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Strengthening the RC Member with CFRP Stirrups

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***Abstract*—Strengthening of reinforced concrete (RC) structures using externally bonded Fibre reinforced polymer (FRP) composites is an effective method in improving the structural performance under both service and ultimate load conditions**
RC beams failing in shear are subjected for observation. and they have to be rehabilitated using the following FRP composites using hand lay-up technique
Carbon Fibre Continuous Tow [CFRP(C)] Composite
Carbon Fibre Scrap [CFRP(S)] Composite
Hybrid combination of CFRP(C) and GFRP composite-[H-CF(C)-GFRP]
Hybrid combination of CFRP(S) and GFRP composite-[H-CF(S)-GFRP]
Hybrid combination of CFRP(C) and CFRP(S) composite-[H-CF(C)-CF(S)RP]

Index Terms*— *Glass Fibre Reinforced Polymer (GFRP), Shear Strengthening, Jacketing, Wrapping

INTRODUCTION

By the strengthening of Reinforced Concrete (RC) structures using externally bonded Fibre Reinforced Polymer (FRP) composites, is an effective method of improving the structural performance under both service and ultimate load conditions. It is a rather simple and economical approach to meet the increased load carrying capacity for a structure [1]. The use of lay-up FRP composites under increased load conditions reveals a reduced deflection and smaller crack widths [2]. Also, the use of composites offers several advantages like ease of bonding to curved or irregular surfaces, lightweight/ease of application and fibre flexibility to orient in a desired direction for strengthening. Furthermore, its high fatigue strength, high stiffness and good durability make it an excellent choice for infrastructure strengthening [3]. Compared to traditional methods used for the infrastructure strengthening that involve partial or complete shutting down of facilities, strengthening involving the FRP laminates is less time consuming and does not involve large displacements of the resources[4].

Various reinforced concrete (RC) structural elements such as beams, slabs and columns can be strengthened using externally bonded FRP sheets. In the recent years several studies have been conducted to investigate the flexural strength of reinforced concrete (RC) members. However, few have concentrated on shear strengthening. The importance of shear strengthening may be considered as even more critical than that of flexural strengthening since shear failures occur without advance warning (i.e. sudden) and are more catastrophic compared to flexural failures that are generally progressive in nature and provide ample warning of failure[5]. Deficiencies in shear can be due to:

i. insufficient shear reinforcement,
ii. use of outdated codes,
iii. a reduction in the steel area due to corrosion, or
iv. an increase in the service load due to change of occupancy for the structure [6].

1.1 Fibre Reinforced Polymer Composite Materials

FRP composite materials consist of fibres embedded in or bonded to a matrix with well-defined interfaces between them. In this form, both fibres and matrix retain their chemical and physical identities, but they produce a combination of properties that can't be achieved with either of the constituents acting alone [7]. In general, fibres are the principal load carrying members, while the surrounding matrix keeps them in orientation and desired location, acts as load transfer medium between them and protects it from environmental effects. Commercially, the principal fibres come in various types of glass and carbon as well as aramid. Other fibres, such as boron, silicate carbide and aluminium oxide, are in limited usage. All fibres can be incorporated into a matrix either in discontinuous (chopped) lengths or in continuous lengths.

A polymer used as a matrix, is defined as a long chain molecule containing more than one repeating units of atoms, joined together by strong covalent bonds. Polymers are classified into two broad categories: thermoplastics and thermosets. Among the thermoset polymeric materials, epoxies and polyesters are widely used, mainly because of the ease of processing [9].

1.2 Materials For Strengthening Of Structures

Fig (1) presents a comparison of stress-strain behaviour of materials that can be available for strengthening of structures. It can be seen that a non metallic fibres have

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strengths more than 10 times of that steel [10]. The ultimate strain of these fibres is also very high. In addition, density of these materials is approximately one-third of that steel. Due to its corrosion resistance FRPs can be applied on the surface of structure without worrying about its deterioration and also they protect the concrete core from environmental attack [11].

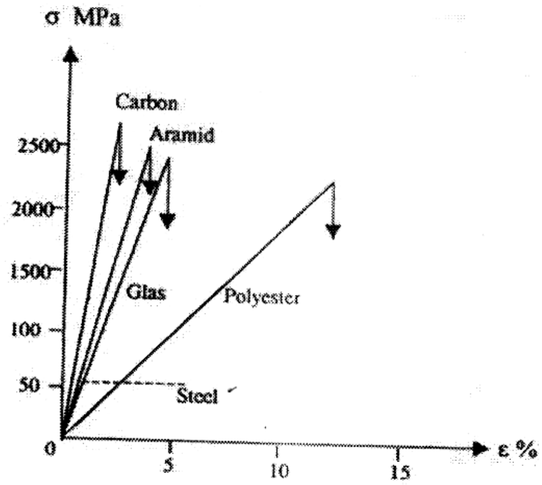

Fig 1 Materials for Strengthening of Structures [12]

1.3 Types and Properties of FRP Used for Strengthening

The main fibre types used are glass (GFRP) , carbon (CFRP), and aramid (AFRP). There are two types of GFRP – E-glass and AR-glass. E-glass is the most commonly using GFRP but it has the disadvantages that it is attacked by the alkali in fresh concrete grout. AR-glass (AR = alkali resistant) is the example to this.

E-modulus (hence ultimate strain and ultimate tensile strength) is the defining property of all FRPs and it dictates the preferred uses for each generic type [13]. Typical properties are given in Table (1)

Table 1, Properties of FRP Composites

Types of FRP composite	E-modulus (GPa)	Ultimate strain (%)	ultimate tensile strength (MPa)
CFRP(Laminate)	165-215	1.3-1.4	2500-3000
CFRP(sheet)	240-640	0.4-1.6	2650-3800
GFRP(sheet)	65-75	4.3-4.5	2400
AFRP(sheet)	120	2.5	2900

1.4 Methods of Shear Strengthening

The shear strength of RC beams can be substantially increased by bonding FRP strips or sheets as external shear reinforcement. The RC beams may be shear strengthened in various ways: [6]

(i) Complete wrapping

The whole cross section of beam is covered by FRP. This beam is called wrapped beams.

(ii) U- jacketing

FRP jackets covers the two sides and tension face of the beam.

(iii) Side bonding

FRP strips bonded to the sides of the beams only.

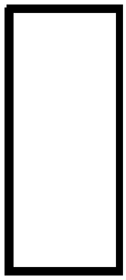

Fig 1 Complete wrapping

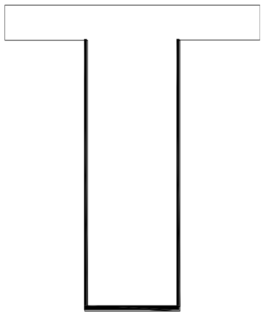

Fig 2 U-jacketing

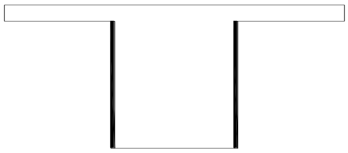

Fig 3 U Side bonding

AIM OF THE INVESTIGATION

Numerous research works has been done on beams strengthened using FRP composites. However, only few works have been done using CFRP composites. This project aims at studying the effectiveness of using CFRP(S) for strengthening of beams failing in shear.

Scope of the Present Study

It is a well known fact that carbon fibre continuous tow CFRP(C) is very effective in strengthening of RC structural elements. However it is less popular in India due to its high cost. Hence, in this thesis work an investigation has been made to study the effectiveness of using **carbon fibre scrap CF(S)** for strengthening of RC beams failing in shear and also aims at studying the effectiveness of using CFRP(S) both as monolithic fibre composite and hybrid fibre composite. In hybrid fibre composite the behaviour of CFRP(S) along with Glass fibres and CFRP(C) for rehabilitation of RC beams failing in shear has been investigated. The parameters considered for study are

i. Initial cracking load
ii. Ultimate load
iii. Energy absorption
iv. Stiffness at yield and ultimate loads
v. Deflection ductility and
vi. Load-deflection characteristics

RC beams failing in shear were taken for study and they were rehabilitated using the following FRP composites using hand lay-up technique:

- Carbon Fibre Continuous Tow [CFRP(C)] Composite
- Carbon Fibre Scrap [CFRP(S)] Composite
- Glass Fibre [GFRP] Composite
- Hybrid combination of CFRP(C) and GFRP composite- [H-CF(C)-GFRP]
- Hybrid combination of CFRP(S) and GFRP composite- [H-CF(S)-GFRP]
- Hybrid combination of CFRP(C) and CFRP(S) composite- [H-CF(C)-CF(S)RP]

The FRP composites listed above were bonded to the sides and bottom of the RC beams in the form of U-wraps as discussed by

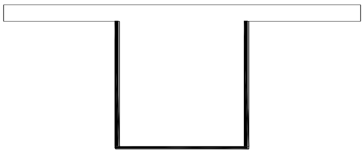

Figure 5 U-Wrap

Epoxy resin was used for bonding the fibres to the beams. The behaviour of CFRP(S) treated beams were compared with those of their control beams (beams tested to failure without treatment) and those treated using other composites.

Details of RC Beam

Fourteen beams of size 150 × 150 × 1000mm were taken for study as shown in figure (3.2). Two beams were used as control beams and twelve beams were rehabilitated using CFRP composites. As per requirements 3 nos. of 10mmdia bars were provided on tension side. In order to hold the stirrups, 2nos. of 8mm diameter rods were provided on the compression side also. In order to introduce shear failure in the beams, the spacing of stirrups was increased to 250mm.

Reinforcement Details of Beam

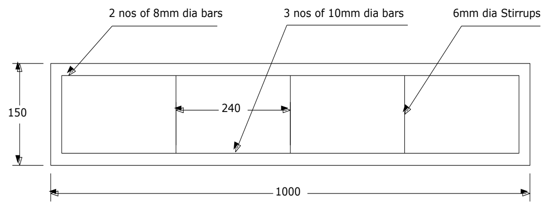

Fig 6 Longitudinal Section of Beam

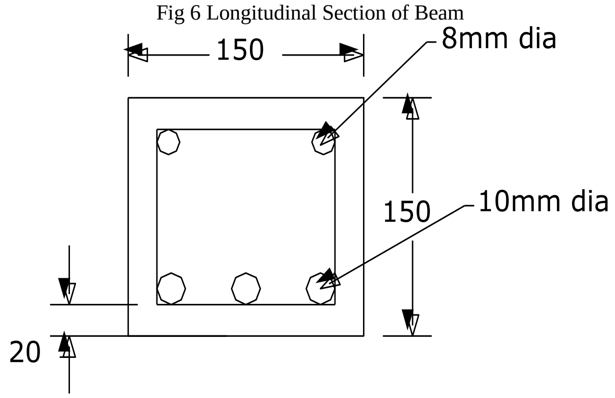

Fig 7 Transverse Section of Beam

MATERIALS USED FOR CASTING BEAMS

(i) Cement: Ordinary Portland Cement (OPC) of 53 grade was used for the investigation.

(ii) Fine Aggregate: Sand passing through IS 4.75 mm sieve conforming to zone II as per IS standard specifications. Specific gravity of fine aggregate was 2.63

(iii) Coarse aggregate: Crushed granite aggregate passing through IS 20mm sieve and retained on IS 10mm sieve were used. Specific gravity of coarse aggregate was 2.78

(iv) Steel: Tor steel of Fe 415 grade was used as longitudinal reinforcement where as mild steel Fe 250 was used as transverse reinforcement.

Table 2 Physical properties of coarse aggregate

Sl.no	Characteristics	Value
1	Type	Crushed
2	Specific gravity	2.64
3	Water absorption	0.5%
4	Bulk Density	1.38
5	Fineness modulus	7.88

Table3 Physical properties of cement

Sl.no	Name of the test	Result
1	Fineness test	7%
2	Standard consistency test	26%
3	Specific gravity	3.14

V RESULT

Test result for Normal Concrete(M_{20})	
Compressive strength	14 days: 24.50 N/mm^2
	28 days: 30.93 N/mm^2
Split tensile strength	28 days: 2.21 N/mm^2
Flexural strength	28 days: 2.89 N/mm^2

Comparison of Concrete Beam with CFRP Beam

Three reinforced beams one control beam, one beam wrapped with CFRP sheet and one beam with induced crack then wrapped with CFRP (retrofitting) were made and tested to failure. The beam were of size 150 x 150 x 1000mm

The beams were casted in moulds and were cured for 28 days. 3 point loading test was performed on beams till failure.
The control beam (S_1) failed at 30.93KN. Load applied on the beam S_2 to produce cracks. Both S_2 and S_3 where wrapped in CFRP sheets by hand lay-up method using epoxy resin and hardener, mixed proportionately at 2:1 ratio.
The beams where then loaded to failure and corresponding values where recorded.

SL.NO	S_1	S_2	S_3
Ultimate load	30.93	44.69	54.79

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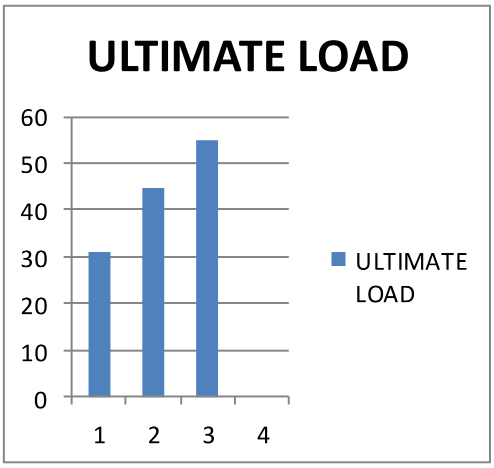

RESULTS AND DISCUSSION

- Wrapping CFRP sheets over the beam S_3 and testing it showed 77.14% increase in bearing strength compared to the beam S_1 without CFRP.
- Appearance of crack was delayed when wrapped with CFRP sheets.
- The failure mode of the control beam is a typical bending failure pattern. For the beams strengthened with CFRP sheets, appearance of cracks delayed.
- There were two major failure modes for the beams strengthened, i.e. snapping and deboning of CFRP sheets, and shear cracks propagated towards the loading point accompanied by deboning of the CFRP sheets.

CONCLUSION

- Wrapping CFRP enhances overall performance of RC members due to its high resistance to varying load.
- Anisotropic response to loads makes CFRP to be used not only for strengthening but also for enhancing compressive and dissipating seismic loads too.
- Epoxy resin plays an important role in imparting strength to members by providing adequate binding strength to CFRP sheets and making the structure more durable.
- CFRP sheets can be easily wrapped and the procedure is simple since its being bonded externally.
- CFRP wrapping is an effective method of retrofitting since it's easy to wrap CFRP and it requires less deterioration of existing structure.

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