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EXPERIMENTAL INVESTIGATION ON BEHAVIOR OF CONCRETE STRENGTHENED WITH GFRP WRAPPING

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ABSTRACT

Nowadays, repair, rehabilitation, and strengthening of surviving structures play a significant part in the construction industry. Numerous old structures are to be retrofitted to bear higher loads. A promising and innovative retrofitting system for concrete structures requires the use of externally bonded Fiber Reinforced Polymer (FRP) composites. Furthermore, the increasing number of development activities need to strengthen the existing buildings to enable them to take additional loads. In this paper, an effort has been made to examine the effect of GFRP flexible wrapping on Beams to enhance the load carrying potential of beams and to assess the behavioral improvement of GFRP composites on beams. This paper exhibits the results of experimental investigations on concrete beam restricted with high-strength Glass Fiber Reinforced Polymer (GFRP) composites. The various parameter fiber orientations were considered. Various wrap fiber orientation of 0^{o}, 90^{o}, $\pm 45^{o}$ and mixtures of them were examined. The results confirmed a notable improvement in the compressive strength and stiffness of the GFRP-wrapped concrete beams.

Keywords: repair, rehabilitation, retrofitting, Fiber Reinforced Polymer, Glass Fiber Reinforced Polymer

I. INTRODUCTION

Retrofitting of concrete structures is done to withstand higher design loads and to minimize the rate of deterioration, with the help of conventional building materials. The FRP composite laminates are produced by fibers and resins. (Balasubramanian et.al.2007), n FRP system, the resins and coating are used to bind the concrete substances and to improve the aesthetic appearance of the structure. This system consumes high tensile strength and is non-corrosive in nature. Inspite of its light weight those materials are wrapped around the structure to strengthen it and present an aesthetic look. The wrapping is necessary to fit the structure before the attachment of polymer resin.

Hence the FRP systems are costlier than conventional materials, skilled labor and equipment are necessary for installation of the FRP system. It is highly challenging while execution process takes place. Many systems have been used for strengthening the existing RC Beams using FRP composites (BIS: 456-2000, Balasubramanian et al., 2007, Barros et al., 2007, Kao et al., 2007, Karim et al., 1994).

II.MATERIAL USED

In this study, the following materials were used to strengthen the existing RC beams with FRP laminates.

- Ordinary Portland Cement:
  - Specific gravity – 2.95
- Natural river sand or Fine aggregate:
  - Specific gravity – 2.95
  - Fineness modulus – 3.04
- Gravel or Coarse aggregate:
  - Specific gravity – 2.90
  - Fineness modulus – 5.40

III.MATERIAL PROPERTIES

Properties of FRP

1. **Tensile Behavior:** There are various factors which govern the stiffness and tensile strength characteristics of FRP material, such as type, shape and orientation of fiber. The tensile strength of FRP material was ruled by quantity of fibers used in the mix. FRP repair system was mainly based on type of fiber and method of usage; it did not depend on the net fiber area. The mechanical properties of these systems were based on the examinations done on samples with known amount of fiber content.
2. **Compressive Behavior:** The FRP laminates failed due to longitudinal compression which includes shear failure. It depends on the type and quantity of fiber used. The tensile strengths of GFRP, CFRP & AFRP were 55%, 78% and 20% of their compressive strength respectively. Based on literatures, the modulus of elasticity of GFRP, CFRP and AFRP under compression was 80%, 85% and 100% of modulus of elasticity respectively under tension of the same material. (Barros, et al., 2007)

Physical Properties:

1. **Density:** Density of FRP materials will range from 75-130 lb/ft^3($1.2 - 2.1 g/cm^3$), it is 4 – 6 times lower than the density of steel. Reduction in density of FRP material offers various advantages like lower transportation cost, easy handling of materials and reduction in dead load.

Table 1: Density of various FRP materials lb/ft³ (g/cm³)

Steel	GFRP	CFRP	AFRP
490	75 - 130	90 - 100	75 - 90

2. **Coefficient of thermal expansion:** The co-efficient of thermal expansion of FRP materials depend on the type of fiber, type of resin and quantity of fiber content. Negative sign in co-efficient thermal expansion indicates that FRP materials contract with rise in temperature and expands with drop in temperature. Concrete has a thermal expansion co-efficient of $4 x 10^{-6}$ to $6 x 10^{-6}$ /°F.

Table2: Co-efficient of thermal expansion of FRP materials

Direction	Thermal expansion Co-efficient $x10^{-6}$/°F($x10^{-6}$ /°C)		
	GFRP	CFRP	AFRP
Longitudinal	3.3 to 5.6 (6 to 10)	-0.6 to 0 (-1 to 0)	-3.3 to -1.1 (-6 to -2)
Transverse	10.4 to 12.6 (19 to 23)	12 to 27 (22 to 50)	33 to 44 (60 to 80)

3. **Effect of high temperature:** Glass Transition temperature (T_g) is known as the temperature When amphora's material changes from brittle, vitreous state to a plastic state. Beyond this temperature, due to its molecular rearrangement, modulus of elasticity of polymer isreduced. It depends on the type of resin used. FRP composite material shows better thermal characteristics compared to resin. It happens when glass and aramid fibers reach 1800 °F and 350°F respectively. From the test results, higher T_g value reduces the tensile strength of about 20% in GFRP and CFRP (Karim, et al., 1997)

Test Specimens: A total 9 concrete Beam of size 150mm X 230mm X 1200mm and 9 concrete cubes of size150mmX150mm, all specimens, were moist cured for 28 days at room temperature. The cylinder specimens were divided into three groups consisting of 3-cylinder specimens confined with WRM at 45° inclination in group I, 3 confined with WRM at 90 ° in group II and 3 unconfined (control) in group III. Specimens confined with WRM at 45°, were designated as I_1, I_2 and I_3. And specimens confined with WRM at 90 ° were designated as S_1, S_2 and S_3. Similarly, unconfined cylinders were designated as C_1, C_2 and C_3 and concrete cubes as 7_1,7_2,7_3 14_1,14_2,14_3,28_1,28_2 and 28_3 respectively.

Procedure to bond FRP: The concrete Beam cured as above was cleaned to remove any dust particles and completely dried before the resin application. The solution was made with a mixture of polyester resin, catalyst (Methyl Ethyl Ketone Peroxide) and accelerator (Benzyl Peroxide). Accelerator and catalyst of 5ml each was utilized in the preparation of 1litre of resin. Then GFRP sheet was directly applied on the surface and proper care was taken to make a zero-void bonding. (Kao, 1997).

IV.TEST SPECIMENS: Concrete cylinders of 28 days and concrete cubes of 7 days were going to be tested for the average compressive strength. The concrete beams will be confined by wrapping them with glass fiber reinforced plastics. The Woven Roving Mat (WRM) having a density of 610g/m² was going to be used. The resin systems to be used in this work were the general purpose Isothalic resin.

Test Procedure: All the specimens were left at room temperature for at least 7 days before testing. This was done to ensure that the resin had enough time to cure. They were kept at room temperature for 28 days. All specimens were loaded in axial compression until failure, using a Universal Testing Machine (UTM) or compression testing machine (CTM).

V.RESULTS AND DISCUSSIONS

1. Compressive strength of concrete

Table 3: Test results for cubes

Curing in Days	Specimen Identification	Stress N/mm²	Avg stress in N/mm²
7	7_1	9.33	9.55
	7_2	9.77	
	7_3	9.55	
14	14_1	18.67	18.44
	14_2	18.22	
	14_3	18.44	
28	28_1	27.55	28.00
	28_2	28.44	
	28_3	28.00	

Specimen 1: (7_1, 14_1 and 28_1):

- 7_1–By testing the compressive strength in CTM the values were found to be 9.33 N/mm².
- 14_1–By testing the compressive strength in CTM the values were found to be 18.67 N/mm².
- 28_1–By testing the compressive strength in CTM the values were found to be 27.55 N/mm².

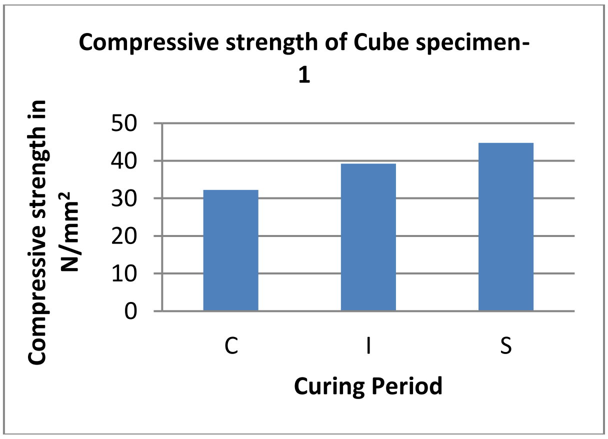

Fig. 1: Compressive strength of Cube specimen-1

Specimen 2: (7_2, 14_2 and 28_2):

- 7_2 –By testing the compressive strength in CTM the values were found to be 9.77 N/mm^2.
- 14_2 –By testing the compressive strength in CTM the values were found to be 18.22 N/mm^2.
- 28_2 – By testing the compressive strength in CTM the values were found to be 28.44 N/mm^2.

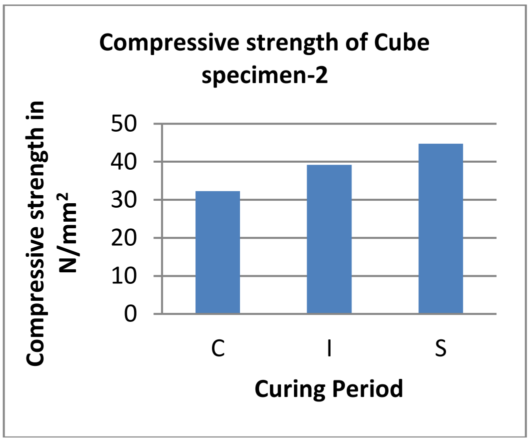

Fig. 2: Compressive strength of Cube specimen-2

Specimen 3: (7_3, 14_3 and 28_3):

- 7_3 – By testing the compressive strength in CTM the values were found to be 9.55 N/mm^2.
- 14_3 – By testing the compressive strength in CTM the values were found to be 18.44 N/mm^2.
- 28_3 – By testing the compressive strength in CTM the values were found to be 28.00 N/mm^2.

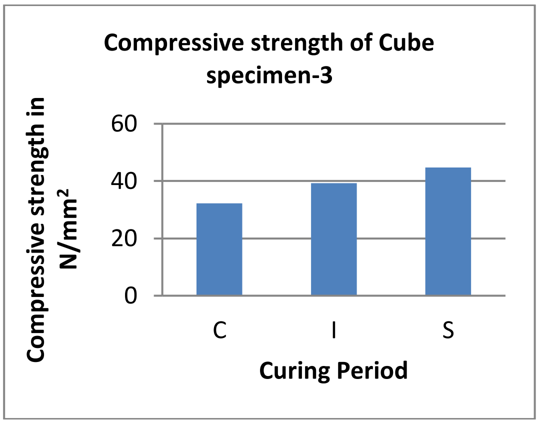

Fig. 3: Compressive strength of Cube specimen-3

Average stress for specimen (7, 14 and 28):

- 7 – By testing the compressive strength in CTM the values were found to be 9.55 N/mm^2.
- 14 – By testing the compressive strength in CTM the values were found to be 18.44 N/mm^2.
- 28 – By testing the compressive strength in CTM the values were found to be 28.00 N/mm^2.

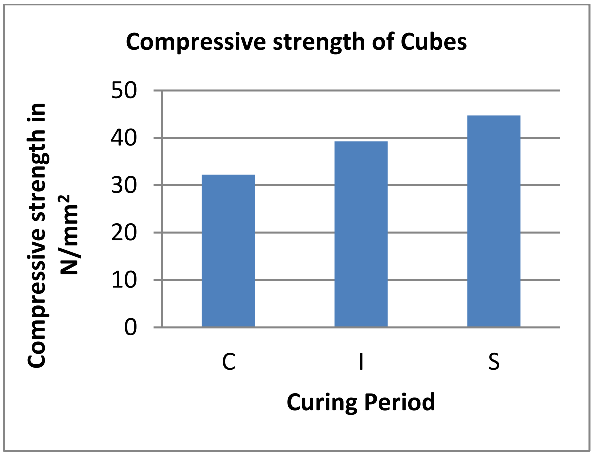

Figure 1: Compressive strength of Cubes

Table-4: Test results for Beam

Specimens	Specimen Identification	Stress N/mm^2	Avg stress in N/mm^2
Beam	B1	31.12	32.25
	B2	33.52	
	B3	32.12	
GFRP applied at 45^0	I1	39.61	39.23
	I2	40.74	
	I3	37.35	
GFRP applied at 90^0	S1	45.27	44.73
	S2	44.70	
	S3	44.22	

Specimen 1: (B_1, I_1 and S_1):

- B_1 –By testing the Flexural strength in Loading Frame the values were found to be 31.12 N/mm^2.
- I_1 –By testing the Flexural strength in Loading Frame the values were found to be 39.61 N/mm^2.
- S_1 –By testing the Flexural strength in Loading Frame the values were found to be 45.27 N/mm^2.

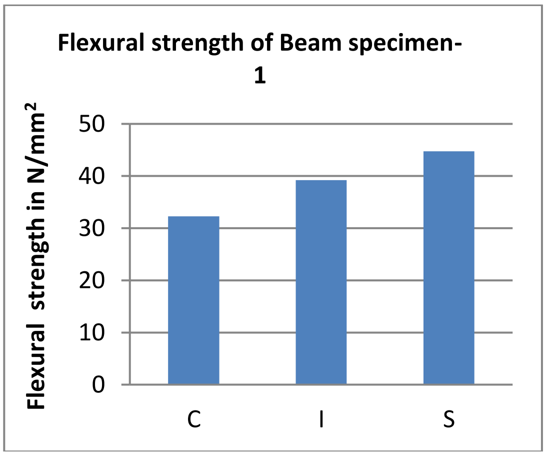

Fig. 4: Flexural strength of Beam specimen-1

Specimen 2: (B_2, I_2 and S_2):

- B_2 –By testing the Flexural strength in Loading Frame the values were found to be 34.52 N/mm^2.
- I_2 –By testing the Flexural strength in Loading Frame the values were found to be 40.74 N/mm^2.
- S_2 –By testing the Flexural strength in Loading Frame the values were found to be 44.70 N/mm^2.

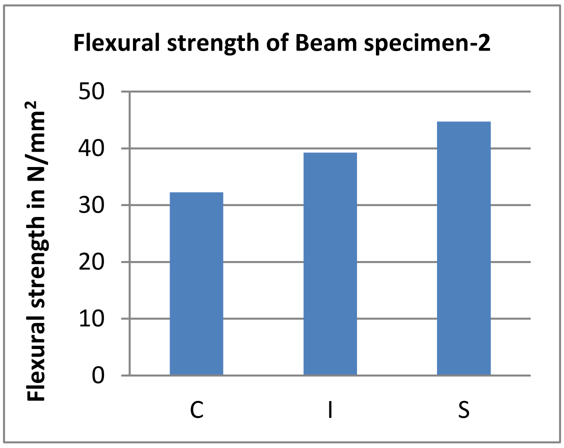

Fig. 5: Flexural strength of Beam specimen-2

Specimen 3: (B_3, I_3 and S_3):

- B_3 –By testing the Flexural strength in Loading Frame the values were found to be 31.12 N/mm^2.
- I_3 –By testing the Flexural strength in Loading Frame the values were found to be 37.35 N/mm^2.
- S_3 –By testing the Flexural strength in Loading Frame the values were found to be 44.22 N/mm^2.

Table 5: Test Avg results for Beam

Specimens	**Specimen Identification**	**Stress N/mm^2**	**Avg stress in N/mm^2**
Beam	B1	32.22	32.25
	B2	32.42	
	B3	32.12	
GFRP applied at 45^0	I1	40.61	39.23
	I2	39.64	
	I3	37.45	
GFRP applied at 90^0	S1	45.37	44.73
	S2	45.70	
	S3	43.12	

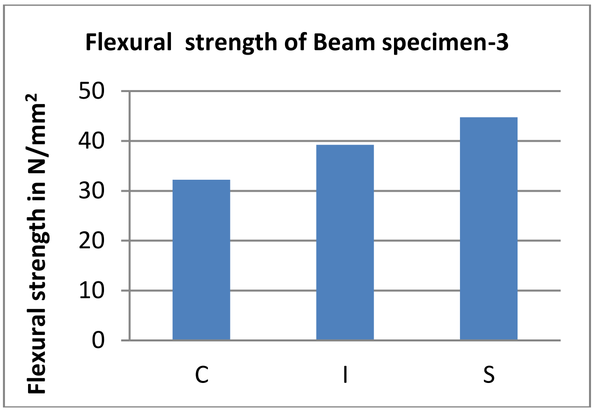

Fig. 6: Flexural strength of Beam specimen-3

Average stress for specimen (B, I and S):

- B –By testing the Flexural strength in Loading Frame the values were found to be 32.25 N/mm^2.
- I – By testing the Flexural strength in Loading Frame the values were found to be 39.23 N/mm^2.
- S –By testing the Flexural strength in Loading Frame the values were found to be 44.73 N/mm^2.

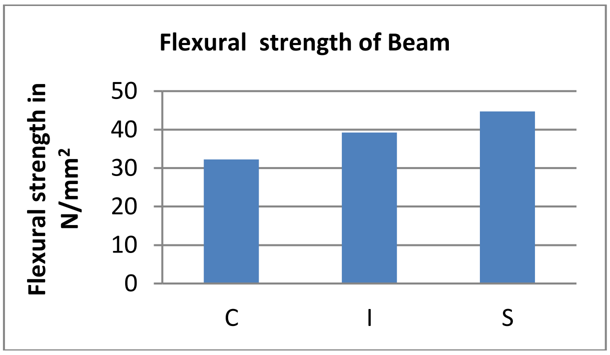

Fig. 7: Flexural strength of Beam

VI. CONCLUSION

Based on the test result the Glass Fibers Reinforced Polymer composites the following conclusions have been drawn:

- The usage of GFRP wrappings results in improving the compressive strength.
- The load carrying capacity of plain concrete beam is increased by wrapping with GFRP flexible wraps.
- The increase in stiffness varies with the imposed displacement level and reaches higher values
- The Flexural strength increases by about 27.2% for beam wrapped with GFRP at 45 degree.
- The Flexural strength increases by about 49% for beam wrapped with GFRP at 90 degree.

- The load carrying capacity of plain concrete beam is increased by jacketing with GFRP flexible wraps.

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