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Experimental Study on GFRC Beam Reinforced With GFRP Rebar Under Flexure

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Abstract
Concrete is week in tension and cracks under tensile stress. As concrete is having low tensile strength, ductility and resistance to cracking is limited to improve these properties and an attempt has made to study the effect of addition of glass fibers in ordinary Portland cement concrete. As steel is prove to corrosion. Glass fiber reinforced polymers (GFRP) reinforcement bars was used. This paper presents an experimental study as flexural behaviour of GFRC beam reinforced with GFRP rebar. A total of six beams measuring 150 mm wide x 250 mm deep x 1800 mm long were casted on M35 grade of concrete and tested up to failure under two-point loading. Glass fibers 1.5 % was used and companion specimens was tested for its mechanical properties compressive strength, flexural strength and splitting tensile strength. Conclusions were made based on load carrying, initial crack load, stiffness, ductility, energy dissipation capacity and service ability limits.

Keywords:GFRP rebars, GFRC, Stiffness, Ductility, Flexure.

1.INTRODUCTION

Concrete without any fibres will develope cracks under tensile stress condition. Development of these cracks causes elastic deformation of concrete. Plain concrete is a brittle material and have low modulus of rupture and strain capacity to meet the required values of flexural strength and to enhance the strain capacity of the plain concrete, the fibres are being used in normal concrete. The addition of glass fibres in plain concrete shows higher flexural strength than plain concrete.

Glass fibre reinforced concrete (GFRC) is one of the most versatile building materials. Which is composed of cement, sand, coarse aggregate, special alkali resistant (AR) glass fibres and water. GFRC is a thin, high strength concrete with many applications in construction. The Glass Fibers are of Cem-FIL Anti - Crack HD AR glass fiber with modulus of elasticity 72 GPa, filament diameter 14 microns, Specific Gravity is 2.68, length 12 mm and having the aspect ratio of 857.1. The number of fibers per kg is 212 million. Alkali resistant fibers act as the principle tensile load carrying member while the concrete matrix binds the fibers together and helps transfer loads from one fiber to another.

GFRP reinforcing bars are made glass fibers. As GFRP bars are non-corrosive helps it to extend lifecycle of reinforced concrete structures and reducestheir maintenance, repair, and replacement costs. GFRP rebar is becoming a viable reinforcement alternative and its design is different from conventional steel reinforced concrete. Design the important challenge in GFRP rebar design is consideration of a brittle failure mode in GFRP-reinforced members.

2.REVIEWOF LITERATURE

Shirsath et al have conducted an experimental studyon RC beam of size 50X230X2000mm with concrete mix design for M25 grade concrete. All beams were tested under two point loading in universal testing machine of 100 tone capacity. Glass fibres of 0%, 1.5 %, 2.0% by volume fraction of concrete were used. The percentage increase of flexural strength for 1.5% glass fiber concrete beam is about 11% to that of the conventional concrete beam and for 2% proportion of GFRC beam there has been decrease in flexural strength by 16% to that of conventional concrete beam. Hence the flexural strength increases up to a certain limit and decreases thereafter.

Abid Alamet al have conducted an experimental testing of RC beam of size 100X100X500mm with concrete mix design for M20, M30 grade concrete. The glass fibres of 0.02% by volume fraction of concrete were used. The compressive strength is concrete show a marginal increase on addition of fibres to concrete mixes. Increased strength was reported as 26.6% and 25.78% for M 20 and M30 grade of concrete. However further addition of fibres improves average strength up to 7% for M 20 grade and 8.8% for M 30 grade of concrete.The tensile strength of concrete also shows an increasing trend. For M 20 & M 30 grade of concrete increased tensile strength were observed to be 24.7% and 26.10%.

Dhinakaran et al have conducted an experimental study on RC beam of size 125 X 250 X 3200 mm with concrete mix design for M40 grade concrete. Total number 12 beams were casted out of which, 6 beams were reinforced with GFRP and the other 6 beams with traditional steel reinforcement. The GFRP reinforced beam proves to be economical by achieving a lower net present value with the increased service life of the beam. The life cycle time of GFRP reinforced beam was approximately two times when compared with the steel reinforced beam which further reduces the net present value of the beam. The benefit to

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cost will be still greater on considering the entire structure due to the increased quantity. Thus the study on the Cost benefit analysis reveals that GFRP reinforced beam proves to be powerful by achieving the higher benefit with the given cost of the beam. Hence with the combined advantages of structural performance, serviceability, suitability for aggressive environments and economy, GFRP reinforced beams is strongly recommended.

- ❖ In this study, GFRC beams with GFRP rebar were investigated for its load-deformation characteristic, load carrying capacity, failure mode, stress-strain characteristics across cross section and flexural performance.
- ❖ Also results were compared with the flexural performance of concrete beams.

3.EXPERIMENTAL PROGRAMME

3.1. Materials

1].Cement -Ordinary Portland cement of 53 grades available in market was used. Cement used was tested for various proportions as per IS: 4031-1988 and found to be conforming to various specifications of IS: 12269-1987. specific gravity is 3.02 and fineness is 3200cm^2/gm.

2].Fine aggregate river sand, passing through 4.75 mm size was used. specific gravity of fine aggregate is 2.71. 20 mm coarse aggregate with specific gravity of 2.94 was used.

3].Glass fibre used are of Cem-FIL Anti-Crack HD with modulus of elasticity 72 GPa, Filament diameter 14 microns, specific gravity 2.68, length 12 mm and having the aspect ratio of 857.1. The number of fibres per kg is 212 millon fibres. 1.5 percentage glass fibre for M35 grade of concrete mix were cast and tested.

4].Gfrp rebars-In the present investigation replacement of steel reinforcement as glass fiber reinforced polymer. GFRP bars possess mechanical properties different from steel bars, including high tensile strength combined with low elastic modulus and elastic brittle stress-strain relationship.Steel rebars were used for stirrups and they were of 6mm diameter and fy 415. The main longitudinal GFRP bars were of 10mm diameter. Mix proportion of M35 grade concrete was designed as per IS code method. The proportion and w/c ratio for M35 is 1:1.77:2.84:0.45.

3.2. Reinforcement Details

Experimental work includes casting, curing and testing of six beams (1800 mm length, 150 mm width and 250 mm depth). Beams were simply supported at their ends with the effective span of 1500 mm. A view of longitudinal section and cross section of a typical beam specimen is shown fig.1. Two various rebar were used GFRP 10 mm diameter was used on for GFRP beam.Main bar at top and bottom. HYSD bar of steel 6 mm stirrups were used for GFRP beams. HYSD steel rebar of 10 mm diameter and 6 mm stirrups were used for three beams. Bottom and top concrete clear cover of 20 mm was maintained for all beams.

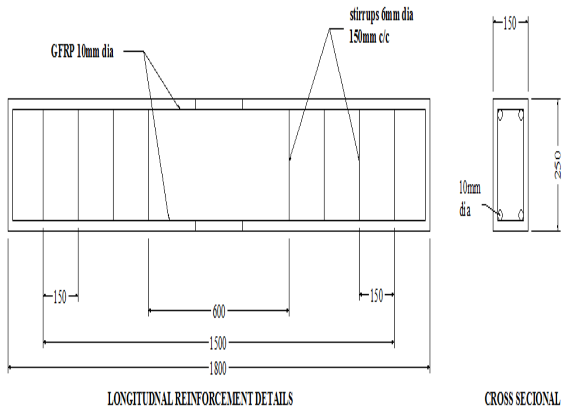

Fig.1. Longitudinal reinforcement details

3.3. Test setup

Test specimen consists of two different concrete beams: conventional concrete beam reinforced with steel rebar (normal beam), GFRC beam reinforced with GFRP rebar. Totally six beams were casted: three normal beams and three GFRP beam companion specimens 3 cubs of 150×150×150 mm were tested for Compressive strength, 3 cylinder 150mm dia, 300mm length cylinders were tested for split tensile strength and prism of 100×100×500 mm were tested for flexural strength 1.5percentage glass fibre for M35 grade of concrete mix were cast and tested.

The test setup involves a two point loading system by using a spread beam and two rollers. Totally 3 LVDTs were placed at the midpoint of the beam and under loading to measure the deflection. Strain in main rebar were also measured for both top and bottom main reinforcements.

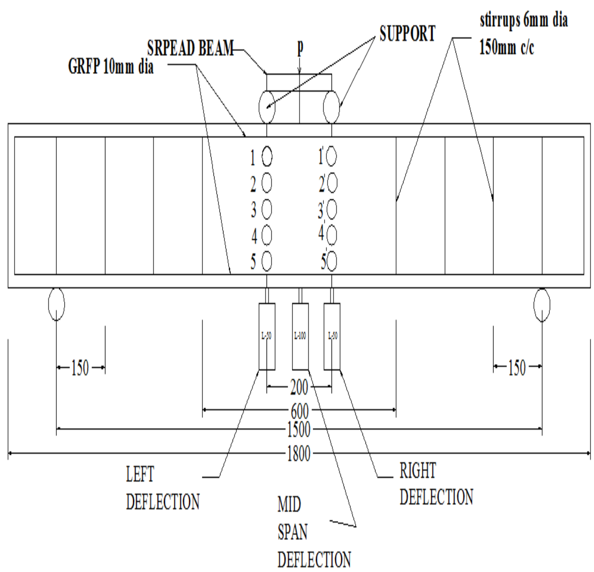

Fig.2. Beam test setup details-(a)

- LVDT at left – deflection 1
- LVDT at Centre – deflection 2
- LVDT at right – deflection 3

Fig.3. Beam test setup details-(b)

4. RESULT AND DISCUSSION

4.1. Companion Specimen Results

TABLE I: Compressive Strength Test Results

Type of concrete	Specimen	Initial Crack Load (kN)	Final Crack Load (kN)	Compressive Strength (N/mm²)	Avg. compressive Strength (N/mm²)
Conventional Concrete	1	763	874	38.84	38.49
	2	516	828	38.07	
	3	652	839	38.57	
GFRC with 1.5% glass fibre	1	659	920	40.88	40.88
	2	813	912	40.53	
	3	669	928	41.24	

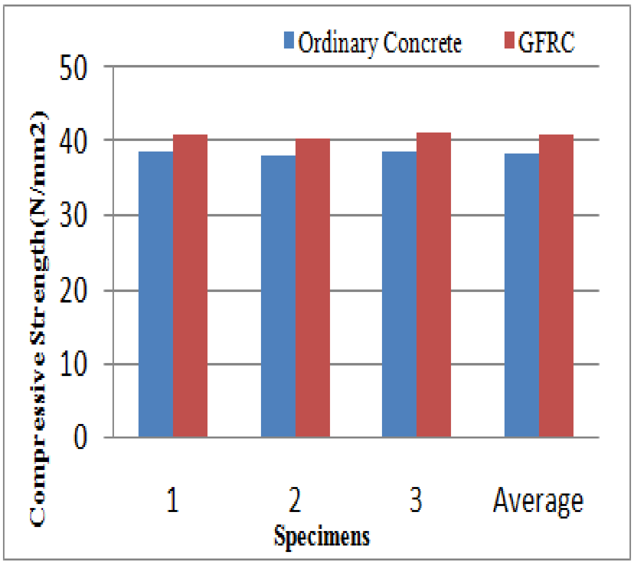

Fig.4 Compressive strength (ordinary concrete Vs GFRC)

TABLE 2: Split tensile Strength Test Results

Type of concrete	Specimen	Final Crack Load (kN)	Split tensile Strength (N/mm²)	Avg. Split tensile Strength (N/mm²)
Conventional Concrete	1	187	2.7	2.63
	2	194	2.74	
	3	173	2.45	
GFRC with 1.5% glass fibre	1	245	3.46	3.15
	2	214	3.03	
	3	210	2.97	

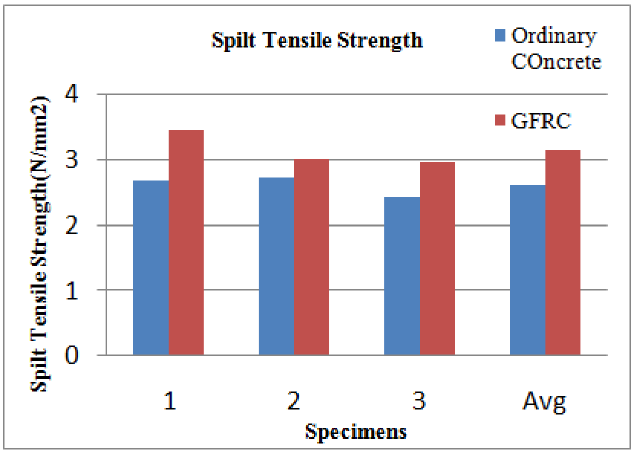

Fig.5. Split tensile strength (ordinary concrete Vs GFRC)

Table 3: Flexural Strength Test Results

Type of concrete	Dimensions (mm)	Specimen	Ultimate Load (kN)	Flexural Strength (N/mm²)	Avg. Flexural Strength (N/mm²)
Conventional Concrete	100x 100x 500	1	14.5	4.35	3.85
		2	12	3.6	
		3	12	3.6	
GFRC with 1.5% glass fiber	100x 100x 500	1	16.5	4.95	4.29
		2	13.6	4.08	
		3	12.8	3.84	

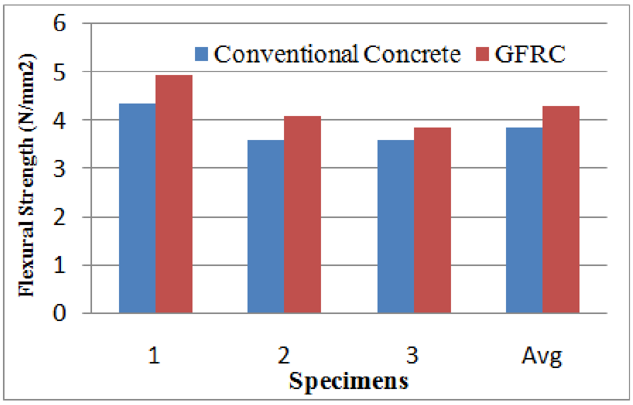

Fig.6. Flexural strength (Normal Vs GFRC with GFRP beam)

4.2. Load Vs deflection characteristics

4.2.1.Companion Specimen Results for GFRC beam shown in fig 7,8,9 and table 4,5,6.

For specimen 1

TABLE 4: Load Vs deflection (GFRC with GFRP beam – 1)

S.no	Load (kN)	Deflection-1 (mm)	Deflection-2 (mm)	Deflection-3 (mm)
1.	0	0	0	0
2.	25	1.4	1.7	1.5
3.	34	2.5	3.0	2.7
4.	45	5.6	6.6	6
5.	55	6.7	7.9	7.3
6.	64	9.1	10.6	9.9
7.	77	11.7	13.7	13.0
8.	87	13.7	16.3	15.8
9.	100	16.3	19.4	18.7
10.	111	18.8	22.3	21.4
11.	122.2	23.8	27.1	25.4

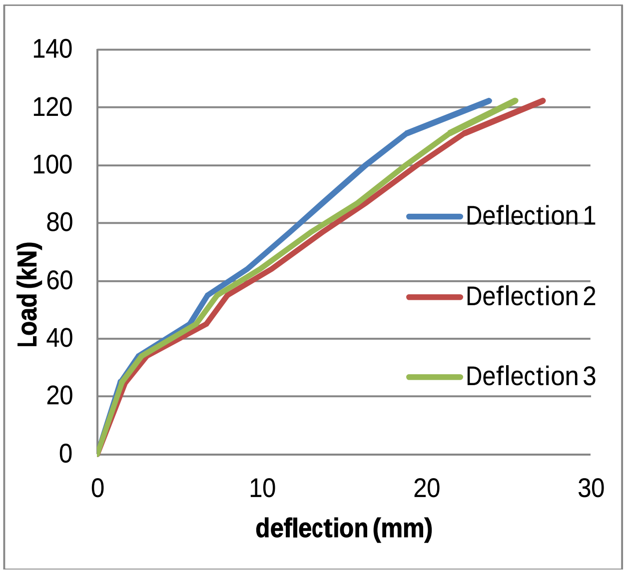

Fig.7. Load Vs deflection (GFRC with GFRP beam – 1)

For specimen 2

TABLE 5 Load vs deflection (GFRC with GFRP beam – 2)

S.no	Load (kN)	Deflection1 (mm)	Deflection2 (mm)	Deflection3 (mm)
1.	0	0	0	0
2.	12.3	0.6	0.9	0.8
3.	25.3	3.3	3.6	3.1
4.	37.9	10.6	10.8	9.9
5.	54.7	13.9	14.2	13.3
6.	73.8	14.1	16.8	16.2
7.	95.2	21.6	24.2	22.8
8.	105.8	23.8	26.4	24.9
9.	117.5	25.7	27.1	26.5
10.	131.9	26.9	28.3	27.7

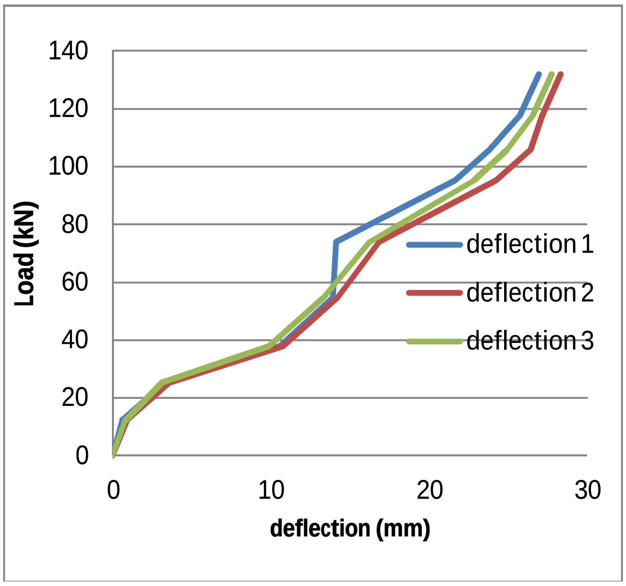

Fig.8. Load Vs deflection (GFRC with GFRP beam – 2)

For specimen 3

TABLE 6 Load vs deflection (GFRC with GFRP beam – 3)

S.no	Load (kn)	Deflection1 (mm)	Deflection2 (mm)	Deflection3 (mm)
1.	0	0	0	0
2.	25	1.8	2.1	2.0
3.	35	6.6	7.4	6.9
4.	48	8.6	9.4	9.1
5.	58	10	10.9	10.4
6.	69	11.1	12.3	11.8
7.	79	12	13.3	12.7
8.	89	15.7	17.4	16.6
9.	99	18.3	20	19.1
10.	109	18.5	20.2	19.3
11.	126	21	22.3	20.9
12.	141.2	23.2	26.5	23.1

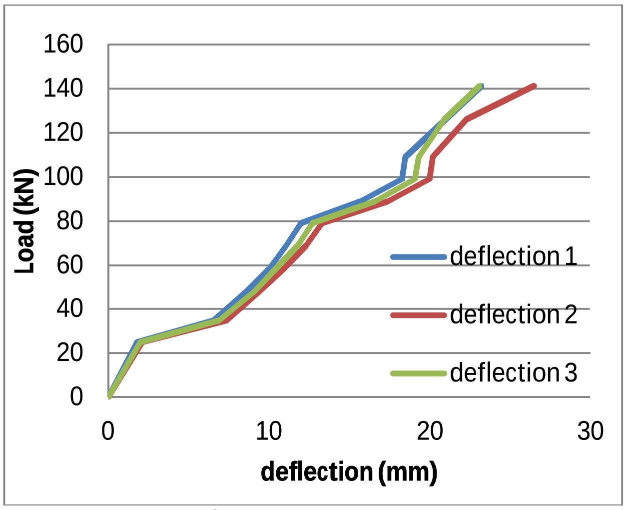

Fig.9. Load vs deflection (GFRC with GFRP beam – 3)

4.2.2. Companion Specimen Results for conventional concrete beam shown in fig 10,11,12 and table 7,8,9

For specimen 1

TABLE 7: Load Vs deflection (Conventional Concrete beam 1)

S.no	Load (kN)	Deflection1 (mm)	Deflection 2 (mm)	Deflection 3 (mm)
1.	0	0	0	0
2.	30.6	0	1.2	0.4
3.	40.6	0	1.3	0.4
4.	53.8	0.3	2.9	1.1
5.	57.2	0.5	3.4	1.4
6.	67	0.8	4.1	1.7
7.	76.6	2.8	8	3.6

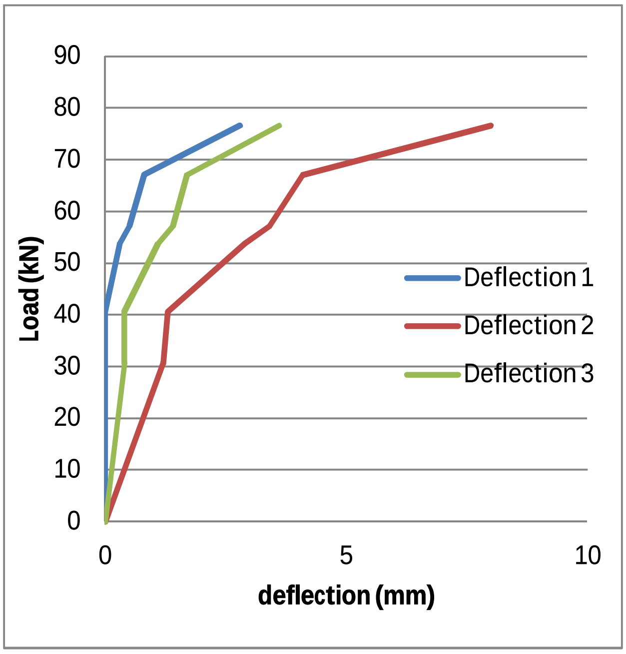

Fig.10. Load Vs deflection (Normal beam – 1)

For specimen 2

TABLE 8: Load Vs deflection (Conventional Concrete beam 2)

S.no	Load (kN)	Deflection1 (mm)	Deflection 2 (mm)	Deflection 3 (mm)
1.	0	0	0	0
2.	20.6	0.9	0.9	0.8
3.	30.6	1.4	1.8	1.3
4.	44	2.3	2.8	2.3
5.	54	3.4	3.9	3.4
6.	64.5	3.7	4.4	3.8
7.	76	4.3	5.1	4.5
8.	86	5.3	6.3	5.8
9.	120	14.8	17.1	17.6

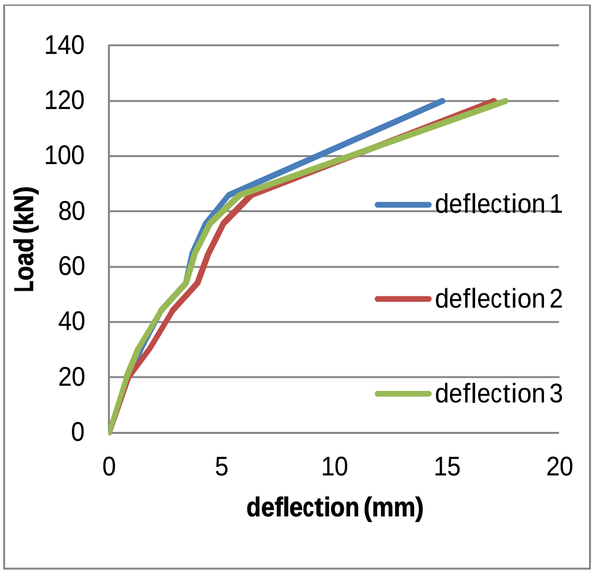

Fig.11: Load Vs deflection (Normal beam – 2)

For specimen 3

TABLE 9: Load Vs deflection (Conventional Concrete beam 3)

S.no	Load (kN)	Deflection1 (mm)	Deflection 2 (mm)	Deflection 3 (mm)
1.	0	0	0	0
2.	21	0.3	1.0	1.3
3.	32	1.5	2	2.6
4.	42	2.2	3	3.4
5.	52	2.5	3	3.7
6.	63	3.4	4	4.8
7.	73	5.3	7	7
8.	96	22.1	24	23.9

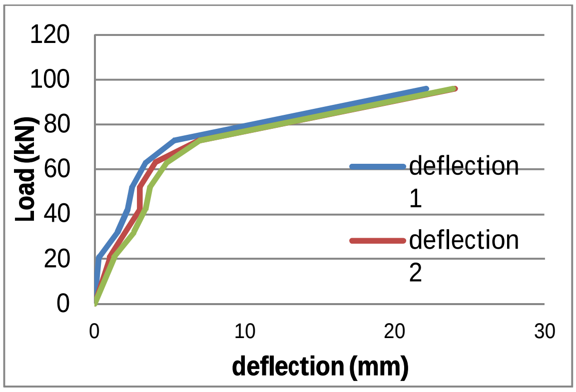

Fig.12: Load Vs deflection (Normal beam – 3)

4.3. Load carrying capacity

Load Vs specime is plotted shown in fig 13,14,15. The maximum load carrying capacity of conventional concrete beam is 97.53 KN and GFRC with GFRP beam is 131.76 KN.

TABLE 10: Load carrying capacity

S.no	Specimen	Ultimate Load kN	Average Ultimate Load kN
1.	GFRC with GFRP beam-1	122.2	
2.	GFRC with GFRP beam -2	131.9	131.76
3.	GFRC with GFRP beam -3	141.2	
4.	Normal beam-1	76.6	
5.	Normal beam-2	120	97.53
6.	Normal beam-3	96	

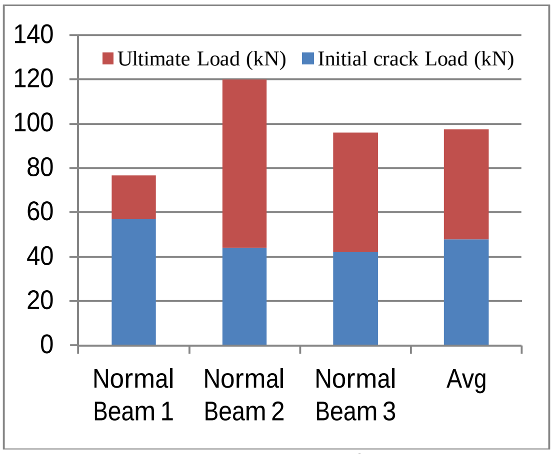

Fig.13: Load carrying capacity for normal beam

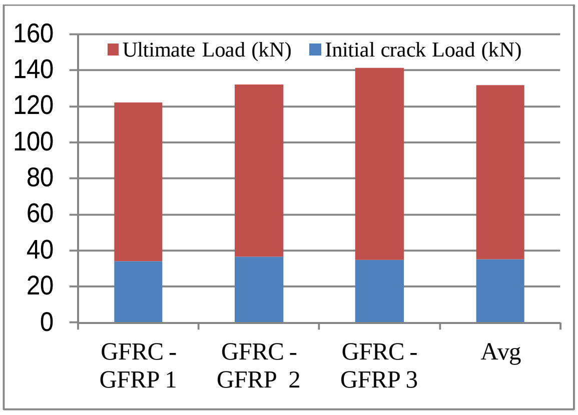

Fig.14: Load carrying capacity for GFRC with GFRP beam

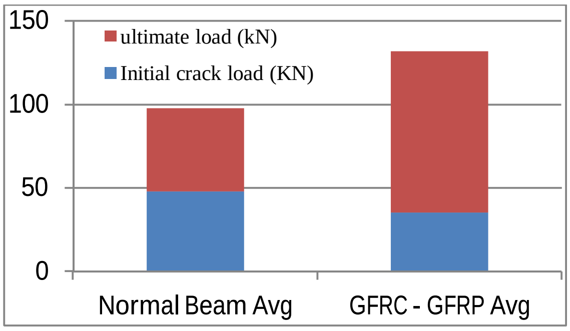

Fig.15. Load carrying capacity for Normal beam Vs GFRC with GFRP beam

4.4. Ultimate moment

Moment vs rotation is plotted shown in fig 16,17,18,19,20,21 and table 10,11,12,13,14,15.
For beam specimen 1

TABLE 11: Ultimate moment for GFRC with GFRP beam-1

S.no	Load (kN)	M_c (kN-m)	Dial reading (m)
1.	0	0	0.05
2.	25	16.25	0.05
3.	34	22.1	0.05
4.	45	29.25	0.10
5.	55	35.75	0.10
6.	64	41.6	0.15
7.	77	50.05	0.15
8.	87	56.55	0.20
9.	100	65.0	0.25
10.	111	72.15	0.25
11.	122.2	79.43	0.45

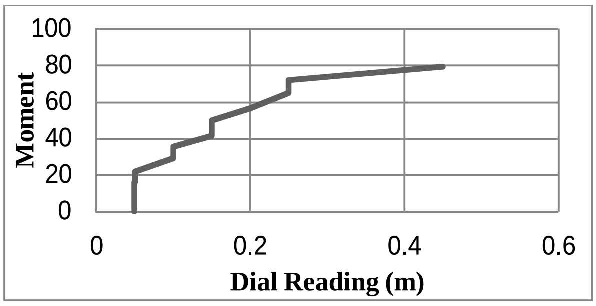

Fig.16. Moment Vs Dial reading (GFRC with GFRP beam-1) For beam specimen 2

TABLE 12: Ultimate moment for GFRC with GFRP beam-2

S.no	Load (kN)	M_c (kN-m)	Dial reading (m)
1.	0	0	0.05
2.	12.3	7.99	0.10
3.	25.3	16.44	0.10
4.	37.9	24.63	0.15
5.	54.7	35.55	0.15
6.	73.8	47.97	0.20
7.	95.2	61.88	0.20
8.	105.8	68.77	0.25
9.	117.5	76.37	0.25
10.	131.9	85.73	0.30

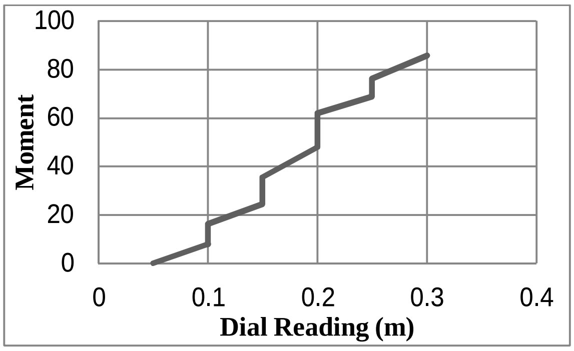

Fig.17. Moment Vs Dial reading (GFRC with GFRP beam-2) For beam specimen 3

TABLE 13: Ultimate moment for GFRC with GFRP beam-3

S.no	Load (kN)	Mc (kN-m)	Dial reading (m)
1.	0	0	0
2.	25	16.25	0.05
3.	35	22.75	0.05
4.	48	31.2	0.10
5.	58	37.7	0.10
6.	69	44.85	0.10
7.	79	51.35	0.10
8.	89	57.85	0.15
9.	99	64.35	0.20
10.	109	70.85	0.20
11.	126	81.9	0.20
12.	141.2	91.78	0.25

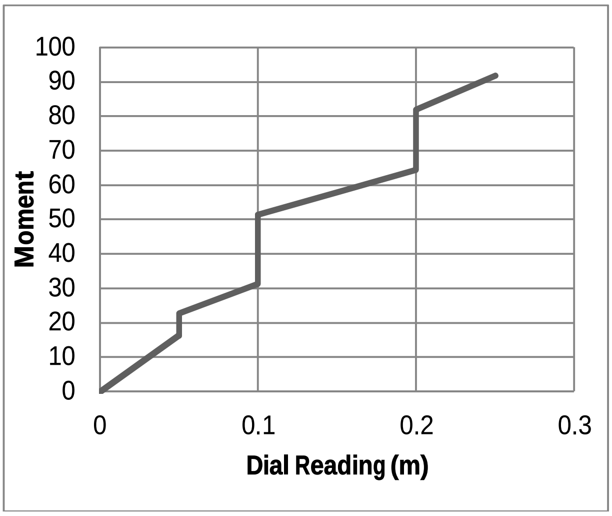

Fig.18. Moment Vs Dial reading (GFRC with GFRP beam-3) For specimen 1

TABLE 14: Ultimate moment for Normal beam-1

S.no	Load (kN)	Mc (kN-m)	Dial reading (m)
1.	0	0	0
2.	30.6	19.89	0.05
3.	40.6	26.39	0.05
4.	53.8	34.97	0.10
5.	57.2	37.18	0.10
6.	67	43.55	0.10
7.	76.6	49.79	0.15

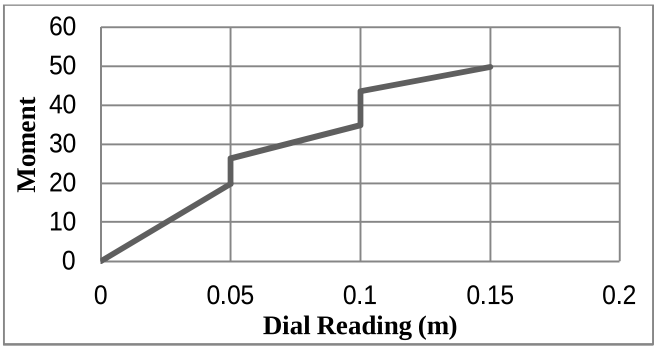

Fig.19. Moment Vs Dial reading (Normal beam-1) For specimen 2

TABLE 15: Ultimate moment for Normal beam-2

S.no	Load (kN)	Mc (kN-m)	Dial reading (m)
1.	0	0	0
2.	20.6	13.39	0
3.	30.6	19.89	0
4.	44	28.60	0.05
5.	54	35.10	0.05
6.	64.5	41.92	0.05
7.	76	49.40	0.05
8.	86	55.90	0.10
9.	120	78.0	0.20

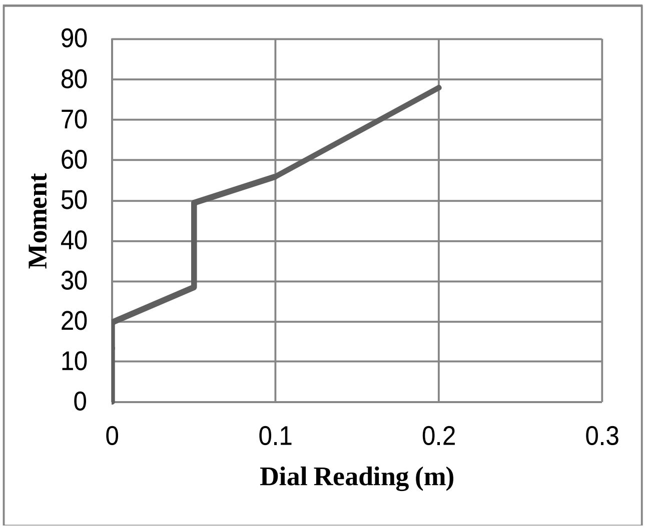

Fig.20: Moment Vs Dial reading (Normal beam-2) For specimen 3

TABLE 16: Ultimate moment for Normal beam-3

S.no	Load (kN)	Mc (kN-m)	Dial reading (m)
1.	0	0	0
2.	21	13.65	0.05
3.	32	20.80	0.05
4.	42	27.30	0.05
5.	52	33.80	0.05
6.	63	40.95	0.05
7.	73	47.45	0.10
8.	96	62.40	0.10

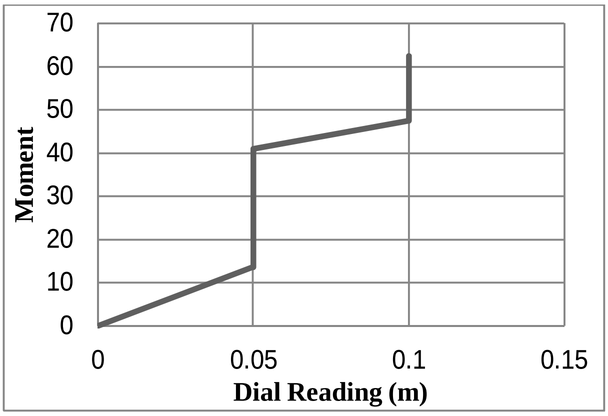

Fig.21. Moment Vs Dial reading (Normal beam-3)

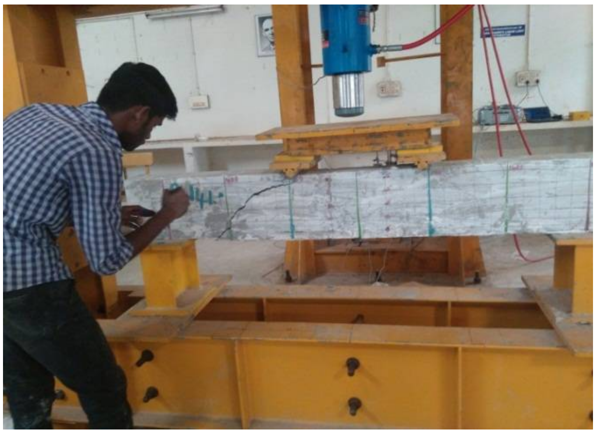

Fig.22. (a)

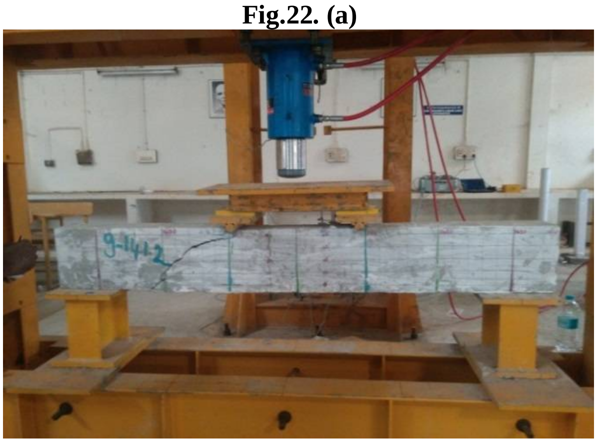

Fig.22.(b)

Fig.22.(a & b). Ultimate load failure and crack pattern

4.5. Stiffness

Stiffness is the rigidity of an object – the extent to which it resists deformation in response to an applied force. Stiffness is measured in force per unit length (N/mm) and is equivalent to the "force constant" in Hooke'S Law.

TABLE 17: Stiffness

S.no	Specimen	Initial stiffness (N/mm)	Avg. initial stiffness (N/mm)	Final stiffness (N/mm)	Avg. final stiffness (N/mm)
1.	GFRC with GFRP beam-1	6.81		4.51	
2.	GFRC with GFRP beam -2	3.51	5.11	4.66	4.83
3.	GFRC with GFRP beam -3	5.11		5.33	
4.	Normal beam-1	25.5		9.575	
5.	Normal beam-2	17.11	18.3	6.818	6.79
6.	Normal beam-3	12.30		4	

4.6. Ductility

Ductility is defined as the ability of a material to undergo permanent deformation through elongation or bendingwithout fracturing.

TABLE 18: Ductility

S.NO	SPECIMEN	DUCTILITY	AVERAGE
1.	GFRC with GFRP beam-1	0.111	0.118
2.	GFRC with GFRP beam -2	0.127	
3.	GFRC with GFRP beam -3	0.117	
4.	Normal beam-1	0.104	0.166
5.	Normal beam-2	0.146	
6.	Normal beam-3	0.250	

4.6. Energy dissipation capacity

Areinforced concrete memberdissipate energy by experiencing in elastic behavior during cyclic loading.

TABLE 19: Energy dissipation capacity

S.no	Specimen	Energy dissipation capacity (N/mm)	Average Energy dissipation capacity N/mm
1.	GFRC with GFRP beam-1	0.201	
2.	GFRC with GFRP beam -2	0.175	0.183
3.	GFRC with GFRP beam -3	0.175	
4.	Normal beam-1	0.068	0.140

5.	Normal beam-2	0.134	
6.	Normal beam-3	0.226	

4.7. Mode of failure

TABLE 20: Crack pattern

S. no	Specimen	Initial crack load(kN)	Ultimate load(kN)	Cracked observed	Type of faliure
1.	GFRC with GFRP beam-1	34	122.2	6to 8 mm	Shear
2.	GFRC with GFRP beam - 2	37.9	131.9	3 to 6 mm	Shear
3.	GFRC with GFRP beam - 3	48	141.2	7 to 8 mm	Shear
4.	Normal beam-1	40.6	76.6	6 to 10 mm	Flexural
5.	Normal beam-2	44	120	7 to 11 mm	Flexural
6.	Normal beam-3	42	96	6 to 9 mm	Flexural

5.CONCLUSIONS

Based on the experimental investigation conducted on beams under two point loading. The following conclusions are drawn:

- The maximum compressive strength of GFRC is 6.3% greater than conventional concrete.
- The maximum split tensile strength of GFRC is 19.8% greater than the value of conventional concrete.
- The maximum flexural strength of GFRC is 11.43% greater than the value of conventional concrete.
- The load carrying capacity of GFRC with GFRP beam was found to be 35.09% greater than the value of conventional concrete beam.
- The value of GFRC with GFRP beam for load Vs deflection is about 27.33mmgreater than conventional concrete beam which is 16.36mm.
- Ultimate moment of GFRC with GFRP beam is 85.64 KN-m greater. when compared to the conventional concrete beam which is 63.36 KN-m.
- Replacement of steel rebar with GFRP rebar beam has shown better result in flexural load carrying capacities.
- The stiffness of GFRC with GFRP beam was found to be 40.57% greater than the value of conventional concrete beam.
- Ductility of GFRC with GFRP beam is 0.118 smaller than the value of conventional concrete beam which is 0.166.
- The value of GFRC with GFRP beam for energy dissipation capacityis about 30.72% greater than conventional concrete beam.
- The addition of glass fibre at concrete reduces the crack under loading conditions. The brittleness of concrete can also be improved by the addition of glass fibre. Since concrete weak in tension, the fibres are beneficial in axial-tension to increase tensile strength.
- The use of GFRP rebars in beam has yielded not only greater flexural strength to the beam but also good shear capacities and bending moment.

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