals that strengthening using FRP provides a substantial increase in post-cracking stiffness and ultimate load carrying capacity of the members subjected to flexure and shear. Fibre-reinforced polymer (FRP) is a composite material made of a polymer matrix reinforced with fibres.

In the last few decades, moderate and severe earthquake have struck different places in the world, causing severe damage to reinforced concrete (RC) structures. Retrofit of these structures before the earthquake provides a feasible cost-effective approach to reduce the hazard to occupants' safety and owners' investment. The deterioration is mainly due to environmental effects, which includes corrosion of steel, gradual loss of strength with ageing, repeated high intensity loading, variation in temperature, freeze-thaw cycles, contact with chemicals and saline water and exposure to ultra-violet radiations. This problem, coupled with revisions in structural codes needed to account for the natural phenomena like earthquakes or environmental deteriorating forces, demands development of successful structural retrofit technologies. The structural retrofit problem has two options, repair/retrofit or demolition/reconstruction. Traditionally, the trend within the construction industries has been towards the latter option. This solution has become increasingly unacceptable due to changing economic and social attitudes concerning existing structures. This fact leads to the necessity for development of appropriate structural retrofit/repair systems.

Shin et al. (2011) [1] examined the effect of hybrid FRPs on structural behavior of retrofitted RC beams and investigated whether different sequences of CFRP and GFRP sheets of the hybrid FRPs have influences on improvement of strengthening RC beams. Retrofitted with hybrid FRPs having different combinations of CFRP and GFRP sheets. Improved ultimate strength and stiffness of a strengthened beam.

Riadh et al. (2004) [2] investigated the failure mechanisms and the influence of several parameters on debond modes such as end cover separation and shear crack debond. Variables in the test included the CFRP bond length, the area of tension reinforcement, the concrete cover and the amount of shear reinforcement. The performance of FRP was influenced mainly by: the ratio of FRP bond length in shear span to concrete depth and the ratio of laminate stiffness to tension reinforcement stiffness.

Hamid et al. (2010) [3] presents an experimental research program aimed at developing a retrofitting technique that utilizes locally available high strength, lightweight, corrosion resistance advanced composites for retrofitting existing reinforced concrete beams. Applied Glass Fiber Composite Laminates (GFCL) to the bottom surface and sides of the concrete beam to increase its stiffness and flexural strength. An increase of 50 to 60% in beam flexural strength and an increase of 75 to 175% in post-cracking flexural stiffness were achieved.

## 2. EXPERIMENTAL PROGRAM

### 2.1 Test Specimens

Thirty six beams with dimensions of 150 × 150 × 700 mm (width × depth × length) are fabricated for testing. All beams are reinforced internally with 8 mm diameter deformed high-tensile steel bars at an effective depth 125 mm. The beams are sufficiently reinforced against shear failure by using high strength steel deformed bar of 6 mm diameter at a spacing of 75 mm center to center. Two-point bending tests on simply supported beams are performed. One beam is used as the control specimen and not preloaded and retrofitted. The remaining beams are retrofitted with FRPs at the tension side and each FRP layer is attached with an adhesive.

**Table -1:** Details of Specimens

| Specimen | Layers of FRPs | Specimen fabrication and preload |
|---|---|---|
| CONTR | 0 | Control specimen |
| CC | 2 | Two layers of CFRP are bonded without preloading |
| GG | 2 | Two layers of GFRP are bonded without preloading |
| CG | 2 | One layer of CFRP is bonded and one layer of GFRP is bonded in sequence for the beams without preloading |
| GC | 2 | One layer of GFRP is bonded and one layer of CFRP is bonded in sequence for the beams without preloading |
| CCG | 3 | Two layers of CFRP are bonded and one layer of GFRP is bonded in sequence without preloading |
| CGC | 3 | One layer of CFRP, one layer of GFRP and one layer of CFRP are bonded in sequence without preloading |
| GCC | 3 | One layer of GFRP is bonded and two layers of CFRP are bonded in sequence without preloading |
| CGG | 3 | One layer of CFRP is bonded and two layers of GFRP are bonded in sequence without preloading |
| GCG | 3 | One layer of GFRP, one layer of CFRP and one layer of GFRP are bonded in sequence without preloading |
| CG-70 | 2 | CG strengthening is executed at 70% of ultimate load of CONTR |
| CGG-70 | 3 | CGG strengthening is executed at 70% of ultimate load of CONTR |

For two layered hybrid FRP sheets, layers of CFRP–CFRP (CC specimen), GFRP–GFRP (GG specimen), CFRP-GFRP (CG specimen), and GFRP–CFRP (GC specimen) sheets are attached at the tension faces of the beams. Likewise, three layers of FRPs are attached to the beams in the orders of CFRP–CFRP–GFRP (CCG specimen), GFRP–CFRP–GFRP (GCG specimen), and GFRP–CFRP– CFRP (GCC specimen), CFRP–GFRP–GFRP (CGG specimen), and CFRP–GFRP–CFRP (CGC specimen) sheets. As listed in Table 1, two beams are retrofitted with hybrid FRPs at the preloaded stage and are compared to the beams retrofitted without preloading. A preload of 70% of the ultimate strength of the control beam was provided.

### 2.2 Material Properties

The beams are made from concrete having 28-day cube compressive strength of 26.87MPa and steel bars. The concrete consisting of ordinary Portland cement, manufactured sand, and crushed gravel of 20 mm maximum size is used to maintain the same quality of concrete for all specimens. The tension reinforcement and shear stirrups are D8 and D6 hot-rolled, high-yield-strength steel bars, where D8 and D6 refer to deformed bars with 8 mm and 6 mm diameters, respectively. The FRPs are cut in the direction of higher strength, namely, the longitudinal direction. A two-part (resin and hardener) epoxy adhesive is applied to the specimens, as suggested by a manufacturer of FRPs.

### 2.3 Specimen Preparation

The moulds were prepared using plywood. The beams were cast in the moulds of size 150mm x 150mm x 700mm. The design mix ratio of 1 : 1.78 : 3.28 was adopted for designing the beam. Two bars of 8 mm diameter were provided as tension reinforcement at the soffit of the beam.

### 2.4 Test Setup

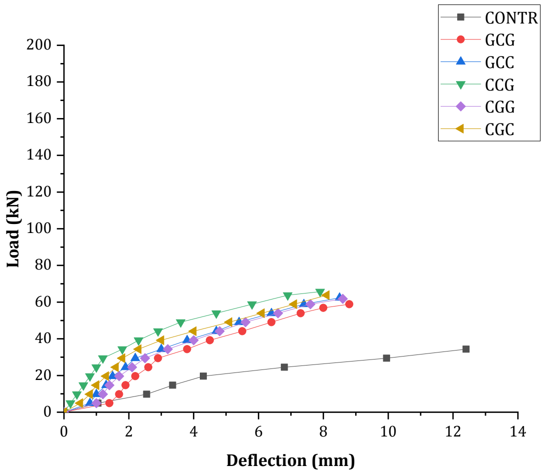
The control beams and the retrofitted beams were tested for the flexural strength. The testing procedure for the all the specimens was same. The beams were cured for a period of 28 days. The surface of control beams is cleaned and washed for clear visibility of cracks. The surface of the retrofitted beams is cleaned with cotton. The two-point loading arrangement is used for testing of beams. This has the advantage of a substantial region of nearly uniform moment coupled with very small shears, enabling the bending capacity of the central portion to be assessed. The load is transmitted through a load cell.

The test beam was supported on roller bearings acting as supports. The specimen was placed over the two steel rollers bearing leaving 40 mm from the ends of the beam. Two point loading arrangement was done as shown in the figure. Loading was done by hydraulic jack. Dial gauge was used for recording the deflection of the beams. The deflections of the beams were noted till the appearance of the first crack using dial gauge. The dial gauge was removed after the appearance of the crack and the load was further applied till fracture load. The ultimate load or fracture load was taken as the load at which the needle of load dial on the UTM returned back. The average of the three trials was taken and the load – deflection graph was plotted.

**Fig-1**: Testing of control specimen : Two point loading

## 3. RESULTS AND DISCUSSIONS

### 3.1 Load versus deflection graph



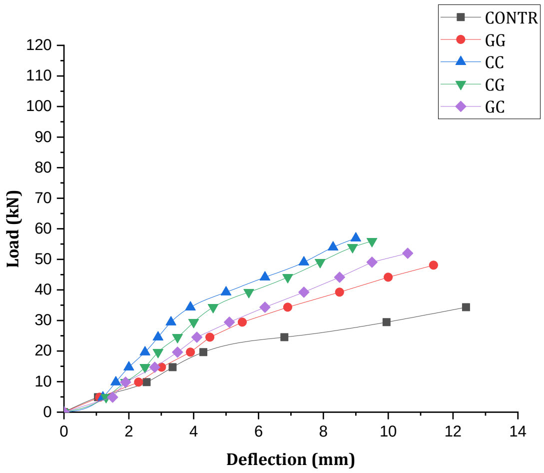


**Chart-1:** Load–deflection relations of: (a) non-preloaded beams retrofitted with two layers of hybrid FRPs and (b) non-preloaded beams retrofitted with three layers of hybrid FRPs

From the tests, it is shown that the FRP retrofitted beams have maximum load than those of the control beam. Among the two-layered FRP retrofitted beams, the CC layered beam show a maximum load of 58kN which is having only a slight variation from CG layered beam of ultimate strength 56kN. This is due to the high ductility nature of GFRP when compared to CFRP. Even though the strength of CFRP is more than GFRP, once CFRP fails it will be a brittle failure. So in order to overcome the brittle failure high ductile GFRP is provided. Also GC layered beam show an ultimate strength of 53kN which is lower than CG layered beam. Thus it implies that ultimate strength will be more when the GFRP is provided as the outside layer. Since CC and CG is having only a slight difference and also considering the cost factor, CG can be selected as the most effective retrofitting arrangement. The cost of CFRP is much more than GFRP.

Therefore CG arrangement can be considered the most effective retrofitting arrangement with higher load carrying capacity.

Compared to two-layered FRP retrofitted beams, three layered FRP retrofitted beams show larger maximum load. The largest maximum load is obtained from the CCG specimen while the GCG specimen shows the lowest. The ultimate load is more when GFRP is provided away from the concrete surface. With increase in number of carbon fiber layers, ultimate strength also increases but considering the cost factor, CGG can the selected as the most effective arrangement. Because the ultimate strength of CCG is 67kN which is only slightly higher than CGG having an ultimate strength of 63kN. The ultimate strength of GCC is 63.6kN which implies that proper arrangement of fiber layers can lower the cost by reducing the number of carbon fiber layers. The FRP retrofitted beams are failed due to debonding or concrete crushing before the FRP sheet reaches its failure state. In other words, the hybrid FRPs are not fully utilized at the time of beam failure because either the debonding of FRP or concrete crushing is occurred prior to FRP failure.

## 4. CONCLUSIONS

This study investigates the structural behaviors of RC beams retrofitted with hybrid FRPs. From the two-point bending tests performed on the FRP retrofitted beams, load–deflection curves were analyzed. The effect of preloading on the RC beam at the time of retrofitting is also investigated. The experimental results are summarized as follows:

(1) Using hybrid FRPs is effective in improving the ultimate strength.

(2) The order of attaching different types of FRPs affects the strength and ductility of the RC beams retrofitted with hybrid FRPs. From the tests, the beams with glass fiber attached at outer side of the beam show the most improved strength and ductility.

(3) The retrofitted RC beams fail before the hybrid FRP sheets reach failure point. This limits the strengthening effect of the hybrid FRPs. Thus, the development of a new retrofitting design method is still needed in order to use hybrid FRPs to their full capacity.

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