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Flexural Behaviour of Hybrid Fibre Reinforced Concrete Beams Strengthened with FRP Laminates

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Abstract- The use of fibre reinforced polymer for structural strengthening and rehabilitation is becoming more popular due to its high strength to weight ratio, good fatigue life, good corrosion resistance and low maintenance cost. The fibre reinforced polymer laminates are introduced to enhance the flexural capacity and ductility of hybrid fibre reinforced concrete (HFRC) beams. This paper presents the results of experimental and analytical studies conducted on HFRC beams strengthened with glass fibre reinforced polymers (GFRP). A total of six beams with a volume fraction of 1% (80% of steel fibre and 20 % of polyolefin fibre) were cast and strengthened with two types of GFRP laminates with varying thickness. The results obtained through experiments were compared with the analytical results. The results show that GFRP strengthened HFRC beams exhibit increased strength, ductility and flexural stiffness.

***Index Terms*- ANSYS, Fibre Reinforced Polymer (FRP); Finite Element Modeling; Polyolefin Fibre; Steel Fibre.**

I. INTRODUCTION

The addition of randomly distributed discrete fibres to the structural concrete increases its stiffness, ductility and load carrying capacity with reduced cracks. Fibres are effective in arresting both micro and macro cracks. In this study steel fibres and polyolefin fibres are combined to produce a hybrid system. Due to lack of information on the ductile performance of hybrid fibre reinforced concrete beams, an attempt has been made to examine the ductile performance of hybrid fibre reinforced concrete beams strengthened with GFRP laminates. The concept of incorporating different type of fibres in cement matrix will offer more engineering properties, because the presence of one fibre enables the more effective utilization of the potential properties of other fibre which results in improved flexural rigidity with controlled cracks.

Kim et al. conducted a study on bending response of fibre reinforced cementitious composites with three different sizes. They concluded that the flexural strength increased with a decrease in size of specimen. Nagabhushanam et al. conducted a study on fatigue strength of fibrillated polypropylene fibre reinforced concrete. They reported that polypropylene fibre reinforced concrete beams can sustain loads beyond the first crack load, but at reduced load level. This post-crack reduction in load carrying capacity decreases as the fibre content increases. Glavind et al. studied the behaviour of normal strength concrete and high strength concrete having different volume fractions of steel and polypropylene fibres. The hybrid mixes, 0.5% by volume of steel and 0.5% by volume of polypropylene fibres were used in the study. They reported that hybridization of these two fibres increase the ultimate compressive strain of the composite. Horiguchi et al. conducted a permeability test on hybrid fibre reinforced concrete containing long and short steel fibres. The permeability of hybrid fibre reinforced concrete showed a lower value than that of the plain concrete. Henrik et al. studied the behaviour of FRP strengthened concrete beams. They proposed a non-linear RC beam element model with bond slip between the concrete and FRP plate. The variables included plate length, plate width, plate stiffness and loading time. They compared beams strengthened in flexure with plates of different axial stiffness of CFRP and GFRP. The authors concluded that GFRP may be a better choice for beams under distributed loads in RC buildings.

Wolanski investigates the use of finite element model for the analysis of reinforced pre-stressed concrete beams. A mild reinforced concrete beam with flexural and shear reinforcement was analyzed to failure and compared to experimental results to calibrate the parameters in ANSYS. The deflections and stresses at the centre line along with initial and progressive cracking of the finite element model were comparable with experimental data obtained from a reinforced concrete beam was modeled quite well and the failure load predicted was very close to the failure load measured during experimental testing. Deflection and stresses at the zero deflection point are modeled well using a finite element package. The load applied to cause initial cracking of the pre stressed concrete beam compare well with hand calculations. Flexure failure of the pre stressed concrete beam was modeled well using finite element package and the load applied at failure was very close to hand calculation results.

Ming-Hung Hsu conducted a study on concrete beams strengthened with externally bonded Glass fibre reinforced plastic plates. Finite element method was employed in stimulating the behaviour of reinforced concrete beams. The results of four-point bending test on beams strengthened with externally bonded GFRP plates showed good concurrence with the analytical results.

Nadeem et al investigated the performance of reinforced concrete beams strengthened with externally bonded FRP composites. The response of control and strengthened beams were compared. The authors observed the tension side bonding of CFRP sheets with U-shaped end anchorages were efficient in flexural strengthening, were as inclined CFRP strips bonded to the side of RC beams are very effective in improving the shear capacity of beams. Tarek et al. studied the load deflection behaviour of RC beams strengthened with GFRP sheets subjected to different environmental conditions. The performances of the specimens were assessed through evaluating the flexural capacity and load deflection relationship of the beams after placing them in different environments. The authors showed that GFRP strengthened beams exhibit increased flexural strength and ductility to a great extent.

II. MATERIALS AND METHODS

A. *Beam Details*

A total of six beams of size 150mm x 250mm x 3000mm were cast and tested. Four beams were strengthened with chopped strand mat and woven roving glass fibre. The fibre reinforced polymer has varying thickness of 3mm and 5mm. All the beams were reinforced with 2-12mm dia bars in the tension face and 2-10mm dia bars were used as hanger bars. The shear reinforcement consisted of 8mm dia 2-legged stirrups at 150mm c/c spacing. The properties of steel fibres and polyolefin fibres used in the study are given in Table 1. The adopted concrete mix proportion is given in Table 2.

B. *Test Set-up*

All the beams were subjected to four-point bending in a loading frame of 750kN capacity. Mid-span deflections and deflection at loading points were measured using dial gauges of 0.01mm accuracy. The test set-up is shown in Fig. 1.

Table 1 Properties of Fibres

Sl. No	**Fibre properties**	**Fibre Details**	
		Steel	**Polyolefin**
1	Length (mm)	60	54
2	Size/Diameter (mm)	0.75 mm dia	1.22 x 0.732 mm
3	Aspect Ratio	80	39.34
4	Density (kg m-3)	7850	920
5	Specific Gravity	-	10GPa
6	Young's Modulus (GPa)	210	10
7	Tensile strength (MPa)	1225	640
8	Shape	Hooked at ends	Straight

Table 2 Concrete Mix Proportion

Ingredient	Quantity
53 grade OPC	450 kg/m^3
Fine aggregate	780 kg/m^3
Course aggregate 20mm	680 kg/m^3
Course aggregate 12mm	450 kg/m^3
Water	160 lit/m^3
Silica flume	25 kg/m^3
Hyper plasticizer	0.80 %

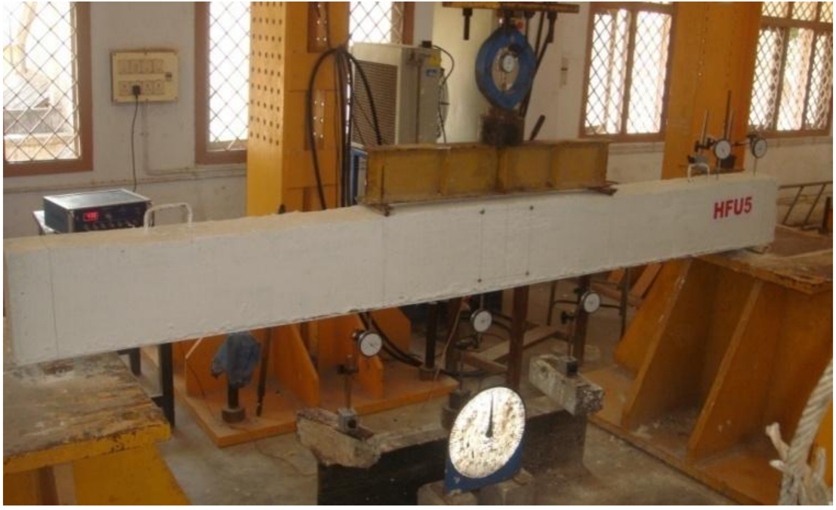


Fig. 1. Test set-up

III. FINITE ELEMENT MODELING

The models developed are based on the finite element method (FEM) implemented in commercial software (ANSYS 14.5). Specific non-linear behaviour of concrete and the elasto-plastic behaviour of steel are taken into account. Generally, there are two approaches to model concrete or cement behaviour. They are (i) the discrete approach (or crack propagation approach), which attempts to reproduce the crack propagation in each element, and (ii) the 'homogenized' approach (smeared crack approach), which simulates a global behaviour of concrete in tension without taking into account the explicit opening of cracks. The main problem with the discrete approach is that, due to the re-meshing process necessary for each load crack step, it is a time consuming method.

A. *Element Type*

The Solid65 element was used to model concrete with smeared cracks. This element has eight nodes with three degrees of freedom at each node (translations in the nodal x, y, and z directions). This element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. The Solid65 element requires linear isotropic and multilinear isotropic material properties to properly model concrete as shown in **Tables 3 and 6**. Link180 element was used to model the steel reinforcement. Two nodes are required for this element with three degrees of freedom at each node, as in the Solid65. The elastic perfectly plastic representation is assumed of reinforcing steel bars in this study. For element Link180 material properties are given in Table 5. Solid185 element was used for GFRP Laminates at the bottom of the beam. This element has eight nodes with three degrees of freedom at each node (translations in the nodal x, y, and z directions). Cracking occurs as soon as stresses in the concrete exceed the tensile strength of the material. For the modeling of crushing, the material is assumed to crush if all principal stresses are in compression. For Solid185 element, the material properties are given in Table 4.

Table 3 Mechanical Properties of Concrete

Young's modulus E_c (MPa)	Poisson ratio μ	Ultimate tensile strength (MPa)	Ultimate compressive strength (MPa)
38327	0.2	5.15	66.5

Table 4 Mechanical Properties of Steel Bars

Young's Modulus E_c (MPa)	Poisson ratio μ	Yield stress (MPa)	Tangent modulus
38327	0.2	415	0

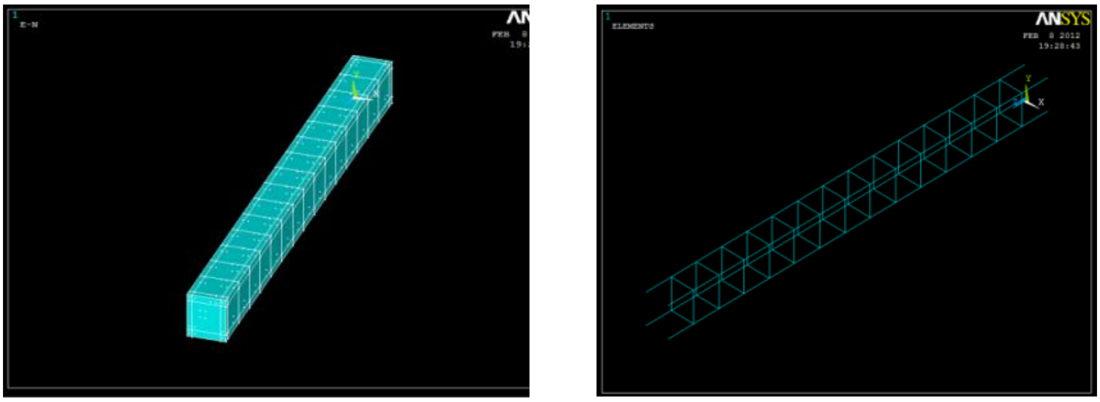
Table 5 Mechanical Properties of GFRP

	Young's Modulus Ec (MPa)	Poisson ratio μ	Tensile Strength (MPa)	Tangent modulus

WR 3mm	6855.81	0.28	181.41	0
WR 5mm	8994.44	0.28	200.70	0
UDC 3mm	13965.63	0.28	617.56	0
UDC 5mm	17365.38	0.28	673.10	0

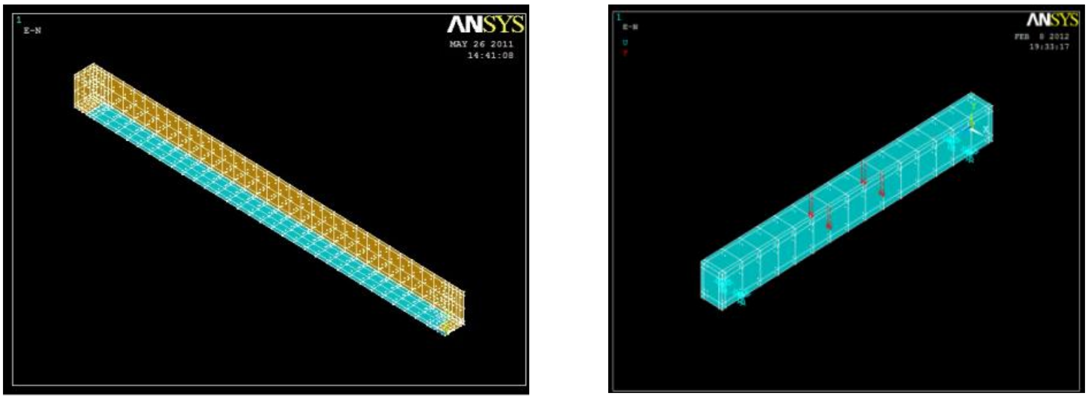
Table 6 Properties of Crushing and Cracking in Concrete Beams

Shear transfer coefficients for an open crack	0.3
Shear transfer coefficients for a closed crack	66.5 MPa
Uniaxial tensile cracking stress	-1
Uniaxial crushing stress	0
Biaxial crushing stressc	0
Ambient hydrostatic stress state	0
Biaxial crushing stress	0



Concrete Beam Modeling

Reinforcement in Beam



FRP wrap in Beam

Loading and Support condition

Fig. 2. Beam Modeling and Loading Condition

Table 7 Test Results

S.No	Beam Designation	Yield Load in kN	Deflection at Yield Load in mm		Ultimate Load in kN	Deflection at Ultimate load in mm	
			Exp	Any		Exp	Any
1	CB	65	5.03	5.55	105	12	10.8
2	HF	100	8.65	7.29	160	17	15.3

3	HFW3	105	7.82	7.95	180	19.8	18.2
4	HFW5	120	8.20	9.25	170	20	20.8
5	HFU3	140	9.10	9.54	185	23	18.72
6	HFU5	160	9.35	8.14	215	26	20.7

IV. LOAD-DEFLECTION RESPONSE

Based on the experimental results, the load-mid span deflection behaviour of Hybrid fibre reinforced concrete beams upto failure were plotted, (Fig.3) compared with the control beams and presented in Table 7. The results of static load tests clearly indicate the superior performance of HFRC beams. The ultimate load carrying capacity of HFRC beams increased upto 63.56%.

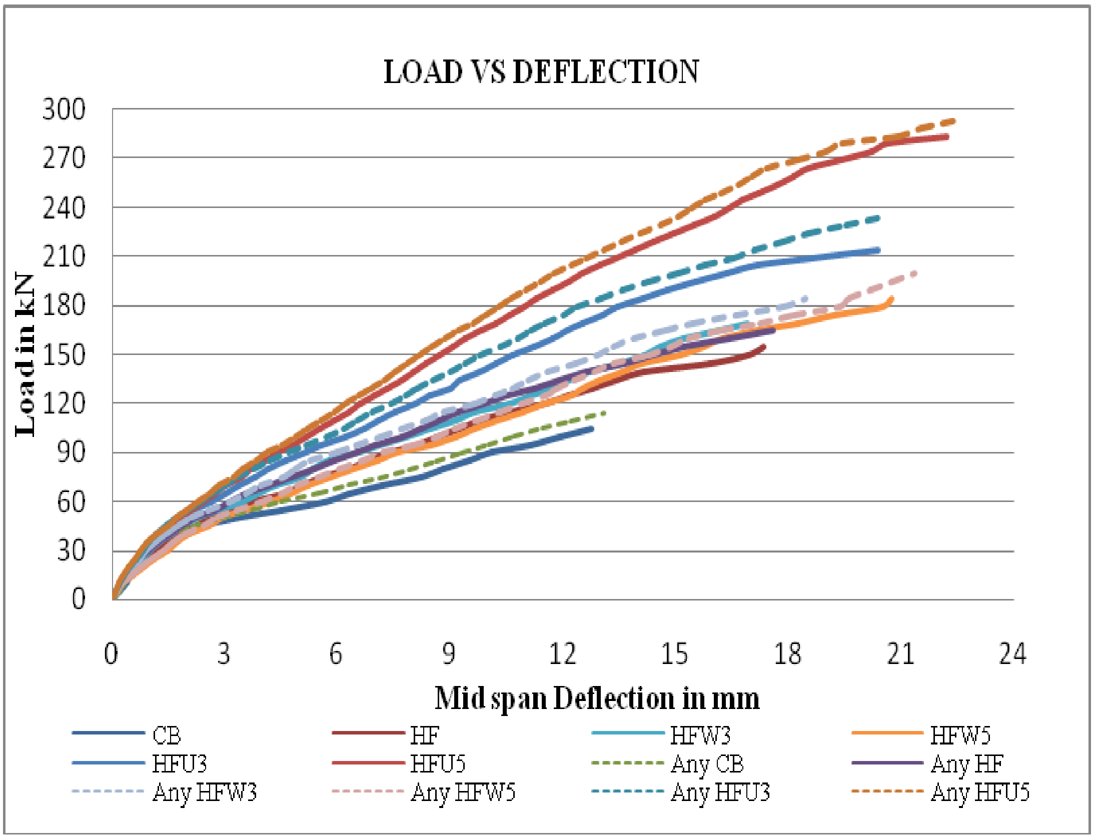


Fig. 3. Load Deflection Response

V. DUCTILITY OF BEAMS

Ductility indices for the tested beams are shown in Figs 4 to 6. The ductility values were calculated based on deflection, curvature and energy absorption. The deflection ductility for the strengthened beam showed a maximum increase of 32.15%. The deflection ductility of HFRC beams with UDC-5mm GFRP laminates showed a maximum increase of 43.51%. The energy ductility of HFRC beams with UDC-5mm GFRP laminates showed a maximum increase of 42. 84%.

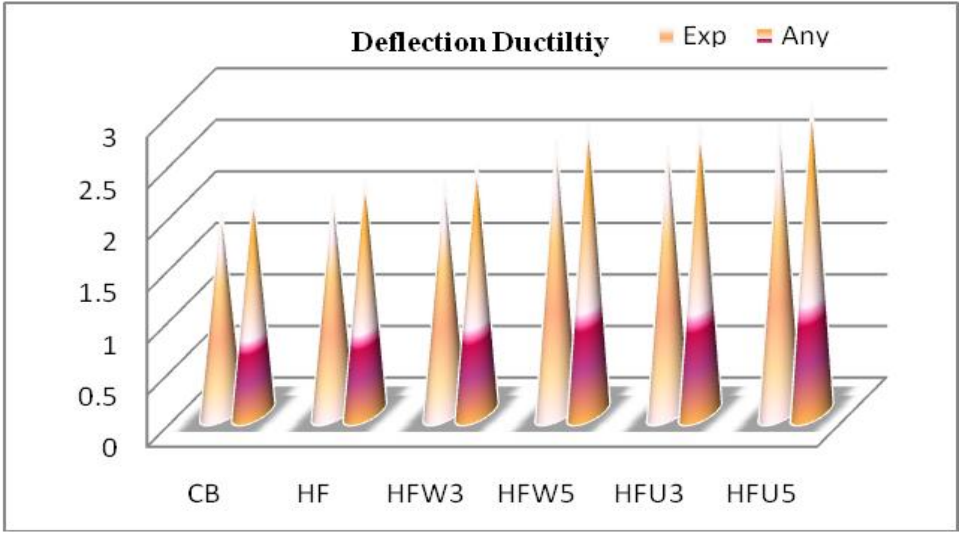


Fig. 4. Deflection Ductility of Beams

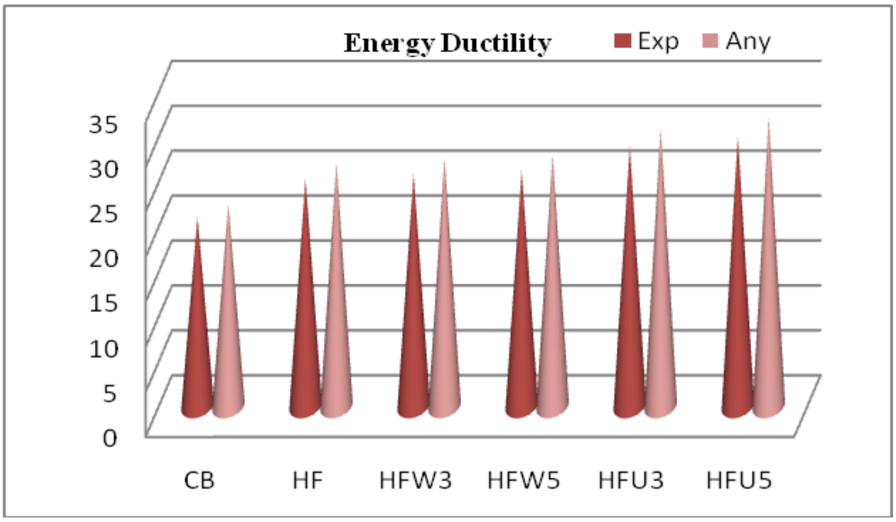


Fig. 5. Energy Ductility of Beams

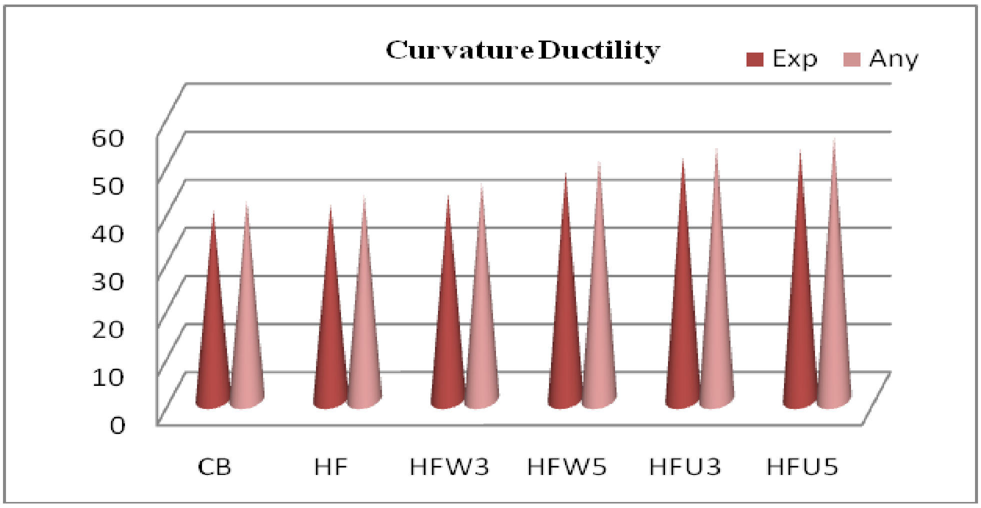


Fig. 6. Curvature Ductility of Beams

VI. RESULTS AND DISCUSSION

The load-deflection curves obtained through experiments and FEA for all beams are shown in Fig 3. The ultimate load carrying capacity of GFRP strengthened HFRC beams exhibit an increase of 25.6% with 3mm UDCGFRP, 43.86% with 5mm UDCGFRP; 14.26% with 3mm WRGFRP and 19.26% with 5mm WRGFRP. GFRP strengthened beams exhibit a decrease of deflection upto 41.31% with 3mm UDCGFRP and 51.56% with 5mm UDCGFRP; 12.078% with 3mm WRGFRP and 11.98% with 5mm WRGFRP. All the beams strengthened with GFRP laminates experienced flexural failure. None of the beams exhibit premature failure of laminate. The beams strengthened with GFRP laminates provide adequate ductility to ensure ductile mode of failure. The result obtained through ANSYS modeling for the specimens varied from 6 to 12.5% for yield deflection, 8.8 to 11.76% for ultimate deflection and 6.2 to 9.9% for deflection ductility.

VII. CONCLUSIONS

Based on the experimental and analytical results, the following conclusions are drawn:

1. GFRP strengthened HFRC beams resulted in higher load carrying capacity. The percentage increase in the ultimate load was 43.86% for beams strengthened with 5mm UDCGFRP laminates.
2. The percentage decrease in deflection at ultimate stage was 51.56% for HFRC beams strengthened with 5mm UDCGFRP laminates.
3. The HFRC beams strengthened with GFRP laminates show enhanced ductility. The increase in the ductility was 24.80%.
4. All the strengthened beams failed in flexural mode only.
5. The results obtained through the finite element analysis (ANSYS 14.5) show good agreement with the experimental results.

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