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STRUCTURAL PERFORMANCE OF CONCRETE FILLED FRP THIN WALLED TUBULAR BEAMS

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ABSTRACT

Corrosion of steel reinforcement in concrete is considered to be the major cause of deterioration in civil infrastructure facilities. The use of fibre-reinforced polymer (FRP) tubes acts as a structurally integrated stay-in-place form for concrete members that expand the service life of structures, enhancing the corrosion resistance and potentially high durability. This paper presents on an experimental study on the structural performance of normal and high strength of concrete infilled FRP thin walled tubular beams with different configurations. The concrete filled FRP thin walled tubular beams showed an increase in ultimate load carrying capacity, stiffness and ductility.

Keywords: FRP tubular beams; HSC; NSC; thin walled; woven roving; unidirectional cloth.

1. INTRODUCTION

The corrosion of steel reinforcement in reinforced concrete structures causes continual degradation to the worldwide infrastructures [1, 2, 3]. In recent years, fibre reinforced polymer (FRP) composites have found extensive applications in civil engineering, both in retrofit of existing structures and in new construction [4,5,6,7,8]. FRP composites possess several advantages over steel, including high strength to weight ratio and good corrosion resistance. To effectively utilize the advantages of FRP material, innovative structural systems are needed which either incorporate composite-efficient forms or which combine these new materials with conventional ones. The FRP tubes employed as structurally integrated stay-in-place forms for concrete structural members such as

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beams, columns, bridge piers and piles etc., has emerged as an innovative solution to the corrosion problem.

The FRP tube acts as a stay-in- place structural formwork to contain the fresh concrete and acts as a protective jacket for concrete. It can be utiltised in cast-in-place or precast industries. At the same time, the FRP shell acts as a non-corrosive material for the concrete for flexure and shear. Utilizing the multi-direction fibre orientation in the tube, which saves the time and cost of assembling the longitudinal rebar together with the stirrups in conventional fabrication methods. Most importantly, the FRP tube provides confinement to the concrete which is significantly, improves the strength and ductility of the member. The contained concrete is also protected from severe environmental effects and deterioration resulting from freeze-thaw cycles.

Several researchers have been carried out in the past to observe the structural behaviour of concrete filled FRP tubes. Fam and Mandal [9] conducted an experimental investigation on the flexural behaviour of prestressed concrete filled FRP beams. The author concluded that prestressing CFFT significantly increased their cracking strengths, initial stiffness and moment carrying capacities. Ahmad et al [10] carried out an investigation to evaluate the damage accumulation, stiffness degradation, fatigue life and residual bending strength of concrete filled FRP tubular (CFFT) beams. It was observed that fatigue performance of CFFT beams was clearly governed by characteristics of the FRP tube and its three phases of damage growth: matrix cracking, matrix delamination and fibre rupture. It also concluded that lower reinforcement index increased stiffness degradation and damage growth and shortened fatigue life. It was also suggested that a maximum load level of 25% of the static capacity be imposed for fatigue design of CFFT. Yutian shao [11] investigated on flexural behaviour of concrete filled fibre reinforced polymer circular tubes. Majid Muttashar et al [12] conducted a study on flexural and axial behaviour of pultruded GFRP tubes filled with low strength concrete to investigate the effect of concrete infill on the strength, stiffness and failure modes. Fam and Rizkalla [13] conducted an investigation on large scale concrete filled FRP tubes, hollow GFRP and steel tubes tested in bending. The study demonstrated the benefits of concrete filling, and showed that a higher strength-to-weight ratio can be achieved by providing a central hole. It was concluded that the flexural behaviour was highly dependent on the stiffness and diameter-to-thickness ratio of the tube and to a much less extent on the concrete strength. Limited literature exists on either with low and high concrete strength filled FRP tubes, however studies on the configuration of FRP tube with normal and high strength of concrete infilled FRP tubes is not addressed so far. Therefore, this study investigated on the flexural performance of different configurations of FRP thin walled tubular beams. The study also examines the feasibility of utilizing concrete filled FRP thin walled tubes as a structural member.

2. EXPERIMENTAL PROGRAMME

2.1 Materials

In the present investigation, ordinary Portland cement of 53 grade was used. The fineness of cement [14] was found to be 7% and its specific gravity [15] was found to be 3.15. The initial and final setting time was obtained as 32 and 520 minutes respectively and it was tested as per IS 4031-1988 (part 5) [16]. Locally available natural river sand was used as fine aggregate in the study. The specific gravity of fine aggregate [16] of 2.65 was obtained from the test conducted. As per IS 383 – 1970 [17], the particle size below 4.75 mm conforming to zone II was found out. The water absorption was found to be 8%. As per IS 2386 (Part 3): 1963 [18], crushed granite stone of size less than 12.5 mm with a specific gravity of 2.68 and water absorption was found to be 1.2%. Potable water was used for the concrete mix recommended as per IS 456:2000 [19]. Metakaolin is used as a mineral admixture. The colour of metakaolin was pinkish white. The specific gravity and specific area of metakaolin was 2.5 and 150000 to 180000 cm^2/g respectively. VARAPLAST PC 432, modified carboxylic ether was used as a chemical admixture and it has a specific gravity of 1.08 at 30°C.

High yield strength deformed bars of 8 mm, 12 mm and 10 mm diameter were used with the yield tensile strength of 435 N/mm^2. Glass fibre reinforced polymer (GFRP) with a thickness of 3 mm was used as a thin walled tube. Two different types of configurations of glass fabrics namely unidirectional cloth (UDC) and woven roving (WR) were used. In unidirectional cloth type, 95% of glass fibres were arranged in 0° direction. In woven roving type, glass fibres were arranged in bi-directional with equal distribution of fibres in two mutually perpendicular directions. Iso – phthalic polyester resin was used for manufacturing of GFRP thin walled tubular beams and is shown in Fig. 1. The properties of GFRP tested as per ASTM D 638 -14 [20] is shown in Table 2.

Figure 1. GFRP thin walled hollow tube

Table 1: Mechanical properties of FRP tubes

Properties	UDC	WR
Elastic modulus(MPa)	7016.25	8543.6
Ultimate elongation (%)	9.5	7.8
Tensile strength (MPa)	332.7	291.45

2.2 Properties of concrete

For the investigation, two different grades of concrete viz., normal and high strength concrete respectively of M 25 and M 60 were used. A trial mix design was done for normal strength concrete (NSC) [21] and high strength concrete (HSC) [22]. The corresponding mix proportions of NSC and HSC was 1: 2: 2.96: 0.45 and 1: 1.26: 2.19: 0.3. Slump test [23], most commonly used method of measuring workability of concrete. The respective observed slump for NSC and HSC was 55 mm and 165 mm. To assess the strength property of NSC and HSC, the tests such a compressive strength [24], and flexural strength test [24] were conducted. The specimens were tested at the age of 28 days after water curing. Table 2 shows the specimens used and results obtained from the various tests.

Table 2: Properties of concrete

Description	Specimens and size	NSC	HSC
Compressive strength of concrete (MPa)	Cube (150 mm x 150 mm x 150 mm)	28.73	64.5
Flexural strength of concrete(MPa)	Prism (100 mm x 100 mm x 500 mm)	4.02	6.60

2.3 Details of specimens

A total number of six GFRP thin walled tubular beams were used in the investigation. The GFRP tube of cross section 150 mm x 150 mm with a length of 1200 mm was used. The longitudinal reinforcement of 2 nos. of 12 mm diameter bars at the tension face and 2 nos. of 10 mm diameter bars at the compression face was provided. Two legged 8 mm diameter vertical stirrups were provided at 150 mm c/c spacing. The detailing of reinforcement in schematic view is depicted in Fig.2. Table 3 presents the details of specimen used in the study.

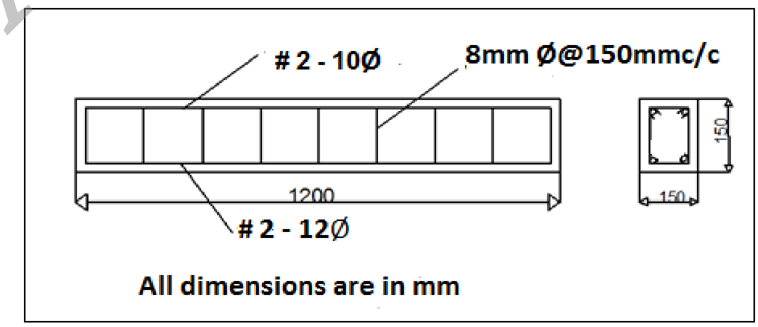

Figure 2. Schematic view of details of reinforcement

Table 3: Details of specimens

Beam ID	**Type of grade of concrete**	**FRP configuration**	**Beam description**
HW	--	WR	Woven roving GFRP hollow tube (HT) served as control specimen
HU	--	UDC	Unidirectional GFRP hollow tube served as control specimen
R2W	NSC	WR	normal strength concrete infilled in woven roving GFRP tube
R2U		UDC	normal strength concrete infilled in unidirectional GFRP tube
R6W	HSC	WR	high strength concrete infilled in woven roving GFRP tube
R6U		UDC	high strength concrete infilled in unidirectional GFRP tube

2.4 Casting of specimens

Figure 3. Placing of reinforcement

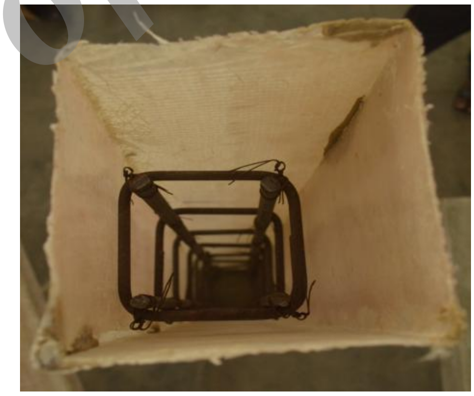

Figure 4. FRP tube with reinforcement

Figure 5. Concrete filled GFRP thin walled tubular beams

The FRP tube itself served as a formwork. Reinforcement cage shown was positioned concentrically inside the FRP tubes before casting as depicted in Fig. 3. Fig. 4 presents the reinforcement placed inside the FRP tube. The FRP tubes was placed vertically and concrete was poured in layers. Electric internal vibrator was used to compact the concrete. After filing the tubes with the concrete, the end surface of the specimens were finished carefully. Top surface of the specimens were cured with water. Fig. 5 shows the concrete filled GFRP thin walled tubular beam specimens.

2.5 Test set up and instrumentation

Fig. 6 depicts the test set up of the GFRP thin walled tubular beam. All the beams were tested in a loading frame of 100 tonne capacity. A hydraulic jack was used to apply the load; and it was transferred to the beam through a load cell of 50 tonnes capacity. Load was applied in increment at rate of 5 kN/min approximately. To measure the mid-span deflections in the beams, linear variable differential transducer (LVDT) was placed at the tension face (bottom face) of the beam. Load cell and LVDT were connected to a 16 channel data acquisition system, which recorded all the data. The test parameters such as ultimate load, deflection, failure mode were observed during the test.

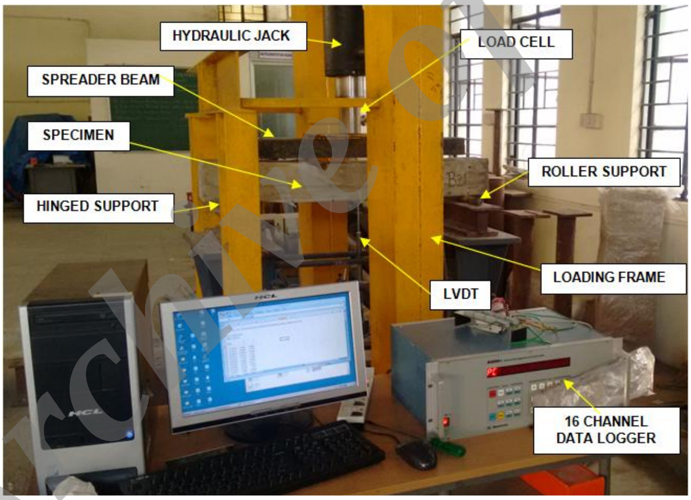

Figure 6. Test Setup for concrete filled GFRP thin walled tubular beams

3. RESULTS AND DISCUSSION

3.1 Results on FRP tubular beams

Table 3 shows the ultimate load and corresponding deflections obtained during the testing of FRP thin walled tubular beams.

3.2 Load-deflection behaviour

The load-deflection behaviour of all the tested beams is shown in Figs. 7 and 8. A linear elastic behaviour until failure was noticed in the hollow FRP tubular beams (HU & HW).

However, bilinear load-deflection curve were seen for concrete infilled FRP tubular beams. The concrete infilled in the beams provided an internal support for FRP tube that enhanced a higher load carrying capacity than the hollow FRP tubular beams. On the other hand, stiffness was greatly dropped due to the flexural tensile cracking in concrete. It can be noticed in Fig. 7 and 8, initially the curve started with a higher stiffness in the beam specimens R2U, R6U, R2W and R6W and it seems that concrete cross-section was very effective in FRP tubular beams.

Table 3: Summary of test results of beams

Beam ID	Ultimate load (kN)	Ultimate Deflection (mm)
HW	100	19.54
HU	120	22.45
R2W	400	48.13
R2U	500	68.54
R6W	450	58.97
R6U	550	75.67

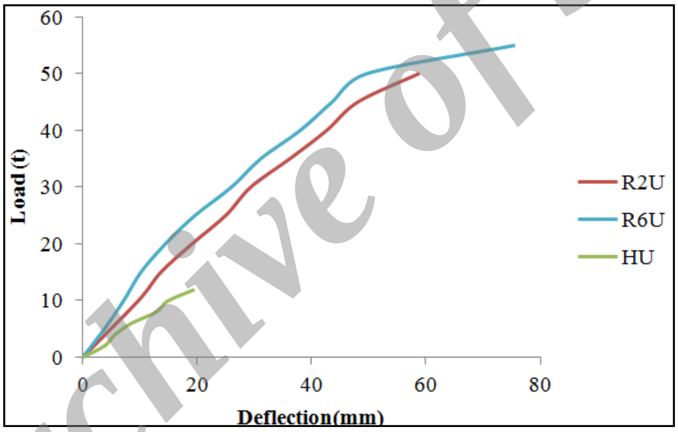

Figure 7. Load deflection for UDC GFRP tubular beams

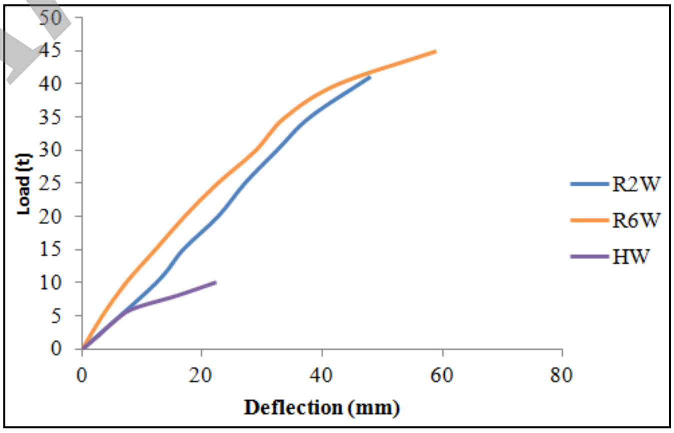

Figure 8. Load deflection for WR GFRP tubular beams

3.2 Failures of GFRP thin walled tubular beams

The typical mode of failure of the hollow and concrete filled FRP thin walled tubular beams are discussed in this section. The UDC GFRP hollow tubular beams (HU) failed in a brittle manner due to the rupture of fibres and premature buckling is shown in Fig. 9. The failure was due to the local buckling in the FRP thin wall which results in material delamination and cracking of the fibres along the edges of the beam under the load application. The failure of the concrete filled FRP thin walled tubular beams was due to flexural compression at the constant moment region including cracks in the fibres in the transverse direction. The web flange separation was observed in UDC GFRP tubular beams filled with normal strength of concrete (R2U) is depicted in Fig. 10.

A transverse compression crack followed by a web crushing was noticed in R6U specimen (Fig. 11). In case of WR FRP hollow tubes (HW), transverse cracking of tubular beam was observed which in turn separated the flange and web of the tubular web followed by web crushing as presented in Fig. 12. Wherein the WR GFRP tubular beams filled with normal grade of concrete (Fig. 13) showed a bottom flange separation. Fig. 14 shows the transverse compression crack and web crushing was noticed in the beam specimen, R6W. It was observed that delamination crack happened at the compression surface which later progressed into the sides. The complete failure occurred after the fibre cracking in the compression side.

Figure 9. Hollow UDC GFRP tubular beams (HU)

Figure 10. NSC infilled UDC GFRP tubular beams (R2U)

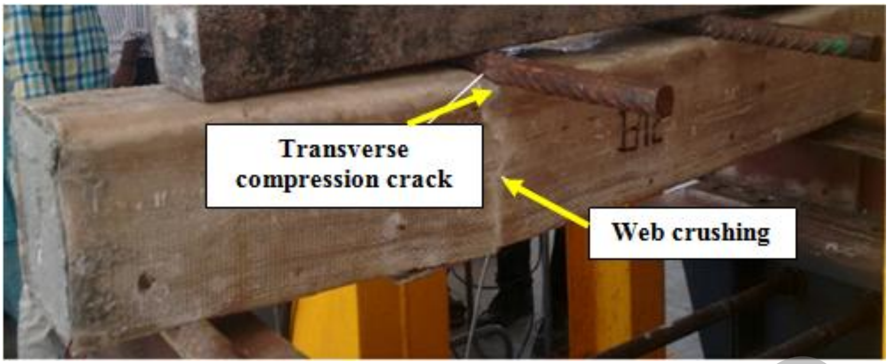

Figure 11. HSC infilled UDC GFRP tubular beam (R6U)

Figure 12. Hollow WR GFRP tubular beams (RW)

Figure 13. NSC infilled WR GFRP tubular beams (R2W)

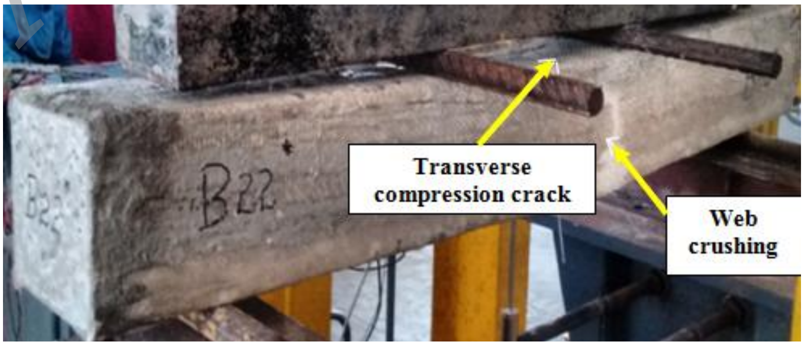

Figure 14. HSC infilled WR GFRP tubular beams (R6W)

3.3 Influence of concrete strength of FRP thin walled tubular beams

The effect of concrete strength on ultimate load carrying capacity of the beam is presented in Fig. 15. The concrete filled FRP thin walled tubular beams showed a significant increase in load carrying capacity in the range of 70% - 78% in comparison to those of the hollow FRP tubular beams. It was observed that FRP tubular beams infilled with high strength of concrete enhanced the ultimate load carrying capacity than the beams infilled with normal strength of concrete. It was noticed that R6U and R6W significantly improved the load carrying capacity respectively by 9.09% and 11.1% with that of the specimens R2U and R6U.

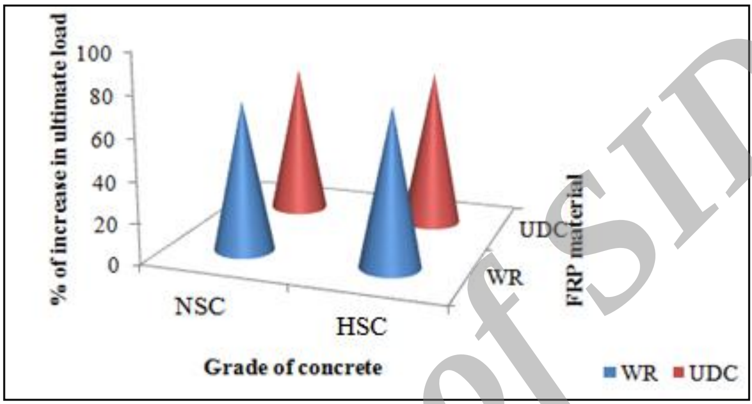

Figure 15. Influence of concrete strength on ultimate load

From Fig. 16, it can be noted that the increase in concrete strength from 28.73 MPa to 64.5 MPa, increased the ultimate load carrying capacity and ductility of concrete filled uni-directional cloth FRP thin walled tube (CFUFT) and concrete filled woven roving FRP thin walled tube (CFWFT) beams. This is due to the fact that the behaviour of infilled beams was governed by the behaviour of FRP tube. Moreover, higher strength concrete also provides higher compression force of the concrete that lead to larger moment carrying capacity of the FRP tubular beam section.

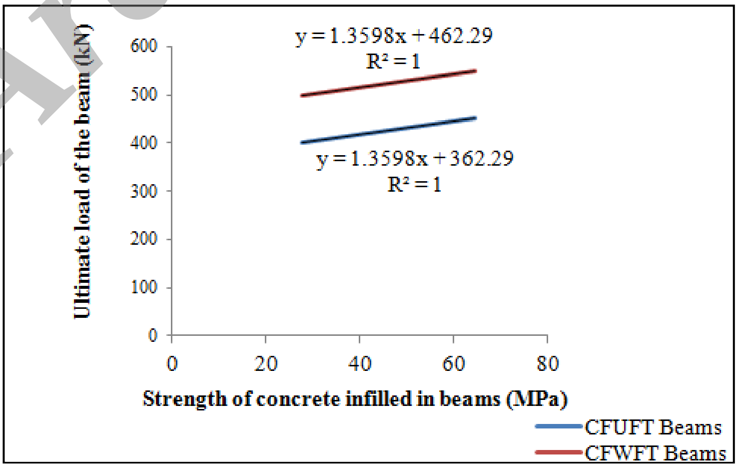

Figure 16. Influence of strength of core material on ultimate load of the beam

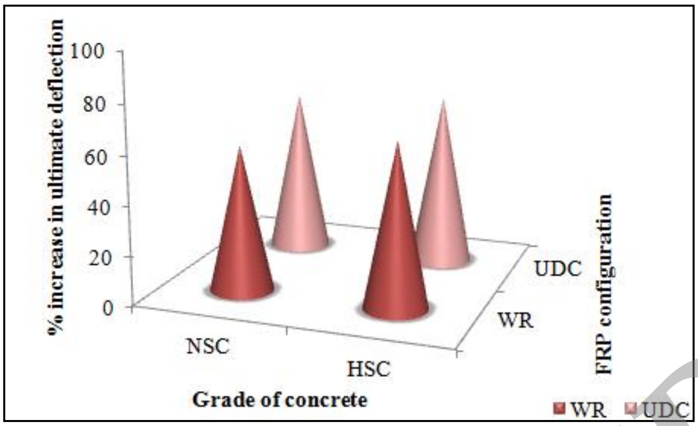

Figure 17. Influence of concrete strength on ultimate deflection

The influence of strength of materials infilled in FRP tubular beams on deflection is depicted in Fig. 17. The concrete infilled FRP tubular beams demonstrated higher deflection of about 71% compared to the hollow FRP tubular beams. It also showed that FRP tubes infilled with higher grade of concrete increased the deflection of about 22.06% for R6U and 29.7% for R6W specimens

3.4 Influence of configuration of FRP thin walled tubular beams

The effect of configuration of FRP thin walled tubular beams on load carrying capacity is shown in the Fig. 18. It is clear to note that the unidirectional cloth type of configuration of FRP enhanced the ultimate load carrying capacity and deflection. The FRP tubular beams attained a maximum increase in ultimate load by 16.6%, 20% and 18.18% with respect to the woven roving fibre reinforced polymer tubes. It is worth mentioning that the 90% of fibres aligned in a longitudinal direction that enhanced the load carrying capacity of beams in R2U and R6W . It also provided a stronger resistance along the longitudinal direction. Wherein the fibres arranged in both direction has a resistance along both longitudinal and transverse direction. It seems that the stress distributed in both directions tends to lower the load carrying capacity of the beam (R2W & R6W).

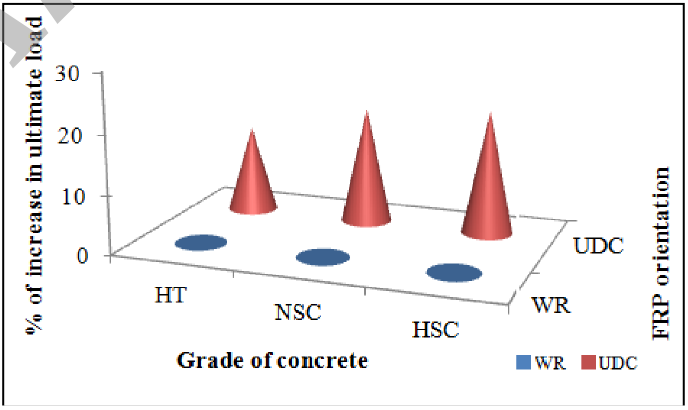

Figure 18. Influence of configuration of FRP thin walled tubular beams on ultimate load

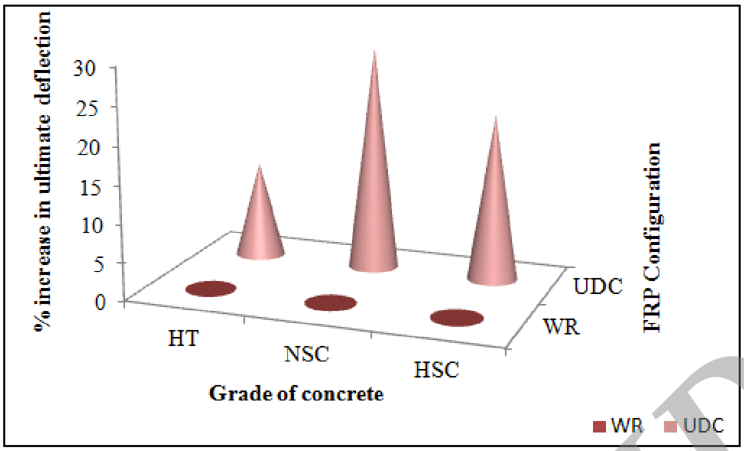

Figure 19. Influence of configuration of FRP thin walled tubular beams on ultimate deflection

Fig. 19 represents the effect of configuration of FRP thin walled tubular beams on ultimate deflection. It is obvious to note that the unidirectional cloth type of configuration of FRP tube tends to stretch the fibres in longitudinal direction which increased the stiffness to a greater extent than the bidirectional alignment of fibres. The FRP tubular beams exhibit an increase in ultimate deflection by 18.3%. The maximum compressive strength of concrete filled in FRP tubular beam showed an increase in deflection by 9.422%.

4. CONCLUSIONS

From the experimental study conducted, the following conclusions were drawn,

1. GFRP thin walled tubular beams filled with reinforced concrete enhanced the load carrying capacity and ductility when compared to hollow tubular beams.
2. FRP thin walled tubular beams filled with high strength of reinforced concrete enhanced the ultimate load carrying capacity than the beams filled with normal strength of concrete.
3. UDC GFRP thin walled tubular beams filled with reinforced concrete of normal and high strength exhibit an improved performance when compared to other material configuration.
4. GFRP thin walled tubular beams filled with NSC and HSC attained a maximum ultimate load carrying capacity respectively by 76% and 78% when compared to other FRP tubular beams.
5. FRP thin walled tubular beams filled with higher compressive strength of concrete showed an increase in ultimate deflection by 22.06% for R6U and 29.7% for R6W specimens.
6. FRP thin walled hollow tubular beams failed in a brittle manner.
7. In WRGFRP thin walled tubular beams failed due to transverse crack occurred in web and separated from the flange.
8. FRP thin walled tubular beams filled with concrete failed due web crushing due to of material delamination of fibre and cracking of the fibres.

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