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Hybrid Fibre Reinforced Concrete Beams Strengthened with Externally bonded GFRP Laminates

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ABSTRACT - ***This paper presents the results of experimental study conducted to examine the effectiveness of Glass Fibre Reinforced Polymer (GFRP) laminates on the performance of Hybrid fibre reinforced concrete beams. For the experimental investigation, a total of four beams of size 150mm x 250mm in cross section with a total length of 3000mm were cast and tested. Two beams were strengthened with Unidirectional Cloth Glass Fibre Reinforced Polymer (UDCGFRP) of 3mm and 5mm thickness. One beam served as base line specimen and the other was cast with 1% hybrid fibre volume fraction (80% of steel fibre and 20% of polyolefin fibre). All the beams specimens were subjected to four-point bending in a loading frame. The results show that GFRP strengthened hybrid fibre reinforced concrete beams exhibit improved performance in terms of load capacity, deformation capacity and ductility. The beams were also modeled using finite element software (ANSYS). The numerical results showed good agreement with the experimental results.***

Keywords – ANSYS, Ductility, FRP, Polyolefin fibre, Steel fibre

1. INTRODUCTION

There is a growing need to strengthen and upgrade the infrastructure because of overloading, ageing of structure, construction faults, seismic effects, wind effects, blast, corrosion of steel reinforcement, de-icing salts etc. Many traditional practices have been developed and adopted over the years. Recently considerable attention has been focused on the use of Fibre Reinforced Polymer (FRP) for structural rehabilitation and strengthening. It has been recognized for high strength to weight ratio, good fatigue life, ease of transportation, low maintenance cost, ease of handling and good corrosion resistance. They have been extensively used in aero space, automotive and other fields. A survey of literature indicates that considerable effort has been directed towards the use of FRP for structural strengthening and rehabilitation. Numerous studies have been devoted to reinforced concrete beams strengthened with externally bonded FRP laminates/sheets both experimentally and analytically. Spadea et al. conducted a study on reinforced concrete beams strengthened with externally reinforced carbon fibre fabric. The effects of retrofitting on strength, deflection, curvature and energy were examined. Raghunath et al. studied the structural response of reinforced concrete beams with externally bonded GFRP reinforcement showed significant improvement in structural performance can be realised through this technique. An adaptive neuro-fuzzy inference system (ANFIS) model was used for this purpose. The predictions of the model were found to agree well with the experimental results. Fanning et al. examined the ultimate response of RC beams strengthened with CFRP plates. The authors concluded that FRP plated RC beams showed an enhance ductility and strength. Toutanji et al. studied the flexural behavior reinforced concrete beams externally strengthened with CFRP sheets bonded with an inorganic matrix. The authors concluded that the load carrying capacity increases with the number of layers of carbon fibre sheets. The beams retrofitted with CFRP laminates showed an increase upto 170% in ultimate loads as compared to control beams has been investigated. Banthia et al. examined the flexural response of hybrid fibre reinforced cementitious composites with seven different types of fibres and different fibre volume fractions showed that the HFRC demonstrate a higher moment of resistance than plain concrete has been studied. Eswari et al. studies the flexural behavior of hybrid cements composites with polyolefin fibres and steel fibres (fibre content was varied from 0 to 2% by volume). Results showed an influence on compressive strength, split tensile strength, ultimate flexural load and deflection. As a result the flexural performance was significantly improved with 2% hybrid fibre content has been investigated. Wu Yao et al. investigated the mechanical properties of hybrid fibre reinforced concrete at low fibre volume fractions with three types of hybrid fibres structures polypropylene - carbon, carbon-steel and steel-polyproplene with constant fibre volume fraction 0.5%, resulted in an increase of 31.4% in compressive strength, 33.92-199.5% in toughness, 32.9% in modulus of rupture and 36.5% in split tensile strength compared to the unreinforced concrete. The carbon steel hybrid proved to be the most beneficial resulting in hybrid effect has been observed. Li-juan et al. conducted a test analysis for fibre reinforced concrete beams strengthened with externally bonded a fibre reinforced polymer sheets. The authors concluded that the FRP strengthened HFRC beams exhibit enhanced strength and ductility than those of HFRC beams has been investigated. Yin et al. studied the structural performance of short steel fibre reinforced concrete beams strengthened with externally bonded FRP sheets were examined. Kachlakev et al. developed a finite element modeling for reinforced concrete structures strengthened with FRP laminates using ANSYS established a methodology for applying computer model to reinforced concrete beams and bridges strengthened with FRP laminates has been studied. Arudini et al. developed a Finite element modeling to stimulate the behavior and failure mechanism of reinforced concrete beams strengthened with FRP plates. The FRP plates were modeled using two dimensional plate elements. These analytical results showed good agreement with the experimental results. But the crack patterns were not predicted in their study. In spite of many studies, the effectiveness of fibre reinforced polymer on hybrid fibre reinforced concrete beams has not been explored. This study examined the experimental results of the flexure behavior of hybrid fibre reinforced concrete (HFRC) beams strengthened with uni-directional cloth type of GFRP laminates.

2. MATERIAL AND METHODS

Beam Details: 150 x 250 x 3000mm beam were cast and subjected to four point bending test as shown in Figure 1. Table 1 shows the specimen details considered in this study. The properties of fibres used in the experimental work are shown in Table 2. The concrete mix proportion adopted is shown in Table 3.Hybrid fibre reinforced concrete beams were strengthened with uni-directional cloth (UDC) GFRP laminates of 3mm & 5mm thickness. After the completion of beam soffit surface preparation, two part epoxy resin was used to bond the GFRP laminates.

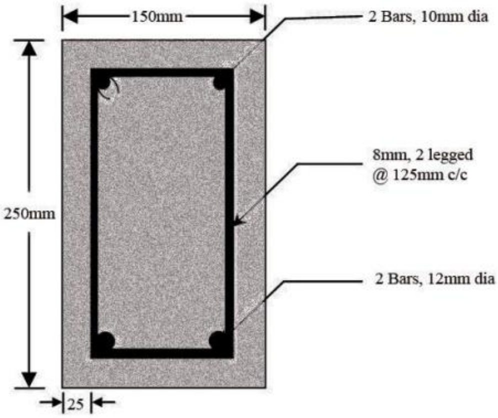


Figure 1: Beam Details

Table 1: Specimen Details

Si. No	Beam Designation	Fibre Volume fraction (V_f)	% of steel reinforcement	Type of fibre (% of V_f)		GFRP Laminates	
				Steel	Polyolefin	Type	Tk in mm
1	CB	-	0.6698	-	-	-	-
2	HF	1%	0.6698	80	20	-	-
3	HFU3	1%	0.6698	80	20	UDC	3
4	HFU5	1%	0.6698	80	20	UDC	5

Table 2: Properties of Fibres

Si. 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 3: Details of Concrete Mix

Ingredient	Quality
53 grade OPC	450 kg/m3
Fine aggregate	780 kg/m3
Course aggregate 20mm	680 kg/m3
12mm	450 kg/m3
Water	160 lit/m3
Silica flume	25 kg/m3
Hyper plasticizer	0.80 %

3. TEST SET-UP

All the beams were tested under four-point bending in a loading frame of 500kN capacity. The deflections at mid-span and load points were measured using dial gauges of 0.01mm accuracy. Crack widths were measured using a crack detection microscope of 0.02mm accuracy. The loading arrangement & instrumentation adopted is shown in Figure 2.

Figure 2: Test Set-up

4. FINITE ELEMENT MODELING

4.1Element Types

For modeling of RC Beams, eight noded Solid65 element with three degrees of freedom at each node as shown in **Figure 3** (translations in the nodal x, y, and z directions), which handles nonlinear behaviour, cracking in three orthogonal directions due to tension, crushing in compression and plastic deformation was used. For modeling reinforcement, two noded Link8 spar element with three degrees of freedom at each node as shown in **Figure 4** (translations in the nodal x, y, and z directions), which handles plasticity, creep, swelling, stress stiffening and large deflection was used. SOLID 46 was used to model FRP composites. The element allows up to 250 layers. The element has three degrees of freedom at each node, translation in x, y, z directions. The element is defined by eight nodes, layer thickness, layer material direction angles and orthotropic material properties. The geometry and coordinate system is shown in the **Figure 5.** The model is capable of predicting failure for concrete materials. Both cracking and crushing failure modes are accounted for. The two input strength parameters **-** i.e., ultimate uniaxial tensile and compressive strengths – are needed to define a failure surface for the concrete as shown in **Figure 6.** Consequently, a criterion for failure of the concrete due to a multiaxial stress state can be calculated. Material properties of all elements are shown in **Figure 7 to 9.** Modeling procedure of beam strengthened with FRP laminates was shown in **Figure 10 to 12.** The loading and support condition of modeled beam was shown in **Figure 13**.

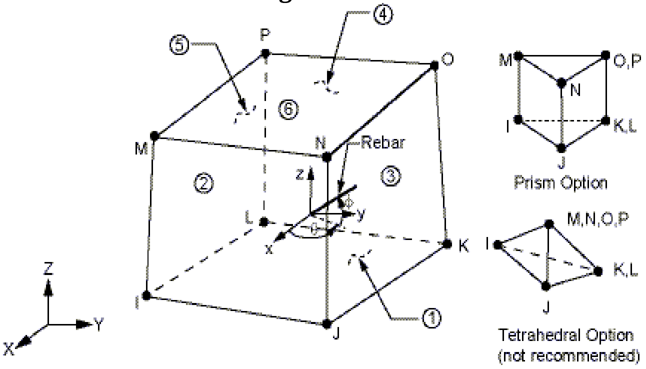


Figure 3: Solid 65 Element

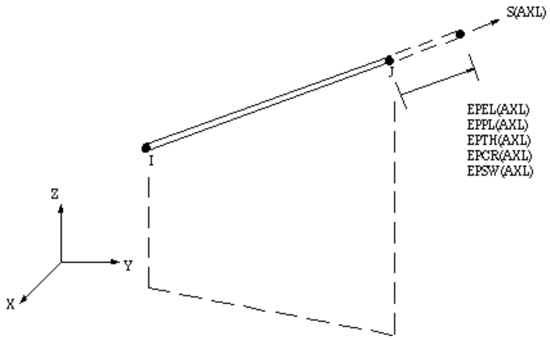


Figure 4: Link 8 Element

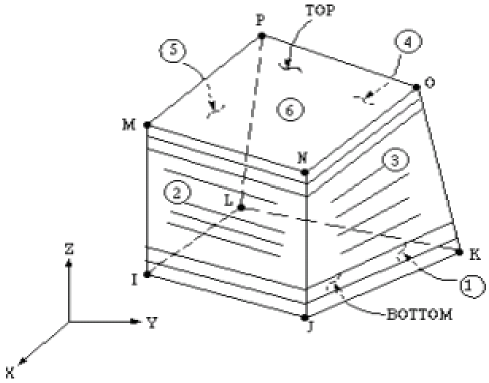


Figure 5: Solid 46 Element

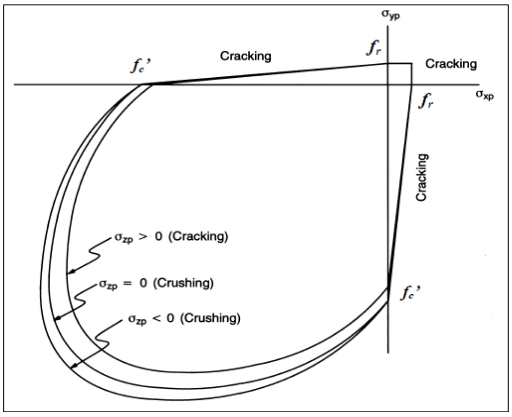
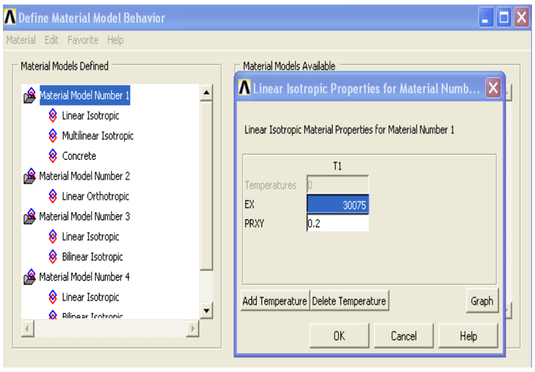


Figure 6: 3D Failure Surface for Concrete

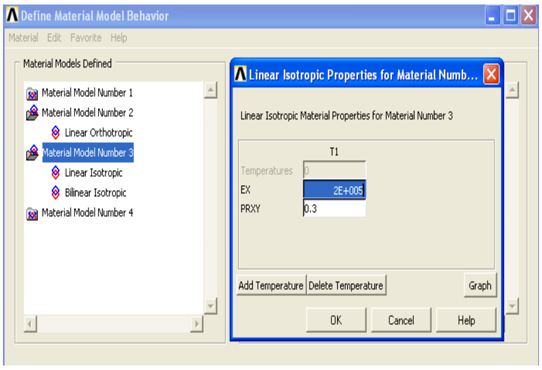


Material Model Number 1
  Linear Isotropic
  Multilinear Isotropic
  Concrete
Material Model Number 2
  Linear Orthotropic
Material Model Number 3
  Linear Isotropic
  Bilinear Isotropic
Material Model Number 4
  Linear Isotropic
  Bilinear Isotropic

Linear Isotropic Material Properties for Material Number 1

	T1
Temperatures	0
EX	30075
PRXY	0.2

Figure 7: Solid – 65

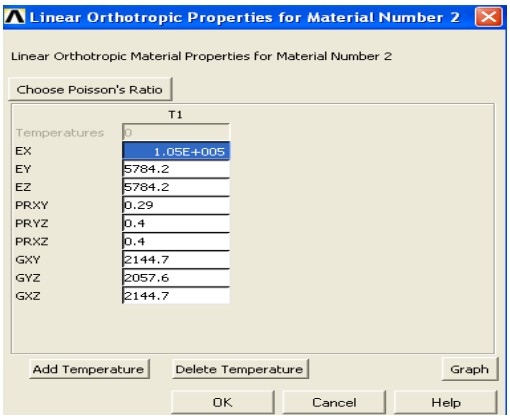


Material Model Number 1
Material Model Number 2
  Linear Orthotropic
Material Model Number 3
  Linear Isotropic
  Bilinear Isotropic
Material Model Number 4

Linear Isotropic Material Properties for Material Number 3

	T1
Temperatures	0
EX	2E+005
PRXY	0.3

Figure 8: Link 8



Linear Orthotropic Material Properties for Material Number 2

	T1
Temperatures	0
EX	1.05E+005
EY	5784.2
EZ	5784.2
PRXY	0.29
PRYZ	0.4
PRXZ	0.4
GXY	2144.7
GYZ	2057.6
GXZ	2144.7

Figure 9: Solid 46

4.2 Modeling procedure of Beam

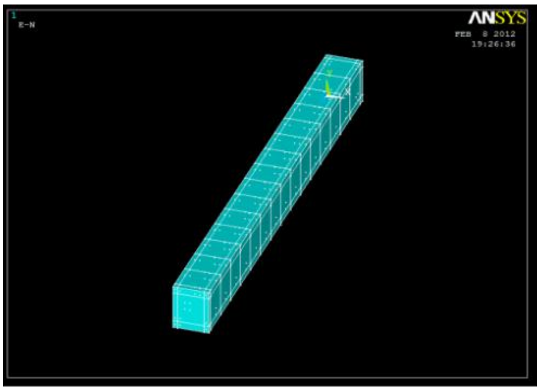


Figure 10: Concrete Beam Modeling

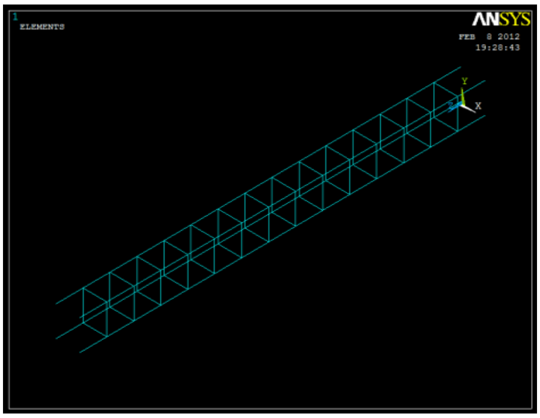


Figure 11: Reinforcement in Beam

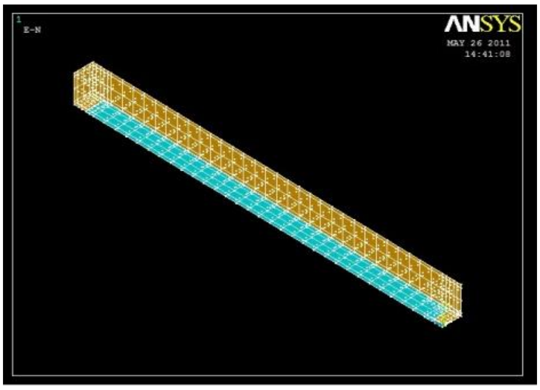


Figure 12. FRP wrap in Beam

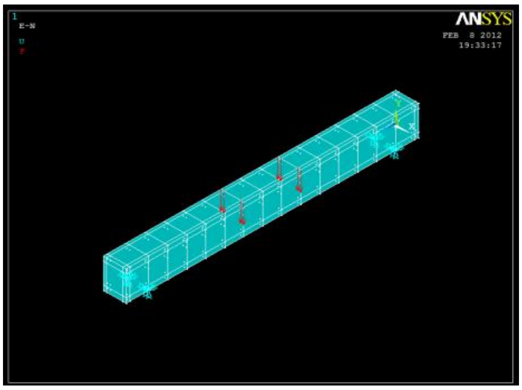


Figure 13. Loading and Support condition

5. TEST RESULTS

Table 4 summarises the test results at yield and ultimate stage of unstrengthened and strengthened HFRC beams.

Table 4: 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	64.76	6.17	5.55	84.69	12	10.8
2	HF	94.65	8.1	7.29	159.42	17	15.3
3	HFU3	144.47	9.78	7.54	214.22	20.8	18.72
4	HFU5	159.42	8.24	7.74	283.97	23	20.7

6. LOAD-DEFLECTION RESPONSE

The load-deflection response for tested beams is presented in **Figure 14.**

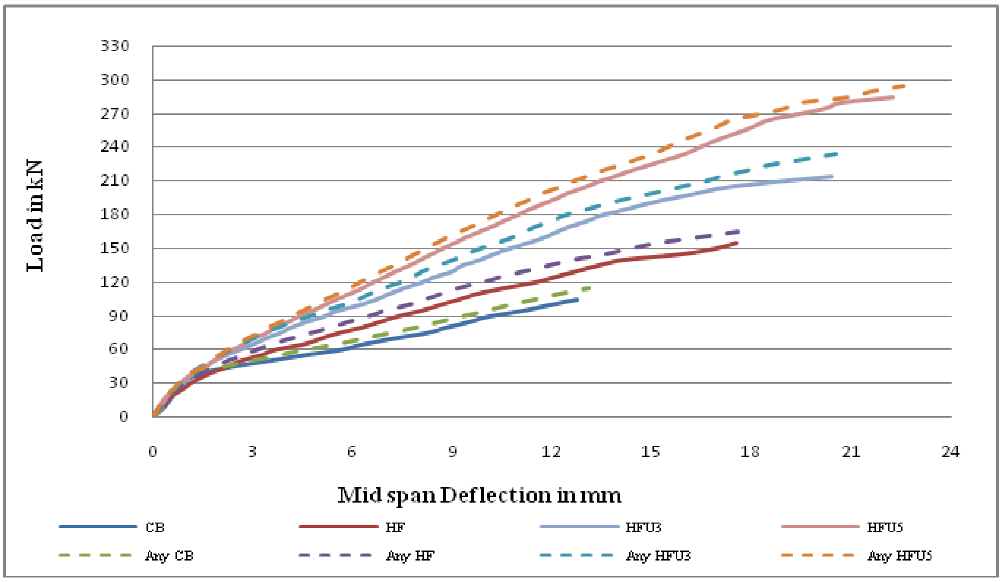


Figure 14: Load – Deflection Response of Beams

7. DUCTILITY OF BEAMS

Ductility indices for the tested beams are shown in **Figure 15 to 17.** The ductility values were calculated based on deflection, curvature and energy. The deflection ductility for the strengthened beam showed maximum increase of 32.15%.

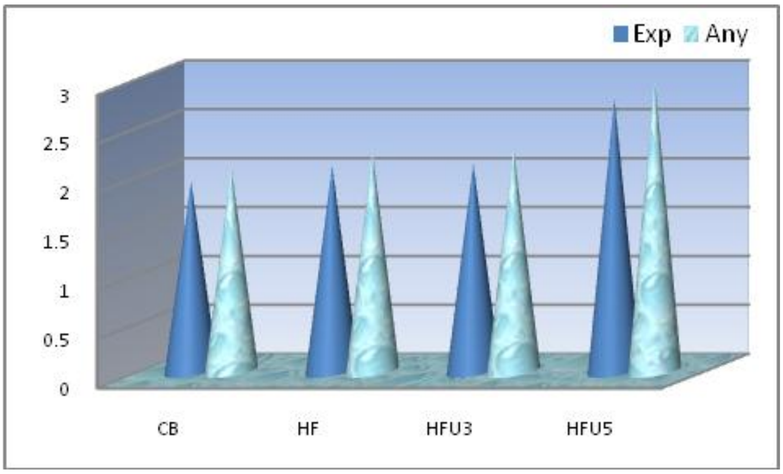


Figure 15: Deflection Ductility of Beams

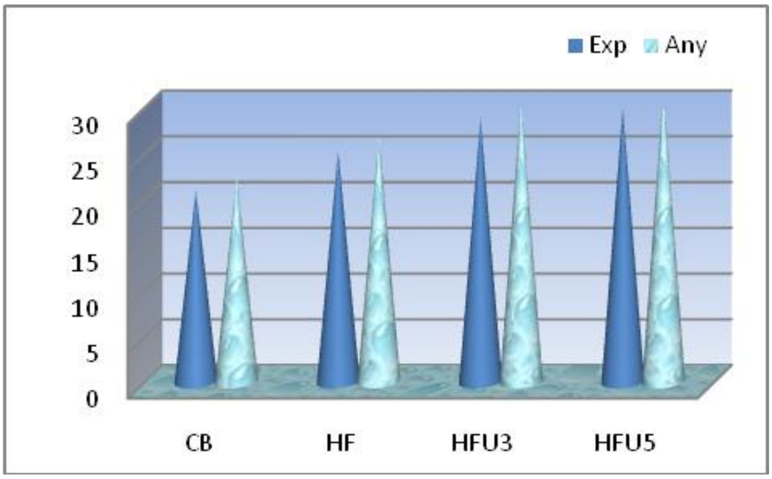


Figure 16: Energy Ductility of Beams

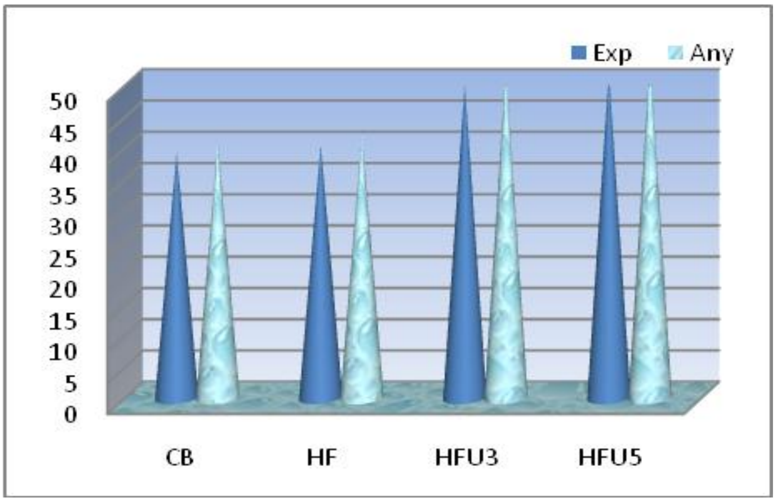


Figure 17: Curvature Ductility of Beams

8. RESULTS AND DISCUSSION

The load-deflection curves obtained through experiments and ANSYS are shown in Figure 14. GFRP strengthened HFRC beams exhibit increase in flexural strength upto 25.6% with 3mm UDCGFRP and 43.86% with 5mm UDCGFRP. GFRP strengthened beams exhibit a decrease of deflection upto 41.31% with 3mm UDCGFRP and 51.56% with 5mm UDCGFRP. 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 results obtained through ANSYS modeling varied from 6-12.5% for yield deflection, 8.8-11.76% for ultimate deflection and 6.2-9.9% for deflection ductility.

9. CONCLUSIONS

Based on the experimental results, the following conclusions are drawn

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

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