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Akhil R¹

¹Narayanaguru College of Engineering, Kanyakumari District, Tamilnadu.

ABSTRACT

Worldwide a great deal of research is currently being conducted concerning the use of fiber reinforced plastic wraps, laminates and sheets in the repair and strengthening of reinforced concrete members. Fiber reinforced polymer (FRP) application is a very effective way to repair and strengthen structures that have become structurally weak over their life span. FRP repair systems provide an economically viable alternative to traditional repair systems and materials. Experimental investigations of flexural behaviour of RC beams strengthened by using glass fiber reinforced polymer sheets are carried out. Externally reinforced concrete beams with Epoxy bonded GFRP sheets were tested to failure using a symmetrical two point concentrated static loading system. Two sets of beams were casted for this experimental test program. The beam casted as weak in flexure and strengthened using glass fibre reinforced polymer sheets out of two beam another is controlled beam. The strengthening of the beam is done with different amount and configuration of GFRP sheets. Experimental Data on load, deflection and failure modes of each of the beams were obtained. The detail procedure and application of GFRP sheets for strengthening of RC beam is also included. The effect of number of GFRP layers and its orientation on ultimate load carrying capacity and failure mode of the beams are investigated.

Keywords: Fibre Reinforced Polymer, Glass Fibre Reinforced Polymer, Fibre Influence, and Shear Behaviour.

1 Introduction

The maintenance rehabilitation and upgrading of structural members, is perhaps one of the most critical problems in civil engineering applications. Moreover a large number of structures constructed in the past using the older design codes in different parts of the world are structurally unsafe according to the new design codes. Since replacement of such deficient element of structures incurs huge amount of public money and time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service lives. One of the challenges in strengthening of the concrete structures is selection of a strengthening method is that will enhance the strength and serviceability of the structure while addressing limitations such as constructability, building operations, and budget. Additional strength may be needed to allow for higher loads to be placed on the structure. This is often required when the use of the structure changes and a higher load carrying



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capacity is needed. Strengthening may be needed to allow the structure to resist loads that were not anticipated in the original design. This may be countered when structural strengthening required for loads resulting from wind and seismic forces. Additional strength may be needed due to a deficiency in the structures ability to carry the original design loads. Deficiencies may be the result of deterioration, structural damage or errors in the original design or construction. The majority of the structural strengthening involves improving the ability of the structural element to safely resist one or more of the following internal forces caused by loading: flexure, shear, axial and torsion.

The purpose of this research is to investigate the flexural and shear behaviour of reinforced concrete beams strengthened with varying configuration and layers of GFRP sheets. More particularly, the effect of number of GFRP layers and its orientation on the strength and ductility of beams are investigated. Two sets of beams were fabricated and tested up to failure. The beam casted as weak in flexure and strengthened using glass fibre reinforced polymer sheets out of two beam another is controlled beam. The strengthening of the beam is done with different amount and configuration of GFRP sheets. The importance to study the strengthening of the beam with different thickness of FRP to optimize the thickness of FRP in the strengthening system provides an economical and versatile solution for extending the service life of reinforced concrete structures. From the literature, it is evident that epoxy resin favored in strengthening and eliminates the deboning failure. Most of the researchers adopted the grade of concrete such as M30 and M35. The research can be extended for higher strength. Future research is needed for a complete awareness for strengthening reinforced concrete beams with different thickness of FRP, with the aim to contribute in the concrete structures repair tasks efficiently as well as to decrease the dimensional stability of the structure.

2 Literature Review

Michael et al 1994 on the field of strengthening structure Michael et al, 1994 experimentally investigated fourteen reinforced concrete beams. The author examined three control beams having same steel reinforcement. They evaluated the strength behaviour by casting beams strengthened with aramid fabric (1 layer), E-glass fabric (3 layers) and graphite fibre fabric (2 layers) and their thickness of 1.04, 1.42 and 1.22 mm, respectively. They found that use of external composite fabric reinforcement increased the flexural capacity by 36 to 57% and 45 to 53% increase in flexural stiffness.

Houssam et al., 1997 investigated the long-term durability of concrete beams externally bonded with FRP sheets and studied the effect of harsh environmental conditions such as wet/dry cycling using salt water on the performance of FRP bonded concrete beams and on the interfacial bond between the fibre and the concrete. Four different types of FRP composite material were used: two carbons and two glasses with a thickness of 1.165, 0.118 and 1.3 mm, respectively. Three different two-part epoxy systems were used: epoxy I



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modified amine/epoxy resin blend, epoxy II poly ox propylene di amine hardener/epoxy resin and epoxy III Amine saturant solvent- free epoxy. They studied that the specimens subjected to wet/dry conditions showed less improvement than those kept at room temperature. The reduction in strength improvement may be attributed to the degradation of the epoxy, which led to the weakening of the bond between the concrete specimens and the FRP sheets. Beams bonded with any of the four different FRP sheets using epoxy II exhibited the highest load capacity, under either condition, room temperature or wet/dry, compared with those bonded using epoxies I or III.

Heffernan P et al, presents the results of an investigation into the fatigue behaviour of reinforced concrete beams post strengthened with CFRP laminates in their paper. Although there has been growing interest and field applications of post strengthening concrete structures using Carbon fiber reinforced plastic (CFRP) laminates, very little information exists regarding the flexural fatigue behaviour of reinforced concrete beams strengthened with CFRP. The results of twenty 3 m and six 5m beams loaded monotonically and cyclically to failure are discussed. Comparisons are made between beams without and with CFRP strengthening. The effect on fatigue life of increasing the amount of CFRP used to strengthen the beams is also examined.

Elsevier et al., generated a comprehensive set of experimental data regarding the effects of collated fibrillated polypropylene fibres at relatively low volume fractions (below 0.3%) on the compressive, flexural and impact properties of concrete materials with different binder compositions. Statistical analysis of results produced reliable conclusions on the mechanical properties of polypropylene fibre reinforced, concrete and also on the interaction of fibres and pozzolanic admixtures in deciding these properties. Polypropylene fibres were observed to have no statistically significant effects on compressive or flexural strength of concrete, while flexural toughness and impact resistance showed an increase in the presence of polypropylene fibres. Positive interactions were also detected between fibres and pozzolanas.

C. Selin Ravikumar et al., through their investigation glass fibres of 450 mm length are added to the concrete by volume fraction of up to 1% to determine its strength and fire resistant characteristics. Comparison of the strength and fire- resistance performance of conventional concrete and glass fibre concrete was made. With 0.5 per cent addition of fibre, the increase in the compressive strength is 13 per cent, the increase in flexural strength is 42 per cent and the increase in split tensile strength is 20 percent over conventional concrete. With 1 per cent addition of fibre, the increase in the compressive strength is 35 per cent, the increase in flexural strength is 75 per cent and the increase in tensile strength is 37 per cent. Therefore reinforcing with glass fibre contributes immensely in enhancing the compressive strength of concrete and the increase is 1.78 times that of normal concrete. From the test results, it is found that the glass fibre possesses the high flexural strength.

G. Jyothi Kumari et al., The present work is to study the behavior of Shear resistance of the silica coated GFRP stirrups in the shear test zone. A series of studies were conducted



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using silica coated GFRP stirrups in shear zone. It is observed that beams with silica coated GFRP flats shear reinforcement have shown failure at higher loads than the theoretical failure loads. Further it is observed that GFRP flats as shear reinforcement exhibit fairly good ductility. The beams with silica coated GFRP bars and Flats as shear reinforcement, have shown failure at loads higher than the theoretical failure loads. This clearly indicates the improved bond of silica coated GFRP bars with concrete. 2. Beams with GFRP reinforcement, both plain and silica coated have shown higher deflections compared to that of controlled beams with HYSD bars thus indicating improved ductility of GFRP-concrete composite.

Murali G et al., Several researches have been carried out on reinforced concrete beams strengthened with fibre reinforced polymer composites. A few works has been focused on strengthening of rectangular beams with different type and different thicknesses of fibre reinforced polymer. Reinforced concrete (RC) structure using externally bonded fibre reinforced polymer (FRP) components has become a very universal practice, extensively accepted by recent design code Glass fibre reinforced polymers sheets are being increasingly used in rehabilitation and retrofitting of concrete structures, since low cost comparison with other types of FRP fibres are generally high strength-to-weight ratio, corrosion resistance and fatigue resistance. A low weight of the fibre make it easy to handle without lifting equipment at site, negligible change of cross section, self-weight and free height of a structure . The importance to study the strengthening of the beam with different thickness of FRP to optimize the thickness of FRP in the strengthening system provides an economical and versatile solution for extending the service life of reinforced concrete structures. From the literature, it is evident that epoxy resin favored in strengthening and eliminates the deboning failure. Most of the researchers adopted the grade of concrete such as M30 and M35. The research canbeextendedforhigherstrength.Futureresearchisneededforacompleteawareness for strengthening reinforced concrete beams with different thickness of FRP, with the aim to contribute in the concrete structures repair tasks efficiently as well as to decrease the dimensional stability of the structure

2.1 Specific Scope of Project

Numerousresearchresultsconcerningthebehaviouroffibrereinforcedconcrete subjected to various load conditions, including flexural, compressive and tensile loadings have been reported. Research reports of the concrete and fibre influence on shear behaviour of composite have been limited and include normal strength concrete only. In this chapter an attempt is made to discuss the available studies on flexural strength behaviour of GFRP. The application of glass fibre reinforced concrete in structural elements has not been extensive at present, but it is expected that the applications will increase once, when sufficient data on short-term and long-term performance of glass fibre reinforced concrete specimens is available and engineers have access to appropriate design procedures. Statistical analysis of



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results produced reliable conclusions on the mechanical properties of polypropylene fibre reinforced, concrete and also on the interaction of fibres and pozzolanic admixtures in deciding these properties. Polypropylene fibres were observed to have no statistically significant effects on compressive or flexural strength of concrete, while flexural toughness and impact resistance showed an increase in the presence of polypropylene fibres. Positive interactions were also detected between fibres and pozzolanas. The laminates are stiff plates or shells that come procured and are installed by bonding them to the concrete surface with a thermosetting resin. The sheets are either dry or re impregnated with resin (known as pre – preg) and cured after installation onto the concrete surface.

3 Experimental Methodology

This chapter gives the details of the experimental programme under taking in this study. As discussed in the previous chapter, very little published information is available on the behaviour of prestressed concrete, in particular, with fibre reinforcement. The behaviour of prestressed concrete with crimped steel fibres forms the thrust of the experimental programme in this study. The experimental work involved careful planning, proper selection and determination of basic mix proportions of the constituent materials such as cement, aggregates, and fibres. Based on the properties obtained for the constituent materials, a design mix proportions for the present study is developed as per codal procedures (IS: 10262-1982). The experimental study consists of casting of two sets of reinforcement concrete (RC) beams. In SET I three beams which are controlled beams. In SET II three beams weak in flexure were casted, were strengthened by using continuous glass fibre reinforced polymer (GFRP) sheets. The strengthening of beam is done with various failure modes of each of the beams were obtained. The changes in load carrying capacity and failure mode of the beams are investigated as the amount and configuration of GFRP sheets are altered. The following chapter explains in detail the experimental study.

3.1 Procedure

Before testing the member should be checked dimensionally, and a detailed visual inspection should be made with all information carefully recorded. After setting and reading all gauges, the load should be increased incrementally upto the calculated working load, with loads and deflections recorded at each stage. Loads will then normally be increased again in similar increments upto failure, with deflection gauges replaced by a suitably mounted scale as failure approaches. This is necessary to avoid damage to gauges and although accuracy is reduced, the deflections at this stage will usually be large and easily measured from a distance. Similarly, cracking and manual strain observations must be suspended as failure approaches unless special safety precautions are taken. If it is essential that precise deflection readings should be taken upto collapse. Cracking and failure mode was checked visually, and a load/deflection plot is to be prepared.



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3.2 Experimental Setup

All the specimens were tested in the loading frame of the “Structural Engineering” Laboratory of Mepco Schlenk Engineering College at Sivakasi. After the curing period of 28 days was over, the beam as washed and its surface was cleaned for clear visibility of cracks. The most commonly used load arrangement for testing of beams will consist of two-point loading. The load is transmitted through a load cell and spherical seating on to a spreader beam. This beam bears on rollers seated on steel plates bedded on the test member with mortar, high-strength plaster or some similar material. The test member is supported on roller bearings acting on similar spreader plates. The loading frame must be capable of carrying the expected test loads without significant distortion. Ease of access to the middle third for crack observations, deflection readings and possibly strain measurements is an important consideration, as is safety when failure occurs. The specimen was placed over the two steel rollers bearing leaving 150mm from the ends of the beam. The remaining 2000mm was divided into three equal parts of 667mm as shown in figure. Two point loading arrangement was done as shown in the figure. Loading was done by hydraulic jack of capacity 100kN. Three number of dial gauges were used for recording the deflection of the beams. One dial gauge was placed just below the center of the beams and the remaining two dial gauges were placed just below the two point loads to measure deflections.

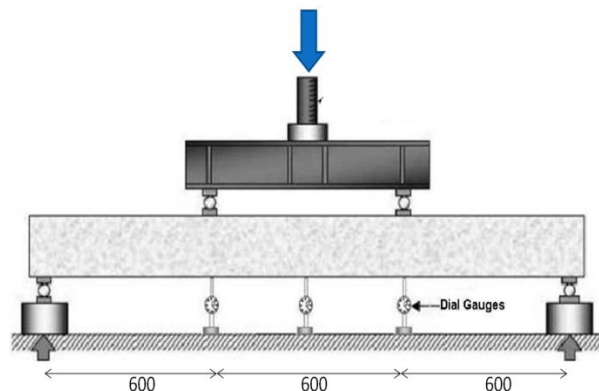


Figure 1: Experimental Setup

4 Result and Discussion

4.1 Flexural Strengthening of Beams

To increase flexural strength, FRP fabrics are bonded as an external reinforcement on the tension side of steel-reinforced concrete beams with fiber orientation along the member length. Depending on the ratio of FRP reinforcement area to the beams cross sectional area and the area of the internal steel reinforcement, the increase up to 50% would be more realistic, which depends on practical considerations such as the concrete dimensions,



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serviceability limits, ductility, effective thickness of FRP fabric reinforcement. The design philosophy of strengthening rectangular RC beams, is equally applicable to other shapes such as T and I- sections having non- prestressed reinforcement

4.2 Assumptions

The following assumptions are made in calculating the flexural resistance of a section strengthening with an externally applied FRP system:

1. Design calculations are based on the actual dimensions, internal reinforcing steel arrangement and material properties of the existing member being strengthened.
2. The strains in the reinforcement and concrete are directly proportional to the distance from the neutral axis that is a plane section before loading remains plane after loading.
3. There is no relative slip between external FRP reinforcement and the concrete.
4. The shear deformation within the adhesive layer is neglected since the adhesive layer is very thin with slight variations in its thickness.
5. The maximum usable compressive strain in the concrete is 0.003.
6. The tensile strength of concrete is neglected.
7. The FRP reinforcement has a linear elastic stress-strain relationship to failure.

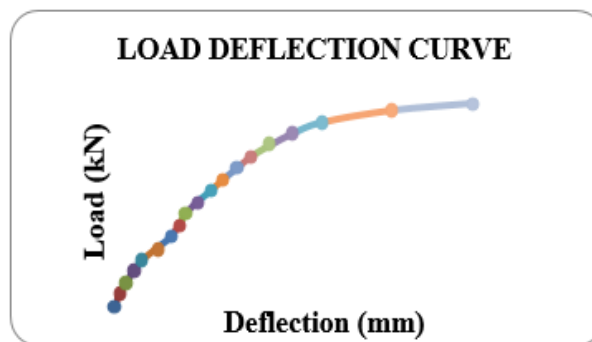


Figure 2: Load v/s Deflection curve for controlled beams

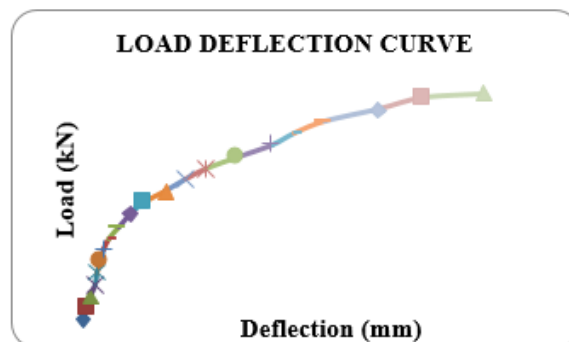


Figure 3: Load v/s Deflection curve flexural beam F1



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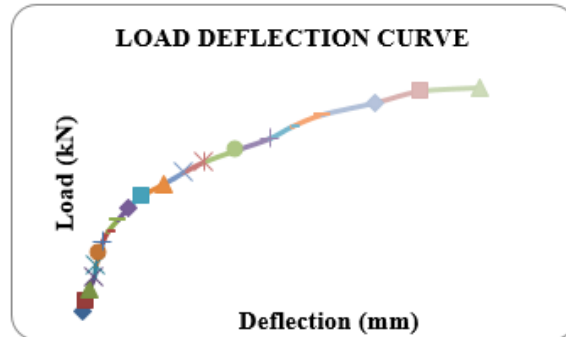


Figure 4: Load v/s Deflection curve for Flexural beam F2

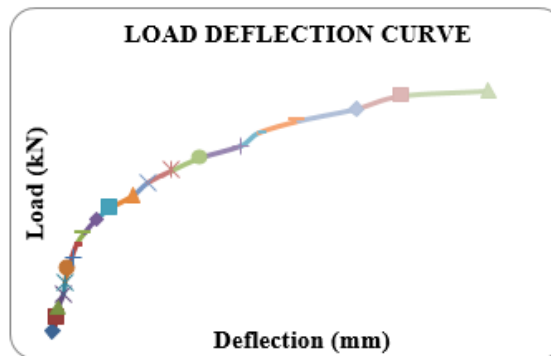


Figure 5: Load v/s Deflection curve for Flexural beam F3

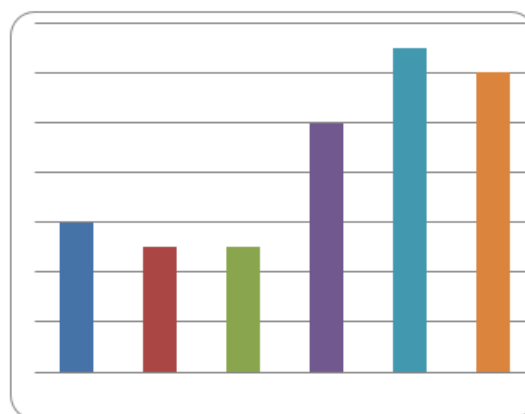


Figure 6: Comparison of Results

4.3 Failure modes

The flexural and flexural strength of a section depends on the controlling failure mode. The following flexural strength should be invested for an FRP



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Strengthened section:

- Crushing of the concrete in compression before yielding of the reinforcing steel:
- Yielding of the steel in tension followed by rupture of the FRP laminated
- Yielding of the steel in tension followed by concrete crushing:
- Tension de lamination of the concrete cover:
- Debonding of the FRP from the concrete
- Substrate (FRP debonding).

A number of failure modes have been observed in the experiments of RC beams strengthened in flexure by GFRPs crushing of concrete at top Rupture of the FRP laminate is assumed to occur if the strain in the FRP reaches its design.

5 Conclusion

In this experimental investigation the flexural behavior reinforced concrete beams strengthened by GFRP sheets are studied. Two sets of reinforced concrete beams, in SET I three control beams and in SET II three beams wrapped with fibre were casted and tested. From the test results and calculated strength values, the following conclusions are drawn:

1. Initial flexural crack appear at higher load by strengthening the beam at soffit than the control beams.
2. The ultimate load carrying capacity of the strengthened beam F2 is 14% more than the controlled beam.
3. Load at initial cracks is further increased by strengthening the beam at the soffit as well as on the two sides of the beam up to neutral axis from the soffit.
4. The load carrying capacity of the strengthened beam F3 is 6% more than F1 .Analytical analysis is also carried out to find the ultimate moment carrying capacity and compared with the experimental results, it was found that analytical analysis predicts lower value than experimental findings.
5. When the beam is not strengthened it failed in flexure but after strengthening the beam in flexure, than flexure failure of the beam takes place which is more dangerous than the flexural failure of the beam as it does not give much warning before failure.

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