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Ductility Behaviour of Steel Fibre Reinforced Concrete Beam Strengthened with GFRP Laminates

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Abstract - *This study represents the results of an experimental investigation conducted on Steel Fibre Reinforced Polymer (SFRP) beams with externally bonded Glass Fibre Reinforced Polymer (GFRP) laminates with a view to study their ductility behaviour. Preliminary tests on six cubes and six cylinders with different proportions of (0.5%, 1%, 1.5%) hooked and crimped steel fibres were tested. With the test results best proportions is adopted for casting the beams. A total of five beams were casted. Four beams of hooked and crimped steel fibres with and without Glass Fibre Reinforced Polymer laminates were casted. A single conventional beam was casted and wrapped with GFRP laminates .Epoxy resin was used for coating. Therefore the results revealed that higher volume fraction of steel fibres also improve the ductility performance of RC beams. The test results show that the beams provided with externally bonded Glass Fibre Reinforced Polymer (GFRP) laminated exhibit improved ductility performance over conventional beams.*

Key words: *Steel fibre, Hooked, Crimped, Aspect ratio, Epoxy Resin.*

1. INTRODUCTION

The use of concrete structures reinforced/ pre-stressed with fibre-reinforced polymer (FRP) composite materials has been growing to overcome the common problems caused by corrosion of steel reinforcement. FRP composites are lightweight exhibit high tensile strength and specific stiffness, are easily constructed. Due to these advantageous characteristics, FRP composites have been included in new construction and rehabilitation of structures through its use as reinforcement in concrete, bridge decks, modular structures, formwork, and external reinforcement for strengthening and seismic upgrade. Extensive research programs have been conducted to investigate the flexural behaviour of concrete members reinforced with FRP reinforcement. The structural elements can be strengthened by varieties of Fibre Reinforced Polymer (FRP) such as Carbon fibre reinforced polymer (CFRP), Glass fibre reinforced polymer (GFRP), Steel fibre reinforced polymer (SFRP) or Wooden fibre reinforced polymer (WFRP).

Ductility is a measure of a material's ability to undergo significant plastic deformation before rupture. It is defined as the ratio of ultimate deformation to yield deformation. The most important aspect of ductility is a precaution of structural failure. Ductile structure can provide an advanced warning before failure.

This work is dedicated to the investigation of flexural behaviour of concrete beams reinforced with GFRP, based on recycled resin recovered from plastic waste materials. A successful and effective incorporation of recycled GFRP as reinforcement in concrete will have the multiple benefits stated earlier as well as create jobs/employment opportunities in the construction industry. This project will also serve as a pilot effort towards the domestication of fibre reinforced polymer technology, especially in the utilization of recycled plastic waste in civil/structural engineering applications in modern countries.

2. SCOPE OF THE STUDY

GFRP are very essential for retrofitting in underground car parks where deflection in beams and buckling in columns are greater. SFRP is found to be versatile material for the manufacture of wide varieties of precast products such as manhole covers, slab elements for bridge decks, highways, runways, and tunnel linings, machine foundation blocks. Glass Fiber Reinforced Polymer with its composite action is possible with most modern light weight deck systems and can improve further the live load capacity. Steel Fibers are very useful in water retaining structures and it anticipates future trends in the field of upgrading structural members.

3. EXPERIMENTAL PROGRAM

A. Materials:

The mix design proposed for the beams is given in Table 1. The grade of concrete used is M30. Ordinary Portland cement of grade 53 was used as the binding material. Coarse aggregate in the size 20mm were used.

Table 1 Mix Design Data

Exposure condition	Extreme
Workability	100 mm slump
Minimum Cement Content	320 kg/m^3
Maximum w/c ratio	0.4
Specific gravity of Coarse Aggregate	2.78
Specific gravity of Fine Aggregate	2.7
Water absorption of Coarse Aggregate	0.5%
Water absorption of Fine Aggregate	1%

B. Mix design arrival

Table 2 Arrival of Mix Design Data

Volume of concrete	1m^3
Volume of Cement	0.156m^3
Volume of Water	0.197m^3
Volume of Total Aggregate	0.65m^3
Volume of Fine Aggregate	1011.92 kg/m^3
Volume of Cement	492.5 kg/m^3
Water Cement ratio	0.4
Cement : FA : CA	1:1.608:2.07

The shape of steel fibre used was hooked and crimped steel fibre with an aspect ratio (l/d) 60. Hooked Steel fibers were added in concrete in a volume fraction of 0.5%, 1%, 1.5%.we choose the best of the three proportions mentioned above in the Table 2 The mix design data are arrived using IS 10262 (2009).

4. MATERIALPROPERTIES

Table 3 Test on materials

materials	**Test for**	**Observed Value**
Cement (OPC53Grade)	Specific Gravity (no unit)	3.14
	Standard Consistency (no unit)	31%
	Initial Setting Time (mins)	26
	Final Setting Time(mins)	49
	Fineness	3%
	28/day Compressive Strength N/mm^2	30 N/mm^2
Fine Aggregate	Specific Gravity (No unit)	2.5
	Sieve Analysis	Zone I
Coarse Aggregate (Max size 20mm)	Specific Gravity	2.68
	Water absorption	1.5%
	Crushing Strength	7.12%

5. WORKABILITY OF CONCRETE

A. SLUMP CONE TEST

The concrete slump tests determines the consistency of fresh concrete before it sets. It is performed to check the workability of freshly made concrete, and therefore the ease with which concrete flows. The test results are shown in table 4

Table 4 Result of Slump pattern

S.NO	W/C RATIO	SLUMP PATTERN
1.	0.4	True Slump

B. COMPACTION FACTOR TEST

Compaction factor test measures the workability of fresh concrete. Compaction Factor is the ratio of weight of partially compacted to fully compacted concrete. The results are shown in table 5

Table 5 Result of Compaction factor

S.NO	W/C RATIO	W1 (kg)	W2 (kg)	COMPACTION FACTOR (W1/W2)
1.	0.4	14.86	17.89	0.83

C. VEE – BEE CONSISTOMETER TEST

Vee – Bee test is conducted to determine the workability of freshly mixed concrete. The test results are shown in table 6

Table 6 Result of Vee-Bee test

S.NO	W/C RATIO	VEE – BEE TIME
1.	0.4	Seconds

6. PRELIMINARY TESTING

A. TESTING OF CUBES

Table 7 Result of Tested cubes

SPECIMEN WITH STEEL PERCENT	FIRST CRACK LOAD (kN)	LOAD CAPACITY (kN)	COMPRESSIVE STRENGTH (N/mm²)
CUBE 1 (0.5%)	426	626	27.8
CUBE 2 (1%)	285	559	24.8
CUBE 3 (1.5%)	205	621	27.6
CUBE 4 (0.5%)	477	487	21.6
CUBE 5 (1%)	205	691	30.7
CUBE 6 (1.5%)	370	689	30.6
CONVENTIONAL CUBE	190	395	17.5

Six concrete cubes with different proportions of hooked and crimped steel fibres (0.5%, 1%, 1.5%) and single conventional cube were casted and tested with 14 days curing period. The test results were compared with the conventional concrete cube. Refer table 7

B. TESTING OF CYLINDERS

Six concrete cylinders of different proportions of Hooked and crimped steel fibres (0.5%, 1%, 1.5%) were casted and tested with 14 days curing period.

Fig 1 Casted Cylinders

Table 8 Split Tensile Test Results

SPECIMEN WITH STEEL PERCENT	LOAD CAPACITY (kN)	TENSILE STRESS(N/mm^2)
CYLINDER 1 (0.5%)	191	2.70
CYLINDER 2 (1%)	226	3.19
CYLINDER 3 (1.5%)	**232**	**3.28**
CYLINDER 4 (0.5%)	222	3.14
CYLINDER 5 (1%)	264	3.73
CYLINDER 6 (1.5%)	**284**	**4.01**
CONVENTIONAL CYLINDER	183	2.58

7. EXPERIMENTAL INVESTIGATION

A. GENERAL OUTLINE OF INVESTIGATION

The investigation is done to study and compare the ductility behavior of steel fibre reinforced beams wrapped with GFRP laminates with the conventional reinforced concrete beam.

B. BEAM SPECIFICATIONS

A total of five beams were casted. Four beams of hooked and crimped steel fibres with and without Glass Fibre Reinforced Polymer laminates were casted. A single conventional beam was casted and wrapped with GFRP laminates. The beams size includes 1 x 0.15 x 0.15 m. The reinforcements of diameter 12mm were used.

Fig 2 Casting of Beams

Fig 3 Casted beams

Fig 4 Immersion curing of beams

Fig 5 Wrapped Beams

8. RESULTS

A.LOAD DEFLECTION GRAPH

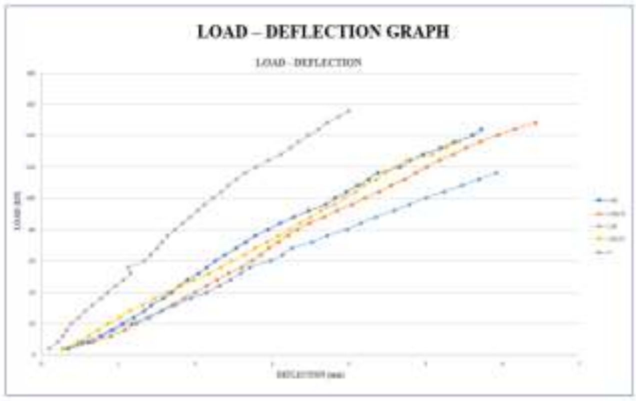

Fig 6 Load Deflection Curve

B.LOAD STRAIN GRAPH

Fig 7 Load Strain Curve

C.MOMENT CURVATURE GRAPHS

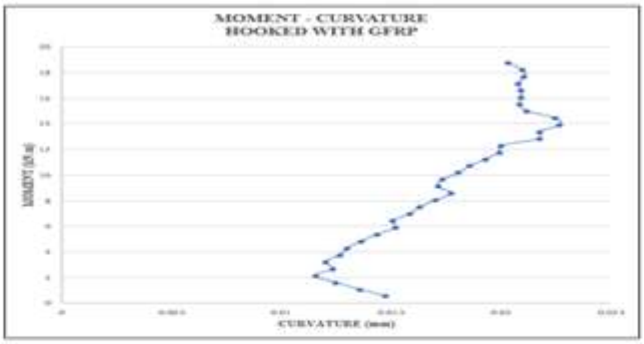

Fig 8 Moment Curvature Curve for HGFRP Beam

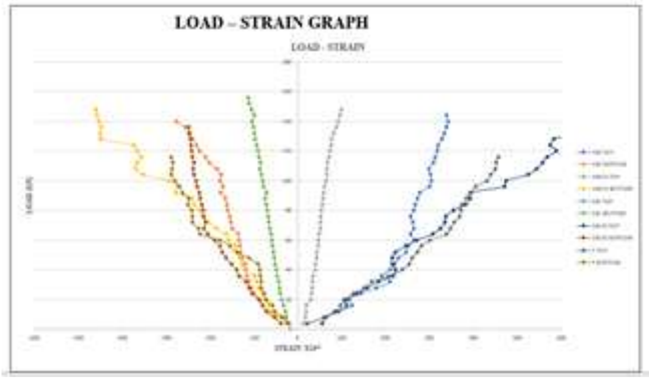

Fig 9 Moment Curvature Curve for CGFRP Beam

Table 9 Hooked with GFRP Laminates

CONTENT	INITIAL LOAD	YIELD LOAD	ULTIMATE LOAD
Load (kN)	4	40	144
Deflection (mm)	0.28	1.69	5.61
Moment (kN.m)	0.535	5.35	18.72
Top strain – 10^{-6}	23	211	342
Bottom strain 10^{-6}	-19	--118	-276
Curvature (mm)	0.014737	0.014322	0.020326
Stress N/mm² – 10^{6}	3.8	23.6	57.2
Flexural strength N/mm²	1.77	17.76	63.93

Table 10 Hooked without GFRP Laminates

CONTENT	INITIAL LOAD	YIELD LOAD	ULTIMATE LOAD
Load (kN)	4	40	144
Deflection (mm)	0.28	1.69	6.16
Moment (Kn.m)	0.53	5.35	19.2
Top strain 10^{-6}	13	211	96
Bottom strain 10^{-6}	-38	-118	-456
Curvature (mm)	0086	0.014	0.013
Stress N/mm² – 10^{6}	7.6	26.2	91.8
Flexural strength N/mm²	1.77	21.31	65.71

Table 11 Crimped with GFRP Laminates

CONTENT	Load (kN)	Deflection (mm)	Moment (kN.m)	Top .strain– 10^{-6}	Bottom strain– 10^{-6}	Curvature (mm)	Stress N/mm² – 10^{6}	Flexural strength N/mm²
INITIAL LOAD	4	0.1	0.53	84	-25	0.004	5	1.77
YIELD LOAD	56	1.125	7.49	179	-59	0.02008	11.2	24.86
ULTIMATE LOAD	156	3.86	20.6	252	-113	0.03509	22.6	69.26

Table 12 Crimped without GFRP Laminates

CONTENT	Load (kN)	Deflection (mm)	Moment (Kn.m)	Top .strain– 10^{-6}	Bottom strain– 10^{-6}	Curvature (mm)	Stress N/mm² – 10^{6}	Flexural strength N/mm²
INITIAL LOAD	4	0.28	0.53	56	-38	0.007	7.6	1.77
YIELD LOAD	52	2.17	6.95	222	-172	0.01	34.4	23.01

ULTIMATE LOAD	136	5.26	17.6	634	-246	0.02	49.4	60.38

Table 13 Conventional with GRPF Laminates

CONTENT	**Load (kN)**	**Deflection (mm)**	**Moment (kN.m)**	**Top .strain– 10^{-6}**	**Bottom strain– 10^{-6}**	**Curvature (mm)**	**Stress $N/mm^2 – 10^6$**	**Flexural strength N/mm^2**
INITIAL LOAD	4	0.3	0.53	21	-20	0.017	4	1.77
YIELD LOAD	40	2.9	8.02	211	-176	0.016	35.2	26.64
ULTIMATE	144	5.7	14.9	342	-284	0.020	57.4	51.5

Table 14 Ductility Parameters

CONTENT	**MOMENT FACTOR**	**DEFLECTION FACTOR**	**CURVATURE FACTOR**	**DEFORMABILITY FACTOR**
HOOKED WITH GFRP LAMINATES	**3.31**	**3.51**	**1.41**	**4.66**

HOOKED WITHOUT GFRP LAMINATES	3.01	2.70	0.776	2.32
CRIMPED WITH GFRP LAMINATES	**3.43**	**2.70**	**1.74**	**5.96**
CRIMPED WITHOUT GFRP LAMINATES	2.42	2.53	1.69	4.08
CONVENTIONAL WITH GFRP LAMINATES	**1.90**	**1.86**	**1.18**	**2.24**

9. CONCLUSIONS

From the test results on Steel Fibre Reinforced Concrete beams strengthened with GFRP laminates, the following conclusions are drawn,

- The Hooked SFRP beam with extreme GFRP laminates exhibit a increase of 31% in moment factor when compared with Hooked SFRP without GFRP laminates.
- The Crimped SFRP beam with GFRP laminates exhibit a increase of 29% in deflection factor when compared with Crimped SFRP beam without GFRP laminates.
- The curvature factor of Hooked and Crimped SFRP beam with GFRP is greater when compared with SFRP beams without Glass Fibre and conventional beam.
- Hooked with GFRP-1.41
  Crimped with GFRP -1.7
- Hooked without GFRP-0.776
  Crimped without GFRP-1.69
- The deformability factor of Hooked with GFRP laminates is 21% greater when compared with Crimped Steel Fibre strengthened with GFRP.
- The flexural strength of Steel Fibre beams with Glass Fibre laminates is greater with respect to the conventional beam.
- The axial stress value of Hooked with GFRP is 60% greater when compared with Crimped GFRP beam.
- It was observed that the Steel Fibre beams strengthened with GFRP laminates has a tendency to bear higher load value when compared with the conventional beam.
- Ductility of concrete is found to increase with inclusion of Fibres. Addition of Steel Fibres is more beneficial in high strength concrete as they are brittle in nature.

10. REFERENCE

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