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Shear Strengthening the RC Member with GFRP Stirrups

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ABSTRACT : 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 RC beams failing in shear are to be taken for study 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]

KEYWORDS: Glass Fibre Reinforced Polymer (GFRP), Shear Strengthening, Jacketing, Wrapping, Compressive strength, Tensile strength, Flexural strength.

I. INTRODUCTION

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. The use of lay-up FRP composites under increased load conditions reveals a reduced deflection and smaller crack widths. 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 stiffness, high fatigue strength and good durability make it an excellent choice for infrastructure strengthening. Compared to traditional methods used for infrastructure strengthening that involve partial or complete shutting down of facilities, strengthening involving FRP laminates is less time consuming and does not involve large displacements of the resources.

Various RC structural elements such as beams, slabs and columns can be strengthened using externally bonded FRP sheets. In recent years several studies have been conducted to investigate the flexural strengthening of RC members. However, few have concentrated on shear strengthening. The importance of shear strengthening may be considered 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. Deficiencies in shear can be due to: [23]

- insufficient shear reinforcement,
- use of outdated codes,
- a reduction in the steel area due to corrosion, or
- an increase in the service load due to change of occupancy for the structure

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1. FIBRE REINFORCED POLYMER COMPOSITE MATERIALS

FRP composite materials consist of fibres embedded in or bonded to a matrix with distinct interfaces between them. In this form, both fibres and matrix retain their physical and chemical identities, but they produce a combination of properties that cannot be achieved with either of the constituents acting alone. In general, fibres are the principal load carrying members, while the surrounding matrix keeps them in the desired location and orientation, acts as a load transfer medium between them, and protects them 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 continuous lengths or in discontinuous (chopped) lengths.

A polymer used as a matrix, is defined as a long chain molecule containing one or more repeating units of atoms, joined together by strong covalent bonds. Polymers are divided 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.

APPLICATION OF FIBRE REINFORCED COMPOSITES IN STRUCTURES

FRPs can be used in the concrete structures in the following forms:

- Plates - at a face of structural elements to improve the shear capacity.
- Bars - as reinforcements in beams and slabs, replacing the steel bars.
- Cables- as tendons and post tension members in suspension and bridge girders.
- Wraps- around concrete members to confine concrete and improve the compressive strength.

MATERIALS FOR STRENGTHENING OF STRUCTURES

Figure (1.1) presents a comparison of stress-strain behaviour of materials that are available for strengthening of structures. It can be seen that a non metallic fibres have strengths that are 10 times more than that of steel. The ultimate strain of these fibres is also very high. In addition, density of these materials is approximately one- third that of steel. Due to its corrosion resistance FRPs can be applied on the surface of the structure without worrying about its deterioration due to environmental attack. They in turn protect the concrete core from environmental attack.

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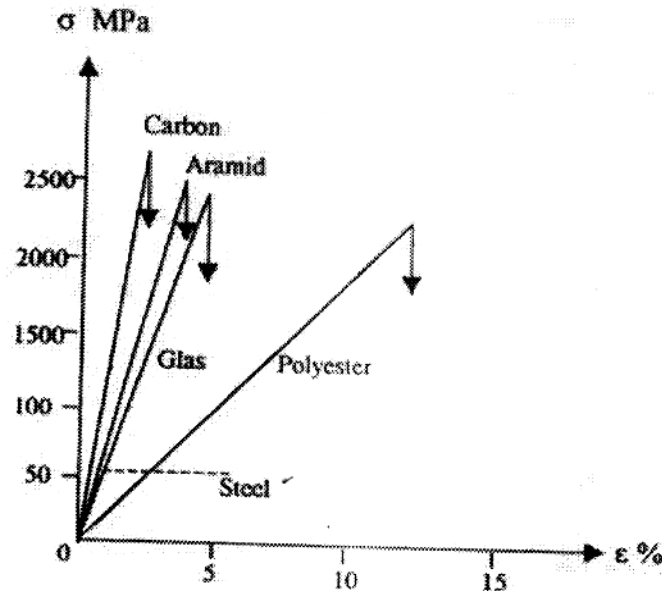


Fig 1.1 Materials for Strengthening of Structures

TYPES AND PROPERTIES OF FRP USED FOR STRENGTHENING

The main fibre types used are carbon (CFRP), glass (GFRP) and aramid (AFRP). GFRP comes in two types – E-glass and AR glass. E-glass is the most common form used but it has the disadvantages that it is attacked by the alkali in fresh concrete grout. AR-glass (AR = alkali resistant) is the answer to this [24].

E-modulus (hence ultimate strain and ultimate tensile strength) is the defining property of all FRPs and dictates the preferred uses for each generic type. Typical properties are given in Table (1.1)

Table (1.1) Properties of FRP Composites

Types of FRP composite	E-modulus (GPa)	Ultimate strain (%)	ultimate tensile strength (MPa)
CFRP(Laminated)	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

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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]

- **Complete wrapping**

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

- **U- jacketing**

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

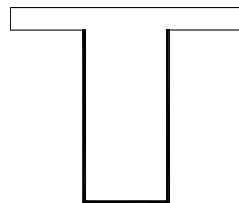
- **Side bonding**

FRP strips bonded to the sides of the beams only.

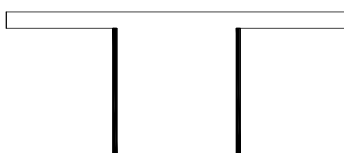
These types are shown in Figure (1.2)



a. Complete wrapping



b. U-jacketing



c. Side bonding

Figure (1.2) Methods of Shear Strengthening

SHEAR REINFORCEMENT SPACING

The transverse FRP reinforcement may be in the form of a continuous wrap or as spaced strips as illustrated in Figure (1.3). The use of strips may be effective in optimizing the amount of material used.

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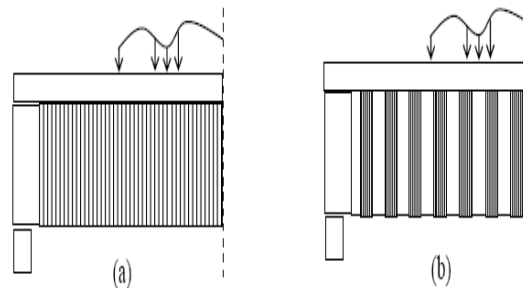


Figure (1.3) Shear Reinforcement Distributions (a) Continuous (b) Strips

FIBRE ORIENTATION

FRP is an anisotropic material with high strength in the direction of the fibres, the fibres may be oriented in such a way to best reinforce diagonal tension cracks. This is achieved by the use of inclined strips Figure (1.4). However, vertical plies are easier to install just as in the case of vertical and inclined stirrups.

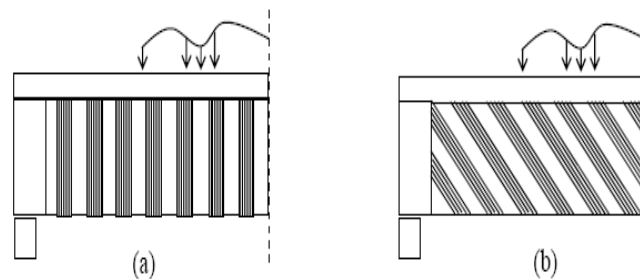


Figure (1.4) Fibre Orientations (a) 90° wrap (b) 45° wrap

II. EXPERIMENTAL PROGRAMME

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. This thesis 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

- Initial cracking load
- Ultimate load
- Energy absorption
- Stiffness at yield and ultimate loads
- Deflection ductility and
- Load-deflection characteristics

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 8, Issue 4, April 2019

METHODOLOGY USED IN THE WORK

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 **Zhicago Zhang, 2005 [30]** as shown in Figure (3.1).

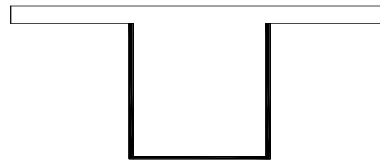
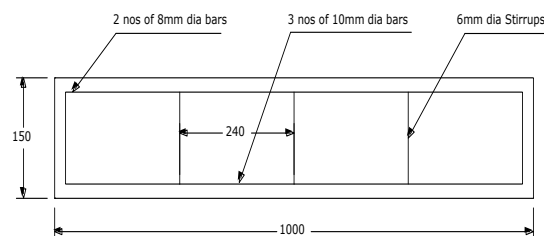


Figure (3.1) U-Wrap

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 $150 \times 150 \times 1000$ mm were taken for study as shown in figure (3.2). Two beams were used as control beams and twelve beams were rehabilitated using FRP composites. As per requirements 3 nos. of 10mm dia 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.



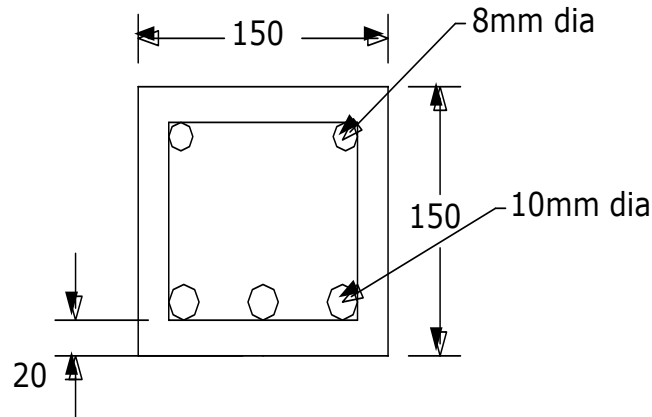
(a) Longitudinal Section of Beam

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Vol. 8, Issue 4, April 2019



(b) Transverse Section of Beam

Figure (3.2) Reinforcement Details of Beam

MATERIALS USED FOR CASTING BEAMS

- **Cement:** Ordinary Portland Cement (OPC)-53 grade was used for the investigation.
- **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
- **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
- **Steel:** Tor steel of Fe 415 grade was used as longitudinal reinforcement where as mild steel Fe 250 was used as transverse reinforcement.
- **Mix proportion:** The mix proportion of **1: 1.58: 3.46** with W/C ratio of **0.55** was used for casting of all the beams. The average compressive strength of concrete was found to be 29.11 N/mm².

III. SUGGESTIONS FOR STUDY

- To study the effectiveness of the treatment measure for various transverse steel reinforcement ratios of beams and various FRP ratios.
- Different patterns of wrapping of fibres to study its effectiveness could be made.
- The effectiveness of FRP composite treatment measure can be studied for various cross-sections and different structural elements.
- Analytical procedures for reinforced concrete and masonry wrapped with FRP materials have to be developed, validated and implemented through laboratory testing.
- Behaviour of different loading conditions could be tried.
- The effectiveness of using FRP composites with polyester resin in rehabilitation of structural elements could be studied.
- Economization of resin by adding filler materials and its effect on the performance of the treated beams could be tried.

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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

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

Mix proportion

Water	Cement	Fine Aggregate	Coarse Aggregate
186	340 Kg/m ³	644 Kg/m ³	1178 Kg/m ³
0.50	1	1.89	3.46

IV. 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

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Vol. 8, Issue 4, April 2019

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Vol. 8, Issue 4, April 2019

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