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Flexural Strength of 10 mm (3/8") Gravel Aggregates Concrete Beams with Glass Fiber Reinforced Plastic (GFRP) and Steel Bar

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***Abstract*— The paper present the experimental study of the flexural strength and deformation of concrete beams containing 10 mm (3/8'') all – in gravel aggregate concrete, reinforced with glass fiber reinforced plastic (GFRP) bars, steel bars and hybrid combination of steel and GFRP bars in diameters of 10 mm, 12 mm and 16 mm. A total of 18 standard cubes and 39 reinforced beams specimens were produced and tested for compressive and flexural strength after 28 days wet curing.**

Results showed that plain concrete exhibit brittle failure. The failure mechanism of beam reinforced with steel and hybrid combination was predominantly ductile characterized by inclined tensile cracks due to a combination of shear and flexural failure. The higher ductility and tensile strength exhibited by beams with hybrid bars was principally responsible for the delay in flexural failure. The ultimate strength of the plain concrete beam was increased by about 5, 7 and 8 times in beam reinforced with steel, GFRP and hybrid bars.

***Index Terms*— GFRP; Steel,Flexural Strength; Reinforced Concrete; Compressive Strength.**

I. Introduction

The degradation of concrete structures due to the corrosion of conventional steel reinforcement in concrete has reduced its life span and increased the cost of repair and maintenance over the years. Steel reinforcement is also heavy and adds to the overallweight of the structural element. These issueshave been of serious concern to engineers, leading to a continued search for alternatives to steel reinforcement in order to increase the life span of structure and reduced the high costs of repair and maintenance of structures damaged by corrosion and heavy use. Several methods such as epoxy coated rebar, galvanization of reinforcement steel, epoxy foundation grouting, synthetic membranes, or cathodic protection have developed and applied. (Kobayashi etal 1984, Annapuranietal 2017, ASTM 548-14)

With the progress made by researchers in the polymer industry, Fiber reinforced plastic (FRP) has the capability of replacing steel reinforcement in the construction of marine structures around the coastal region, bridge deck, parking garages design, automobile and sport facilities among others for more than 15 years without any structural problem (Rostasy, 1996). Other areas where the use of steel reinforcement impairs durability are concrete susceptible to corrosion like in waste water treatment facilities and concrete with inadequate concrete cover (Hughes2011).Following the result of the recent researches, the use of polymer materials instead of steel in concrete structures, led to the entry of fibre reinforced polymer (FRP) into field of constructions (Iman et al 2010). Fibre reinforced polymers (FRP) bars can resist marine chloride or salt water more than steel reinforcement bars and as such is best suited for construction in this kind of harsh environments including offshore and marine structures.

Cracks and voids, inherent in concrete,permit ingress of chlorides which oxidize and corrode the steel, resulting in further expansion and cracking of the concrete surrounding the steel bars. FRP are non-corrosive and as such, they can resist chloride agents and will not rust when in content with them. It therefore lasts longer when used in aggressive environment like water treatment plants instead of steel reinforcement bars. (AlMusallam et al., 1997; Alsayed, 1998, 1997; Benmokrane et al., 1995, 1996). The other advantage of fibre reinforced polymer bars is the non-magnetic characteristics which makes it more suitable where conductor materials are not desirable like high voltage and electromagnetic field. FRP bars have lower density, about a quarter that of steel, which makes it lighter in weight than the conventional steel reinforcements. This leads to lower cost of transportation and lifting, ease of handling in construction, reduced construction time and load on foundation structures. (Thériault and Benmokrane, 1998; Yost et al., 2001). FRP bars have high tensile strength which is twice higher than that of steel reinforcement. The use of FRP materials has been limited by its brittle nature, low modulus of elasticity and low ductility. Other than the brittle failure mode, the major shortcoming of FRP reinforcing bars is their relatively low stiffness, when compared to steel. This reduced stiffness, combined with other factors such as different bond behaviour and lower tension stiffening, results in deflections that are larger than in conventional steel-reinforced beams, at any load stage (Chidananda&Khadiranaikar2017). Lack of ductility of FRP bars has made it difficult to have comprehensive codes and standards for these bars. The above cited researches on concrete members, reinforced with FRP show that no yielding was observed due the linear relation between stress and strain in FRP bars. The width and extent of cracks in these beams were investigated Chidananda& Khadiranaikar(2017),Benmokrane et al., (1996) Vijay and

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GangaRao, (2001) among others. Deflection of concrete beams with FRP was about four times greater than similar samples of steel reinforced beams and the load – deflection diagram exhibited a straight line variation (Saadatmanesh and Ehsani, 1991; Victor and Shuxin, 2002). In addition, the useFRP in high strength concrete has been found to behighly effective (Vijay and GangaRao, 2001;

This study investigates the flexural strength of GFRP bars in comparison with that of steel bars. Four different arrangements of bars were investigated in order to determine the most appropriate reinforcement positions of the GFRP bars.

II. Experimental Methods

A. MaterialsUsed

A finely ground inorganic material which, when mixed with water, forms a paste that sets and hardens by means of hydration reactions and which, after hardening, retains its strength and stability even under water. The Portland limestone cement (CEM 11/ B-L) used for this experimental study is manufactured by Dangote cement factory and conforms to NIS 444 and EN 197-1: 2000. The material also conforms with the American Concrete Institute (ACI) Specifications for low strength concrete.

GFRP Reinforcement Bars (Fiber Reinforced Polymer Reinforcement Bars)

Glass fiber reinforced polymer bars used in this research study was obtained from the ENGINEERED COMPOSITE LIMITED United Kingdom England. The properties of the fiber bars as obtained from the manufacturer are as indicated in Appendix 1.The GFRP specifications conform to ASTM D725 10 mm, 12 mm and 16 mm.

Particle Size Distribution

Particle size distribution of aggregate was carried out and the result are presented in PSD graph plotted in Figure 2.1 below.

From the particle size distribution graph, the aggregate fits into the grading envelope and conform to BS EN 933-1 showing that aggregate is adequate for concrete production.

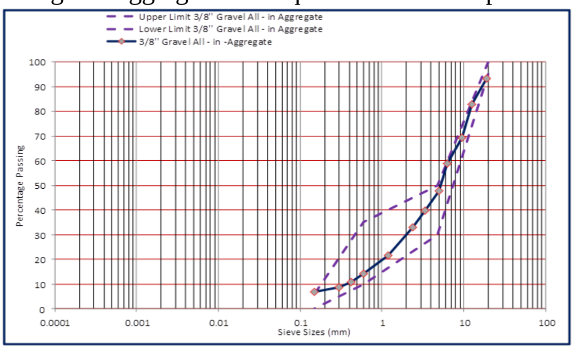

Figure 2.1 Particle SizeDistribution of 10 mm (3/8'') All – in Gravel Aggregate

Plate 2.1 Glass Fibre Reinforcement Bars

Properties	STEEL	GFRP	CFRP	AFRP
Nominal yield stress(Mpa)	276-517	N/A	N/A	N/A
Tensile strength(Mpa)	483-690	483-160	600-3690	1750-2540
Elastic modulus(Gpa)	200	3551	120-580	41-12
Yield strain (%)	0.14-.25	N/A	N/A	N/A
Rupture Strain (%)	06-Dec	12-3.1	0.5-1.7	1.9-4.4

B. Material Properties

Concrete Mix Design

The concrete mix design was carried out using the Absolute volume method complying with the BS EN 206 -1 :2003, the mix proportions for this normal concrete mix was determined based on the results of the sieve analysis shown in Appendix 3- 10 and discussed in Chapter 4, section 4.1.

Appendix 11 shows the particle size distribution for the typical 10 mm (3/8'') gravel aggregates in its natural state.

The mix design aggregate content were 1: 2:4:0.5 mix proportions, recommended in Ephraim & Thank God (2005) for the washed 10 mm (3/8'') gravel concrete in the present study. The resulting mix compositions and quantities are shown in Table 3.2.

Materials	**Weight (Kg)**	**Ratio**
Cement	400	1
Fine aggregate (sand)	800	2
Coarse aggregate (gravel)	1640.8 2	4
Water	200	0.5

Batching, Mixing and Handling

The various concrete casting activities to be carried out in the production of the test specimens and the quality test on fresh concrete should be in accordance with the NIS Standard and International concrete best practice.

The value of strength below 5% the population of all possible strength measurements of the specified concrete and reinforcement bar are expected to fall.

The mixing of 10 mm (3/8'') reinforced concrete was done in the laboratory in accordance with the American Concrete

Institute (ACI 544.1R-96) recommendation. Concrete batching was done by adopting a common mix ratio of 1:2:4 by weight of cement, sand and granites, with water / cement ratio of 0.5. It was design to give a compressive strength of 30 MPa on the target mix of 43.12 N/mm^2 at twenty eight days and slump value ranges from 100-150mm. Water cement ratio of 0.5 was adapted to ensure proper compaction and workability, so that good strength can be achieved. Concrete mixing was done by the use of a mechanical concrete mixer in the Civil Engineering laboratory of Rivers State University (RSU). The cement and the fine aggregates (sand) were first placed in the concrete mixer and allowed to rotate for about two minutes, followed by the addition of combinations of the D10 Aggregates & D12 and water was added actually to control workability of concrete. Upon the gradual additions of the mixing water, different ranges of slumps were taken to monitor mixed concrete workability and to avoid slurry during the addition of water into the mix. The mixture was allowed to rotate in the mixer for two minutes before the addition of coarse aggregate and water. The mixer was allowed for three minutes for proper mixing, care being taken to avoid bleeding of concrete. Slump test was conducted at every mix during concrete batching and the slump value recorded. The concrete was placed in oiled concrete molds and compacted with a table vibrator. The concrete samples were allowed in the molds for twenty four hours after which they were removed from the molds and placed in a curing tank for twenty eight days. The batching and production processes are captured in Plate 3.2.

Beam Reinforcement Details

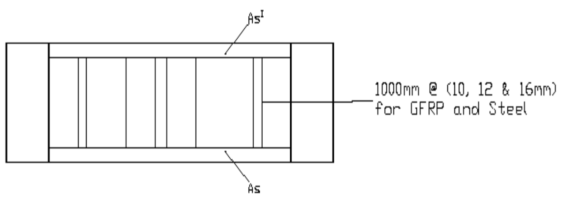

Figure 3.1 Reinforcement Details of Experimental Beams

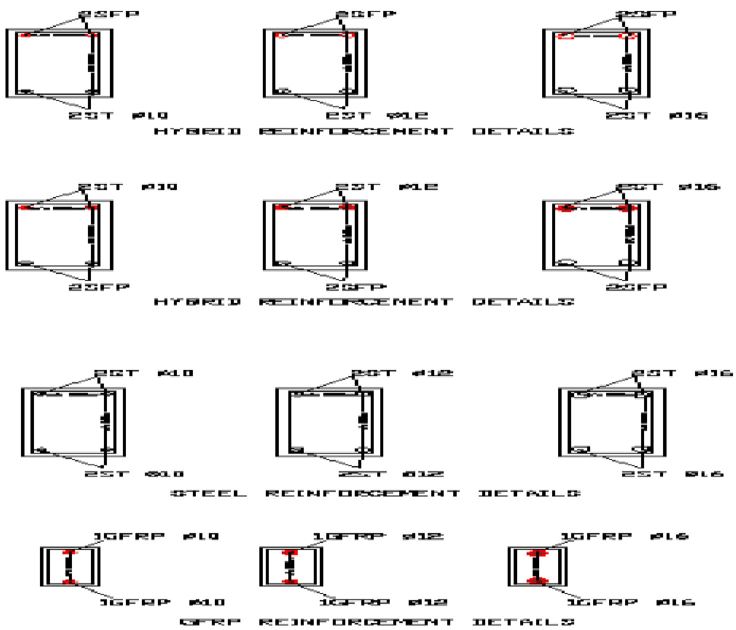

Figure 3.2 Beams (Type 1,2,3) with Reinforcement Details and Dimensions

Figure (a), the first sectional view, represents the hybrid Type 1 with GFRP placed at the Top and Steel placed at the bottom

Figure (b), the second sectional view represents the hybrid Type 2 with GFRP placed at the bottom and steel placed at the top.

Figure (c), the third sectional view represents the steel with steel placed at both top and bottom.

Figure (d), the fourth sectional view represents the GFRP with GFRP placed at both top and bottom.

C. Testing Procedures

Compressive strength test is one of the most common tests conducted on concrete to ascertain concrete grade design for. The 150 x 150 x 150 mm concrete cube where crushed and values recorded for analysis as shown below.

The Flexural Tests were equally conducted on the Beams samples, both reinforced and the un- reinforced for flexural strength analysis to determine the level of beam deformity

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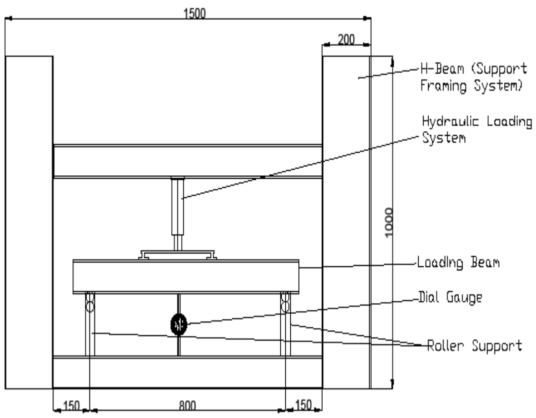

Figure 3.3 Test Set-up for Flexural Test

The various concrete casting activities to be carried out in the production of the test specimens and the quality test on fresh concrete should be in accordance with the NIS Standard and International concrete best practice.

The value of strength below 5% the population of all possible strength measurements of the specified concrete and reinforcement bar are expected to fall.

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III. Results and Discussions

A. *Workability on Fresh Concrete*

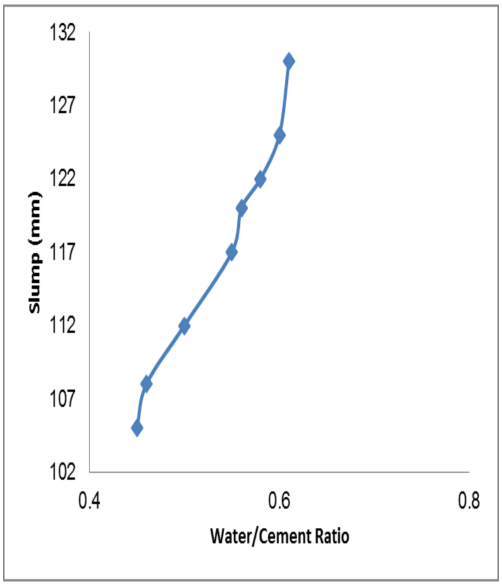

Figure 3.4 Compressive Strength Test/Density

The physical characteristics of the aggregate shows that the results gotten for Coefficient of Curvature, Cc and Coefficient of Uniformity, Cu from the laboratory test values, classify the Aggregate as well graded aggregate because the values of Cu and Cc falls within the acceptable limit of Cu > 4 to 6 & 1 < Cc < 3 as recommended by ASTM D2487-11. These values confirm that the all – in gravel aggregate used in this study meet the requirements of the standards and therefore adequate for concrete mix design and structural purposes.

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Table 3.3 Average Compressive Strength / Density Values

	3 Days		7 Days		14 Days		21 Days		28 Days	
	Cube Strength (N/mm^2)	Density (mm)	Cube Strength (N/mm^2)	Density (mm)	Cube Strength (N/mm^2)	Density (mm)	Cube Strength (N/mm^2)	Density (mm)	Cube Strength (N/mm^2)	Density (mm)
	18.4	24.4	43.5	24.4	44.5	24.4	44.8	24.4	45.3	24.4
	19.4	24.4	44.5	24.4	44.56	24.4	44.85	24.4	45	24.4
	17.4	24.4	43.5	24.4	44.53	24.4	44.65	24.4	45.4	24.4
	18.4	24.4	43.53	24.4	44.54	24.4	44.86	24.4	45	24.4
	18.42	24.4	43.53	24.4	44.55	24.4	44.85	24.4	45.55	24.6
	18.43	24.4	43.5	24.4	44.55	24.6	44.9	24.7	45.78	24.6
	18.3	24.6	43.45	24.6	44.5	24.4	44.75	24.6	45	24.7
	18.4	24.6	43.5	24.4	44.56	24.4	44.73	24.6	45.78	24.7
AVERAGE	18.39	24.45	43.63	24.43	44.54	24.43	44.8	24.49	45.36	24.53

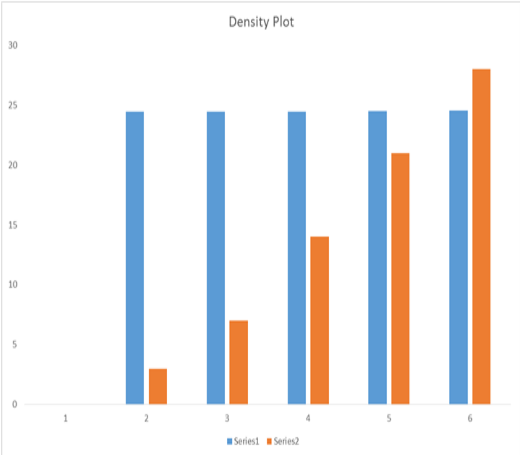


Figure 3.5 Average Calculated Density Plot

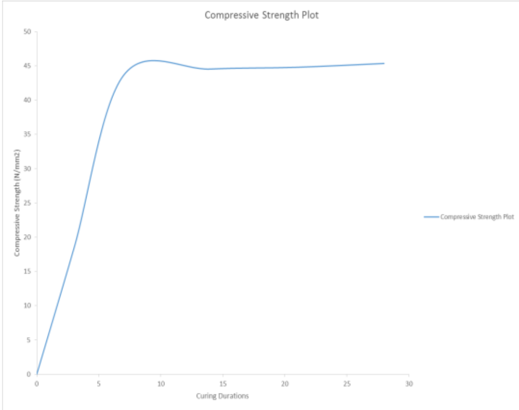
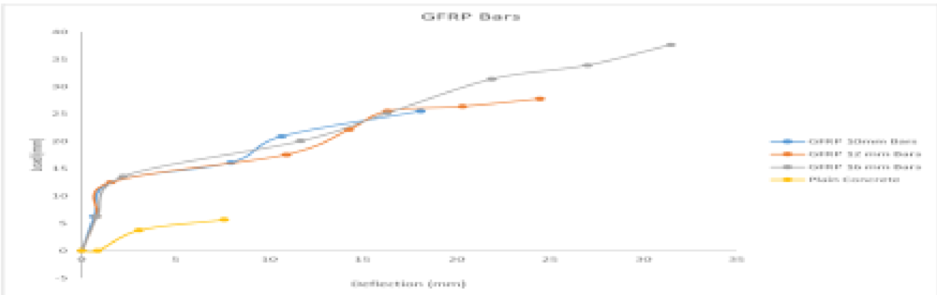


Figure 3.6 Variation of Compressive with Duration of Wet Curing

3.2 Flexural Response of Beams

3.7.1 (GFRP AND STEEL)



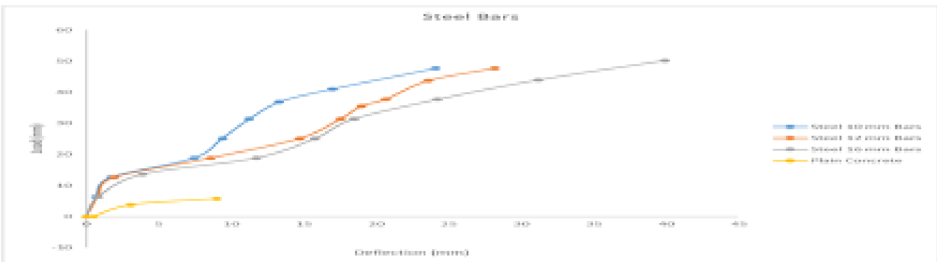


Figure. 3.7 Load-Deflection Curve for 10 mm (3/8") Reinforcement Beam

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Fig 3.7 shows the load – deflection curves for 10 mm (3/8'') all – in gravel concrete beams reinforced with GFRP bars. For plain concrete, failure occurred at a load of 5.68 kN and mid-span deflection of 7.63 mm. The plain concrete behaved non - linearly up to failure. As expected the plain beam exhibited a brittle type of failure while the reinforced beams with FRP bars failed in the flexural manner. From Fig 3.7, it was observed that the flexural resistance increased as reinforcement ratio increased. The ratio of the flexural strength of plain concrete beam to that of GFRP reinforced beams are 1:4.42, 1:4.87 and 1:6.18. This signifies flexural strength increases of 442%, 487% and 618% in GFRP reinforced concrete beams when compared with plain concrete beams for GFRP 10 mm, 12 mm and 16 mm diameters respectively. Similar observation was made by Bencardinoetal. (2016). Due to the high ductility, it was possible to observe that the first crack before the final failure of the beam in this series. The load at the first crack and failure are shown in Table

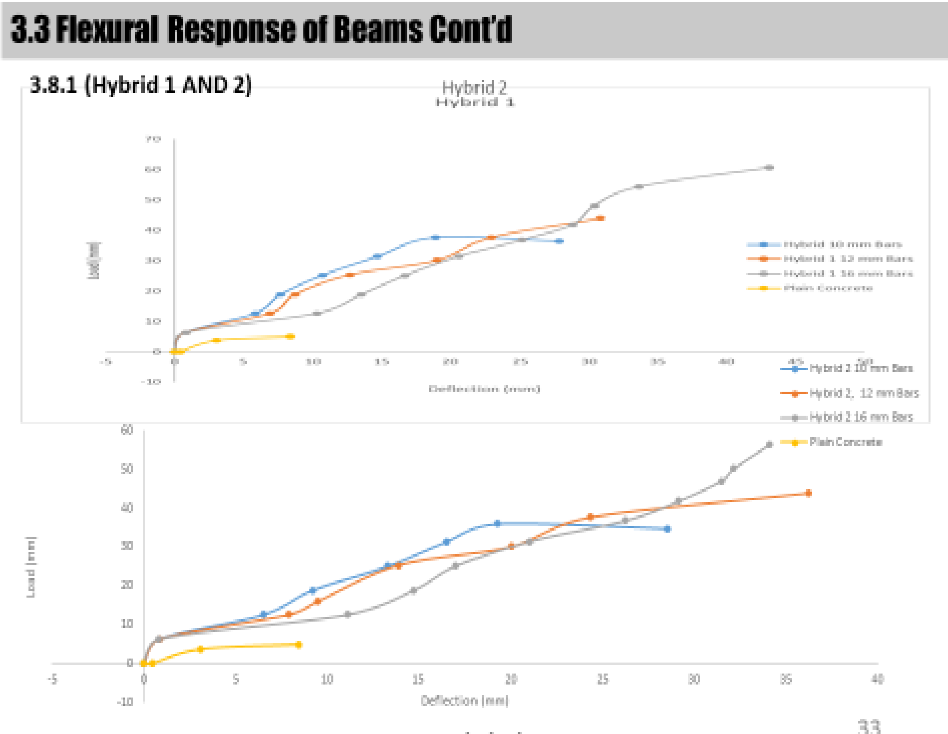

Figure. 3.8 Load-Deflection Curve for 10 mm (3/8'') Reinforcement Beam

Fig 3.8 shows Load – Deflection for beams reinforced with steel reinforcement only. As usual, plain concrete failed in a brittle manner at a load of 5.65kN and mid –spam deflection of 7.63 mm. This plain concrete exhibited a brittle behavior until failure. Other three beams reinforced with steel using diameters of 10mm. 12mm and 16mm failed in the usual ductile flexural manner with yielding of the tension steel followed by cracking and crushing of the concrete.

Similarly, it was observed that the flexural resistance increased as the bars size increased, this confirms the influence of bar ratio on the flexural resistance of the reinforced beam the ratio of the flexural strength of plain concrete beams to that of steel reinforced beam are 1:7.33, 1:8.05 and 1:8.71. This signifies 733%, 805% and 871% increase in flexural strength of steel reinforced concrete beams when compared with plain concrete beams for steel reinforcement bars of 10 mm, 12 mm and 16 mm diameters respectively

Plate 3.9 Beam Failure for Flexural Test

3.9.1 Ductility Index of Concrete Beams with Various Reinforcements

TYPE OF REINFORCEMENT	REINFORCEMENT DIAMETER	REINFORCEMENT RATIO (As/As')	1st CRACK	DEFLECTION (mm)	LOAD (KN)	DEFLECTION (mm)	DUCTILITY INDEX%
PLAIN CONCRETE	N/A	0	3.77	3.08	12.06	11.84	2.71
STEEL (ST)	10 mm		36.81	13.33	47.69	24.13	1.81
	12 mm		43.72	23.6	47.69	28.19	1.19
	16 mm		43.93	31.21	50.2	39.95	1.28
FIBER REINFORCED POLYMER BAR (GFRP)	10 mm		16.11	7.95	25.52	18.13	2.28
	12 mm		25.52	16.33	27.76	24.5	1.5
	16 mm		31.38	21.91	37.65	31.5	1.44
HYBRID 1 (SFP)	10 mm		37.65	18.96	36.44	27.88	1.47
	12 mm		37.65	22.96	43.93	30.89	1.35
	16 mm		54.39	33.67	60.66	43.11	1.28
HYBRID 2 (SFP)	10 mm		35.98	19.24	34.77	28.54	1.44
	12 mm		37.65	24.31	43.93	36.27	1.49
	16 mm		50.2	35.62	56.48	43.11	1.21

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IV. Conclusion

- The flexural strength of plain concrete beams at appearance of first and failure cracks were 3.77 and 5.65 KN respectively with corresponding central deflections of 3.08 and 7.63 mm.
- The ultimate strength of beams increased with percentage reinforcement achieving significant increases of about 4 to 6 times for steel reinforced beams, 7 to 9 times for GFRP reinforced beams and 6 to 11 times for beams with hybrid reinforcements of 10, 12 and 16 mm diameters considered.
- The ductility index was practically constant at about 2 for steel reinforced beams but varied within a wide margin of 1 to 3 for beams with GFRP and mixed reinforcement.

Flexural failure of the concrete beam depends largely on the material strength of concrete and reinforcement the predominant failure mechanism was characterized by tensile cracking along inclined planes due to combined shear and flexural stresses. Hybrid reinforcement exhibited highest flexural resistance to failure. The beams with hybrid reinforcement did not fail completely by concrete crushing, due to partial attainment of ultimate strength of the FRP bars simultaneously with yielding of steel bar

V. Acknowledgement

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