

Retrofitting of Concrete Filled Cold Formed Steel Tubular Beams with GFRP Sheets: Experimental Investigation

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ABSTRACT:It has become a new trend to introduce Concrete-Filled Steel Tube (CFST) members for several modern structural projects. Although, the CFST members possess similarity to other pertinent structural members that demand strengthening for various direct reasons, such as degradation due to the environment, fire, fatigue, upgrades to carry extra loads and ageing. This paper presents a detailed study on the behavior of Concrete-Filled Steel Tube (CFST) retrofitted with Glass Fiber Reinforced Polymer (GFRP) sheets subjected to two point loading. A total of eight CFST specimens of cross section 150mm x 100mm and span 2 meter were prepared .The thickness of the steel used was 2mm.GFRP sheets of 1mm thickness was used for retrofitting

Control beams were tested upto failure and the yield point was found out. The remaining beams were tested upto yield point and retrofitted with GFRP sheets with different length and thickness. After a curing period of 4 days again tested upto failure. The influence of variation of length and thickness of GFRP wrapping on ultimate load carrying capacity, deflection, load strain behavior are studied and are compared with that of control beam. An attempt to study the variation in ductility characters before after retrofitting with GFRP sheets are also carried out

KEYWORDS: GFRP sheets, CFST beam.

I. INTRODUCTION

A very large number of structures have reached the end of their service life either due to the degradation caused by environmental factors or due to a need of an increase in applied loads. These structures may be structurally deficient or functionally obsolete and most are now in serious need of extensive rehabilitation or replacement. Strengthening can be used as the cost effective alternate to the replacement. Strengthening using externally bonded FRP sheets and plates was introduced in the last few decades and proved to be successful in many applications of strengthening reinforced concrete and masonry structures[1]. In strengthening systems, the material is generally expected to have higher or similar stiffness compared to the base material of the deficient structures. This is the case in masonry and reinforced concrete structures but not in steel structures. By introducing new types of high modulus FRP materials, the system shows good potential for use in strengthening steel structures because it has many advantages compared to conventional steel plate strengthening [3] Concrete-filled steel Tube (CFST) is a kind of composite structure, in which concrete is cast into the steel tube and is used successfully for many modern structures because of its relative advantages over other conventional structures [6].

GFRP plates or sheets can be epoxy bonded to the tension face of the damaged members to restore strength and stiffness. GFRP wrapping enables the CFST beam to develop multi mechanical properties and GFRP is an electronic isolation material and so, when combined with steel, it can protect it from the electrochemical corrosion which readily occurs on steel or steel reinforced concrete structures in marine environments [7]Also the thermal expansion coefficient of GFRP is similar to that of steel, which eliminates thermal stress at the interface with the steel surface providing

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compensation for the brittleness of the GFRP, assures the ductility of the whole system.[8] The GFRP sheets bridge over the damaged area and transfer the stresses across. The stress level in the original member will decrease, and that will result in a longer fatigue life. Also where fire risks must be minimized, welding needs to be avoided, then strengthening a structure by bonding of FRP laminates is a very attractive alternative[9]. There have been several studies on repair and retrofit of concrete girders with epoxy bonded FRP materials during the past decade and have epoxy-bonded FRP sheet increased the ultimate load-carrying capacity of steel-concrete composite girders and the behavior can be conservatively predicted by traditional methods[14]. However, very few of them have addressed and proved the use of epoxy bonded composite plates or sheets for strengthening and repair of steel composite structures[15].

II. MATERIAL PROPERTIES AND MIX DESIGN

53 grade Ordinary Portland cement conforming to IS 12269 is used. The specific gravity of the cement is 3.15. Crushed stones of 20mm are used as coarse aggregate. Local river sand was used as fine aggregate in the concrete mixtures. Aggregate shall comply with the requirements of IS 383. The specific gravity of fine aggregate is 2.65 and water absorption is 1%. Fine aggregate corresponds to Zone 1 according to the table 4 of IS 383. The specific gravity of coarse aggregate is 2.68 and water absorption is 0.6%. Coarse aggregate corresponds to 20 mm nominal size according to the table 2 of IS 383. Ethylene glycol is used as admixture which reduces the evaporation of water from the surface of concrete and also helps in water retention. Thus it helps in self curing of concrete filled steel tubes. It helps in providing additional moisture in concrete for more effective hydration of cement and reduced self desiccation. Glycine is used to improve workability of the mix. GFRP sheets of nominal thickness (t_f), ultimate strength (f_{fu}), ultimate strain (ϵ_{fu}) and elastic modulus (E_f) were 1mm, 2930 MPa, 2.58% and 109 GPa, respectively. Epoxy resin based on two-component solvent-free epoxy resin was used in this study. The mixing ratio was 8:1 of component A (resin- bisphenol A) and component B (hardener polyethylenepolyamin) by weight. The elastic modulus, tensile strength and shear strength provided by the manufacturer were 15 GPa, 35 MPa and 13 MPa, respectively. Mix design is done for M25 grade according to IS 10262-2009. Water cement ratio used is 0.42. The mix proportion of concrete is given in the table

Table 1 Mix proportion of concrete

Water	Cement	Fine aggregate	Coarse aggregate	Admixture
154Kg/m ³	367Kg/ m ³	741 Kg/ m ³	1203 Kg/ m ³	2 Kg/ m ³

III. EXPERIMENTAL PROGRAM

Cold formed steel tubes of grade 352 were used to fabricate the specimens according to the standard dimensions. Thicknesses of the sheets were measured by screw gauge at 4 places in each sheet and mean value was taken. The sheets of each specimen were joined together by run welding along the lengthwise direction. The insides of the steel tubes were wire brushed, and deposits of grease and oil were removed. CFST specimens were prepared by filling concrete into the hollow steel tubular sections. Concrete was filled in layers and vibrated by a poker vibrator. The specimens were left for self curing in the laboratory for 28 days. Figure 1 shows the casted CFST specimens

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Figure 1 Casted CFST specimens (a) cross section of CFST specimens (b) shows the vertical section of CFST

Among the eight CFST specimens, two are considered as the control beams and are subjected to two point loading until it fails to take any further load. All the two beams were tested under simply supported end conditions. Supports are fixed at a distance of 150mm from both the ends of beam, so that the clear span is 1700mm. Two point loading is adopted for testing. The testing of beams is done with the help of hydraulic operated jack connected to load cell of capacity 40 ton. The load is applied to the beam with the help of load cell and the values are obtained from the data acquisition system, which is attached with the load cell. Three LVDTs (Linear Variable Differential Transistor) are fixed along the length of the beam to measure deflection. Among the three LVDTs, 2 are placed at a distance of $L/3$ from the clear span and the third one is fixed exactly at the midpoint of the clear span. Strain gauges are placed exactly above and below the midpoint of the beam to measure the compressive and tensile strain respectively. The control beams are stressed upto a level until it stopped taking any further load. Load versus Deflection graph is plotted for the two beams and the average values are taken. This is considered for the calculation of yield point and separately plotted. The remaining 6 beams are loaded upto the yield point and subjected to retrofitting .Figure 2 shows control beams before and after testing



Figure 2 (a) shows the testing of a control beam and 2 (b) shows the control beams after failure

The surface of the CFST specimens should be coarse enough to bond with the FRP composites, for proper interaction. Initially the surface was wire brushed to devoid it from loose matters. Then the specimens were subjected to sand blasting, to make the surface better for bonding and finally cleaned with acetone solution. The adhesive was prepared, by mixing the epoxy and hardener proportionately and a single coat was applied over the surface. Before getting dried the surface was wrapped with GFRP sheets. During wrapping, air may get entrapped and so it was cleared in the fiber direction, by ribbed roller. The specimens were allowed to cure for the period of 4 days under room temperature. Two beams were wrapped with a single layer along 75 % of their length , another two beams were wrapped with single

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layer along 100% of their length and finally the remaining 2 beams were wrapped with double layer along the entire length of beam .Figure 3 shows beams retrofitted with GFRP

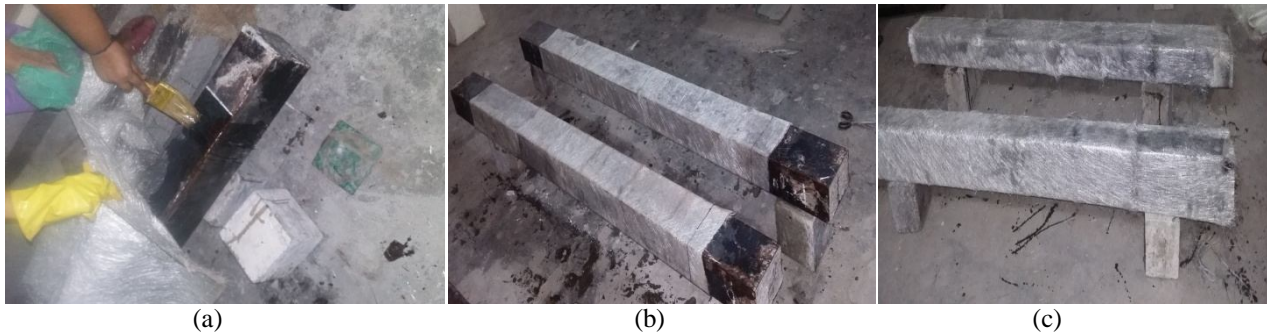


Figure 3 (a) shows surface preparation of beams (b) shows beams wrapped 75% with GFRP and (c) with 100% GFRP

The retrofitted beams are tested upto failure under two point loading .The test setup was same as that of the control beam. Deflection and strain are measured with LVDT and strain gauges respectively. Figure 4 shows testing of retrofitted beam

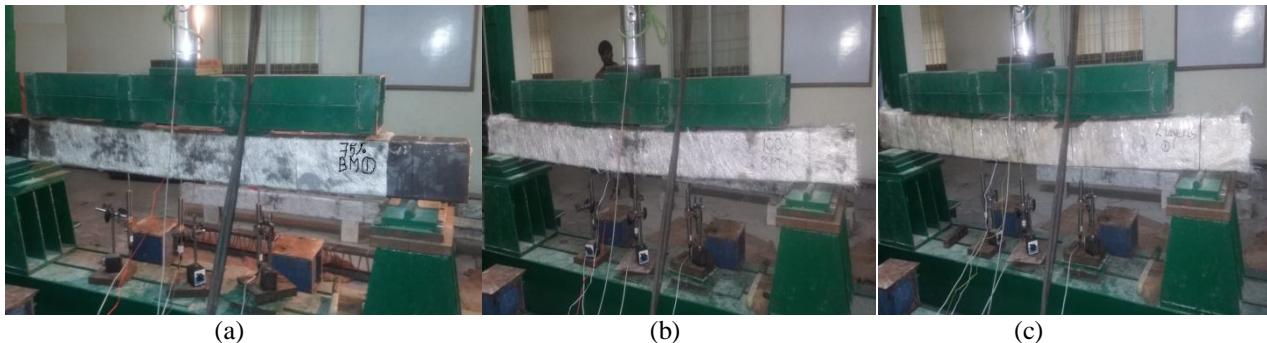


Figure 4 shows testing retrofitted beam(a) wrapped 75% with GFRP (b) 100% GFRP with single layer (c) 100% GFRP with double layer

IV. RESULTS AND DISCUSSIONS

First fresh CFST specimens (2 beams) has been loaded in a two point bend test setup as described previously. This test has been carried out on CFST beams prior to the application of GFRP sheets. The test setup ensures pure bending in central third portion of the beam .The beams have been loaded with equal force on the two load points until it did not take any further load .No visible cracks were observed on the surface of the two beams. The average values for the two beams are taken and the ultimate load for control specimens was obtained as 82.5KN and final deflection was 18.2mm.Since no cracks were visible, the failure of beams are due to crushing of concrete inside.

Like control beams no cracking was observed in retrofitted beam .Failure of beams were due to crushing of concrete. The ultimate load for retrofitted beams wrapped 75% of its length, 100% of its length with single layer GFRP and double layer GFRP are 87.5KN, 94KN, 103KN and corresponding mid span deflections are 17mm, 15mm and 12.6 mm respectively .Load Midspan relation for control and retrofitted beams is shown in figure5

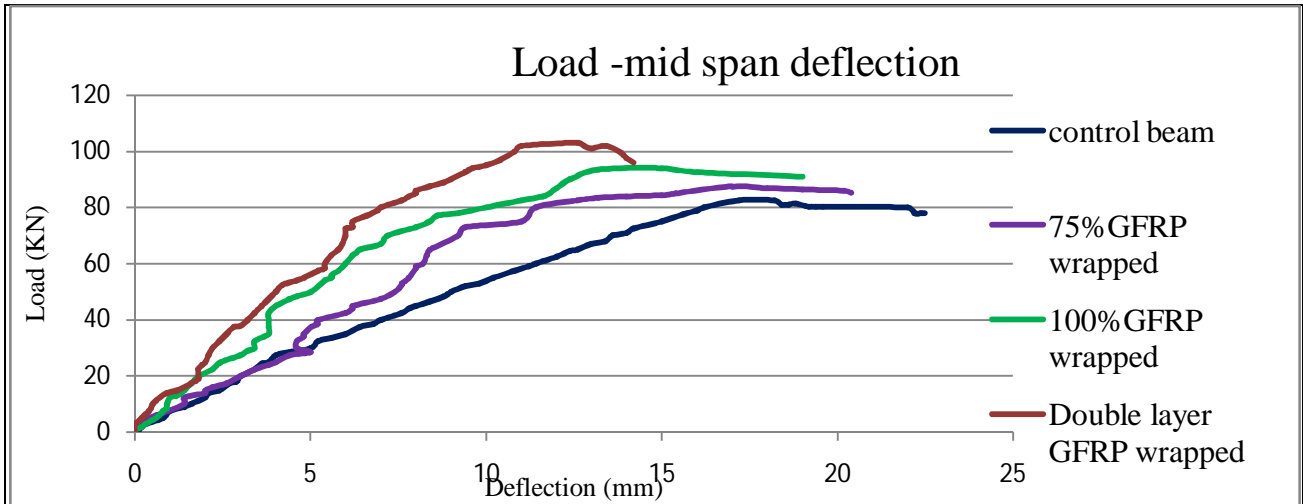


Figure 5 Load- Midspan deflection Graph

Corresponding to the ultimate loads 83 KN, 87.5 KN, 94 KN, 103 KN, the final $L/3$ deflections are 14.95 mm, 13.2 mm, 12.2 mm, 9.8 mm for control beams, 75% GFRP wrapped beam, single layer (100%) and double layer GFRP wrapped beams respectively. Load $L/3$ relation for control and retrofitted beams is shown in figure 6

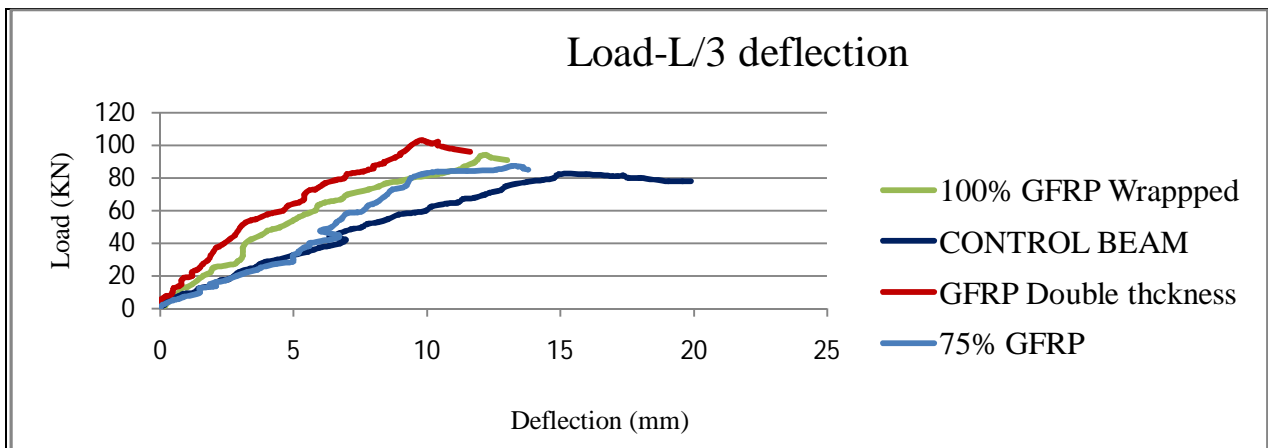


Figure 6 Load- $L/3$ deflection Graph

Tensile strain (at bottom) is found out using strain gauges at mid point of the beam. The average values of loads and strain of control beam and retrofitted beams are plotted and are given below in Figure 7. The tensile strain of control beam, 75% GFRP wrapped beam, 100% GFRP wrapped with single layer and GFRP with double layer are 23×10^{-3} , 21.2×10^{-3} , 20.4×10^{-3} , 18.2×10^{-3} respectively,

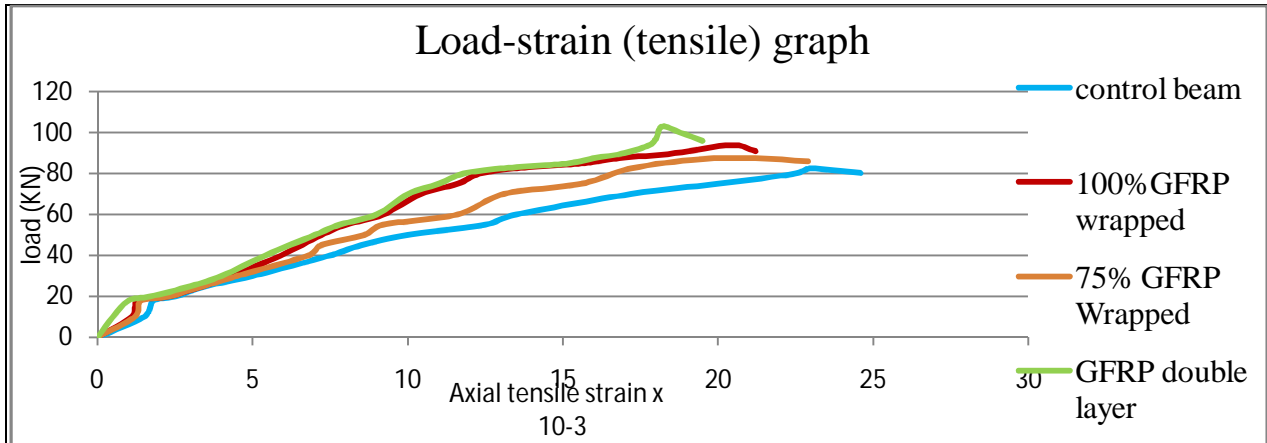


Figure 7 Load tensile strain graph

Compressive strain (at top) is found out using straingages at midpoint of the beam. The maximum compressive strain and of control beam,75%GFRP wrapped beam,100% GFRP wrapped with single layer and GFRP with double layer are -12.5×10^{-3} , -11×10^{-3} , -10.4×10^{-3} , -8.4×10^{-3} . The average values of loads and strain of control beam and retrofitted beams are plotted and are given below in figure8

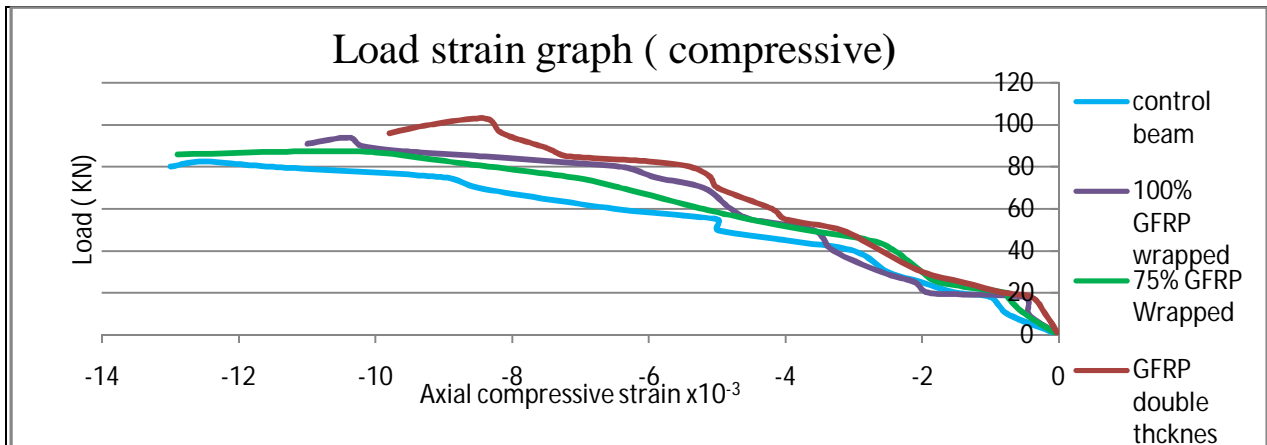


Figure 8 Load compressive strain graph

The failure loads increased upto 6% for beams wrapped along 75% of its length, and 13.9% for beams wrapped 100% of its length with single layer of GFRP and 24.84 %for beams wrapped 100% of its length with double layer of GFRP sheets when compared to control beam. .Figure 9 shows comparison of ultimate load carrying capacity of control and retrofitted beams

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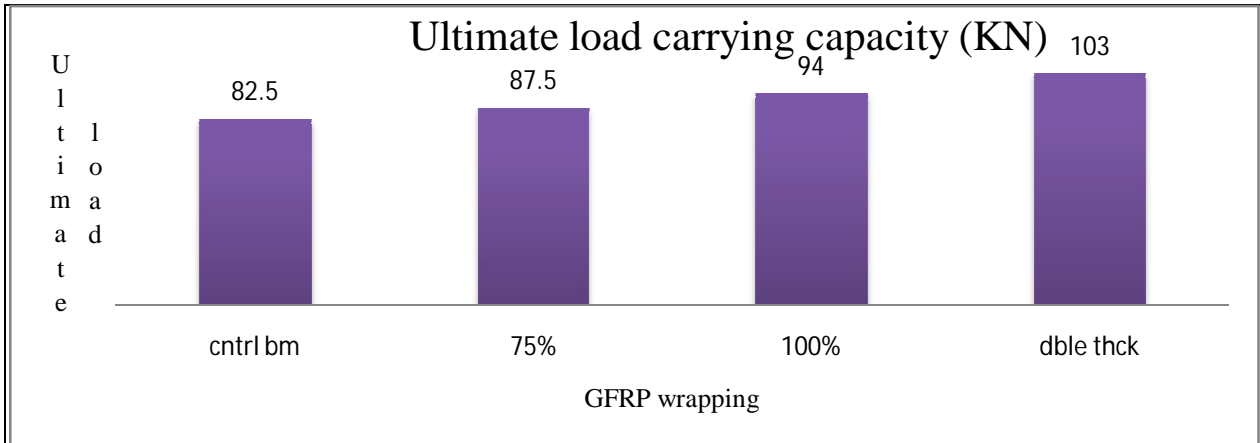


Figure 9 Comparison of load carrying capacity

The mid span deflection decreased upto 7% for beams wrapped along 75 % of its length and 21.3 % for beams wrapped 100% of its length with single layer of GFRP and 44.44 % for beams wrapped 100% of its length with double layer of GFRP sheets when compared to control beam .Figure 10 shows comparison of midspan deflection of control and retrofitted beams

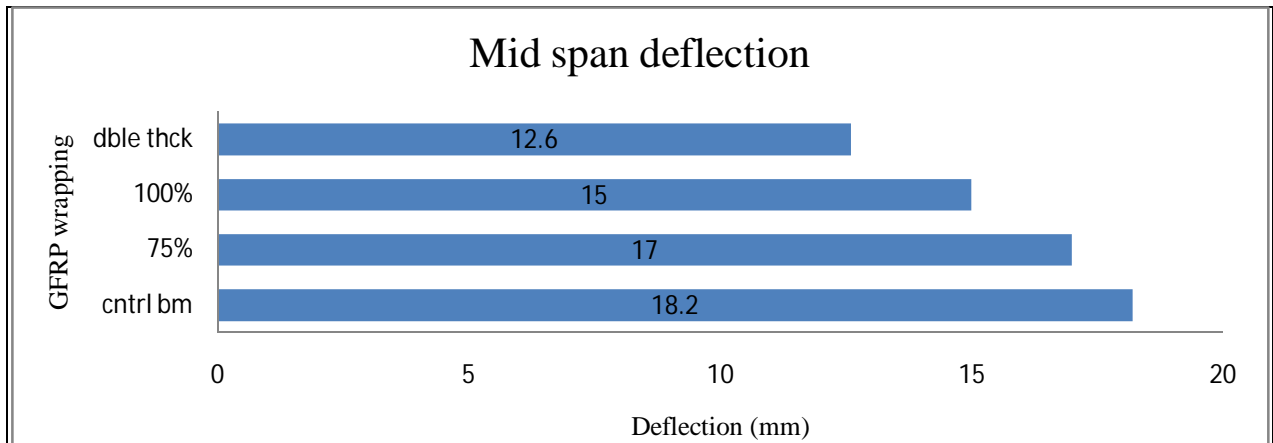


Figure10 Comparison of midspan deflection

The L/3 deflection decreased upto 13.5 % for beams wrapped along 75 % of its length and 22.5 % for beams wrapped 100% of its length with single layer of GFRP and 52.5 % for beams wrapped 100% of its length with double layer of GFRP sheets when compared to control beam. .Figure 11shows comparison of L/3 deflection of control and retrofitted beams

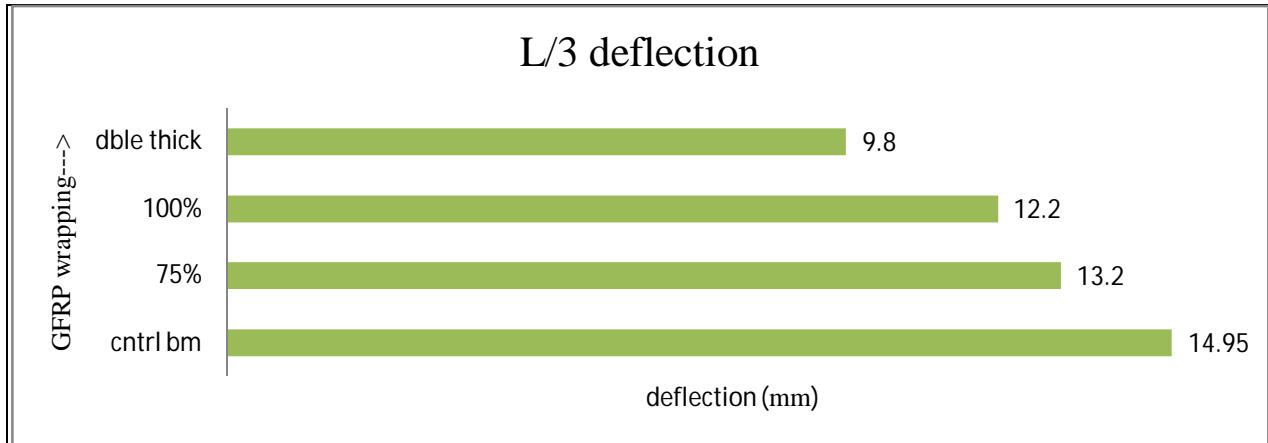


Figure 11 Comparison of L/3 deflection

The compressive strain decreased upto 13.6 % for beams wrapped along 75 % of its length and 20.1 % for beams wrapped 100% of its length with single layer of GFRP and 48.45 % for beams wrapped 100% of its length with double layer of GFRP sheets when compared to control beam. The tensile strain decreased upto 8.4 % for beams wrapped along 75 % of its length and 12.74 % for beams wrapped 100% of its length with single layer of GFRP and 26.37 % for beams wrapped 100% of its length with double layer of GFRP sheets when compared to control beam Figure 12 shows the comparison of compressive and tensile strain of control and retrofitted beam

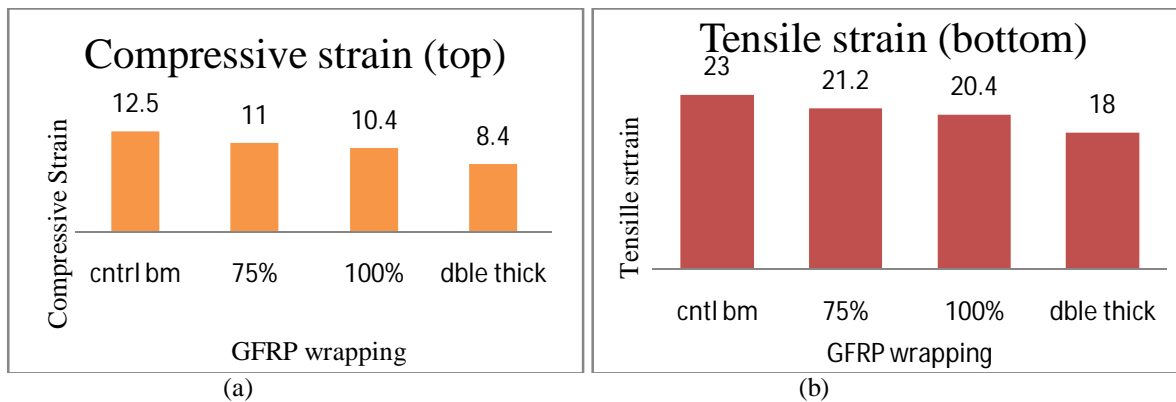


Figure 12(a) comparison of compressive strain and (b) comparison of tensile strain

Ductility ratio is defined as the displacement at ultimate load to displacement at yield point. Yield point is found out for beams wrapped with GFRP along 75 %,100%, and with twice thickness and corresponding deflections are also found out to get ductility ratios

Table 2 Ductility ratios

	ΔU (Ultimate deflection)	ΔY (deflection at yield point)	Ductility ratio
Control beam	18.2	9	2.0
75% wrapped GFRP	17	7.8	2.17
100% wrapped GFRP	15	6.3	2.3
Twice thickness GFRP	12.6	6	2.1

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Ductility increased upto only 8.5% when wrapped with GFRP along 75% of its length and 15% when wrapped with GFRP along 100% of its length with single layer. But ductility increased only upto 5% when wrapped with GFRP along 100% of its length with double layer. This shows that there is a tendency of low ductility or increasing stiffness as the number of layers of GFRP wrapping increases

V. CONCLUSION

Ultimate load carrying capacity and behaviour of rectangular cross-sections of CFST beams strengthened by GFRP sheets along varying wrapping lengths and thickness were studied experimentally in this report. The conclusion of this study can summarise as follows:

- Their load-deflection behavior, is quite different. The CFSTs are initially stiffer due to the higher Young's modulus of steel, compared to GFRP. Once the steel yields, plastic behavior is observed, whereas CFSTs do not show plasticity
- Load carrying capacity of retrofitted beams was significantly improved using GFRP sheets
- Beams wrapped along 75% of its length by GFRP sheet showed very limited improvements (only 6 %) in their ultimate load capacities whereas beams wrapped 100% with single layer and double layer GFRP sheets showed considerable increase in ultimate load capacities (13.9 and 24.8 % respectively)
- Mid span deflection of beams wrapped along 75% of its length by GFRP sheet showed very limited decrease(only 7 %) whereas beams wrapped 100% with single layer and double layer GFRP sheets showed considerable decrease in midspan deflection (21.3 and 44.5 % respectively)
- Considerable decrease in compressive strain and tensile strain was observed for beams wrapped along entire length with twice thickness of GFRP sheets compared to the single layer and 75% wrapped beams
- Ductility increase was only 8.5% and 15 % for beams wrapped 75% and 100% of their length with single layer
- There is a tendency of decreasing ductility when wrapped with twice thickness when compared to that of single layer

REFERENCES

- [1]FamA; Schnerch D; and Rizkalla S" Rectangular Filament-Wound Glass Fiber Reinforced Polymer Tubes Filled with Concrete under Flexural and Axial Loading: Experimental Investigation" *J. Compos. Constr* Vol.9, No 2, Pp. 25-33 ,2005
- [2] Lam, L., and Teng, J. G. (2003). "Design-oriented stress-strain model for FRP-confined concrete." *Constr. Build. Mater.*,Vol. 17,No (6-7),Pp 471-489, 2003
- [3] Fam A ,Dougall , Shaat "Upgrading steel-concrete composite girders and repair of damaged steel beams using bonded CFRP laminates" *Thin-Walled Structures* Vol.47, No-4 Pp-1122-1135,2009
- [4] JeyabharathyAS , Ravi SR "Experimental Investigation on Behavior of R.C.C Beam Retrofitted With Sisal Fibre Sheet" *International Journal of Innovative Research in Science, Engineering and Technology* Vol. 2, Issue 7, July2013
- [5]. Ellobody E "Performance of composite girders strengthened using carbon fibre reinforced polymer laminates" *Thin-Walled Structures* Vol- 49,,No-6 Pp-1441, 2011
- [6.] Probst AD, Kang H K, "Composite Flexural Behavior of Full-Scale Concrete-Filled Tubes without Axial Loads" *J. Struct. Eng* Vol. 136:, Pp1401-1412,2010
- [7.] Tao Z, Han LH, Wang LL." Compressive and flexural behaviour of GFRP-repaired concrete-filled steel tubes after exposure to fire". *Journal of Constructional Steel Research*. Vol-63,No-7 Pp1116-26,2011
- [8]Obaidat YT ,Heyden S, Ola Dahlblom "Retrofitting of reinforced concrete beams using composite laminates" *Construction and Building Materials* Vol-25,NO -5 ,Pp-591-597, 2011
- [9].Karimi. K, Tait.M.J., El-Dakhkhni. W "Testing and modeling of a novel FRP-encased steel-concrete composite column" *Composite Structure*Vol- 93 Pp-1463-1473,2011
- [10] Razaqpur G , Tolba A, Contestabile E "Blast loading response of reinforced concrete panels reinforced with externally bonded GFRP laminates" *Composites: © asce Part B* Vol-38 ,Pp-535-546,2007
- [11].Malvar LJ , Crawford JE,; and Morrill KB "Use of Composites to Resist Blast" *Journal of composites for construction* © asce / november/december 2007 / 60
- [12]. Teng J.G., Hu.Y.M, " Behaviour of FRP-jacketed circular steel tubes and cylindrical shells under axial compression" *Construction and Building Materials* Vol-21 ,No6.,Pp-827-838, 2007
- [13]. Obaidat YT ,Heyden S, Ola Dahlblom "Retrofitting of reinforced concrete beams using composite laminates" *Construction and Building Materials*Vol. 25 ,No2,Pp-591-597,2011
- [14] Tavakkolizadeh" Strengthening of Steel-Concrete Composite Girders Using Carbon Fiber Reinforced Polymers Sheets" *J. Struct. Eng*Vol-129:,No-4, Pp-30-40.2003
- [15]. Ahmed W., Hamidon W , Badaruzzaman, " Finite element analysis of concrete-filled steel tube beams partially wrapped with cfrp sheet" *International Journal of Technical Research and Applications* Special Issue 9 PP. 04-08, (Nov-Dec 2014),