DEVELOPMENT OF GFRP AND UHF COMPOSITE GIRDERS

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ABSTRACT

In this paper, the development of a composite girder using glass fiber reinforced polymer (GFRP), ultra high strength fiber reinforced concrete (UHF) and fiber reinforced polymer (FRP) bolts is illustrated. Experiments were carried out previously with steel bolts which connect the UHF blocks to the GFRP beam. Because of the corrosion of the steel bolts, the life span of the composite girder is reduced. Therefore, in this test series FRP bolts were used. Four point bending tests were conducted for a number of I-beams of same cross-sectional dimensions having epoxy bonded and FRP bolted UHF blocks at the top flange. In order to check the performance of the FRP bolt connections between FRP beam and UHF blocks, different bolt diameters and bolt spacing were considered. Behavior of the strain variation of top flange was compared in order to check the utilization of the ultimate tensile strain of GFRP. In fact, the experiment results show that the failure load of the composite I-beam has reduced compared to similar steel bolt connection. However, failure load similar to steel bolt connection can be achieved with many FRP bolts. Therefore, the FRP bolts can be used in UHF and GFRP composite girder which increase the durability of the girder.

Keywords: Glass fiber reinforced polymer, Ultra high strength fiber reinforced concrete, FRP bolts.

1. INTRODUCTION

Fiber reinforced polymer (FRP) has been used as a construction material recently because of its special characteristics such as high specific strength, light weight and corrosion resistance. In fact the material cost of the FRP materials is very large compared to other construction materials which are generally in use. However, when the life cycle cost of a structure and the carbon emission during the lifecycle of the structure are concerned, FRP materials are one of the best materials for a sustainable development (Tanaka et al. 2006). In this study, GFRP beams which are the most economical among FRP materials were considered. However, the carbon FRP (CFRP) and hybrid FRP (HFRP) have very high tensile strength and stiffness over GFRP. In terms of the cost of the material, GFRP has more importance compared to CFRP and HFRP. However, the self weight of the composite girder has become comparatively low due to reduction of the cross-sectional area of the girder.

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Previously, a set of bending tests were carried out for UHF and GFRP composite girders with steel bolts. But in real situation, steel bolts can corrode and maintenance need to be carried out which is not economical. In this research study, a number of full scale bending tests of UHF and GFRP composite girders were carried out with FRP bolts and the behavior was compared with steel bolts case.

2. BENDING TEST OF COMPOSITE BEAM

2.1. GFRP Beam

GFRP I beams which were produced by pultrusion process using FRP layer composition were used in the experiment and the fibers arrangement in the beam is given in Table 1. Most of the GFRP fibers are oriented in the 0^o direction with respect to their local axes and $\pm45^o$ fibers provide the integrity in both flange and web and reduce the anisotropic behavior of the beam. Table 2 shows the mechanical properties of GFRP beam materials. The overall height, length and the flange width are 250mm, 3500mm and 95mm respectively where the flange and web thicknesses are 14mm and 9mm respectively.

Table 1 : Fiber Arrangement in GFRP Beam

Direction	0°	0/90°	±45°/0°	±45°	Total GF %
Flange	0%	11%	45%	44%	100%
Web	26%	26%	0%	48%	100%

GF – Glass Fiber

Table 2 : Mechanical Properties of GFRP Materials

Mechanical Property	Unit	Notation	GFRP 0°/90°	GFRP MAT	GFRP ±45°
Young's Modulus	N/mm^2	E_{11}	24,000	10,000	11,089
Poisson's ratio	-	u_{12}	0.1	0.308	0.584
Shear Modulus	N/mm^2	G_{12}	3,500	3,800	10,909

2.2. UHF Blocks

Tensile strength cannot be well utilized in a GFRP I-beam subjected to bending stress due to delamination of the fibers at compression flange. By using the UHF blocks, the flexural capacity could be optimized significantly (Hai at el. 2010). UHF blocks were made of high strength concrete by embedding high strength steel fibers (2000 N/mm^2) which are of 15mm and 22mm in length. The steel fiber content is around 1.75% of the volume of the block. Table 3 shows the mechanical properties of the UHF blocks. UHF blocks have length width and height 300mm, 95mm and 35mm respectively. Epoxy resin and FRP bolts were used to fix the UHF blocks to the GFRP beam.

Table 3 : Mechanical Properties of UHF Blocks

Compressive Strength (N/mm^2)	Young's Modulus (kN/mm^2)	Compressive Strain (μ)
188.8	44.0	4930

2.3. Test Setup

Full scale four point bending tests were carried out for four numbers of GFRP and UHF composite I-beams having dimensions as illustrated in Figure 1 and Figure 2. The test parameters (i.e. bolt diameter, bolt spacing and the availability of bolt head inside the UHF block) of each specimen are given in Table 4. In order to prevent delamination at top flange, UHF blocks having compressive strength and Young's modulus of 188MPa and 44GPa respectively were fixed to the top flange using epoxy resin and FRP bolts (see Figure 2).

Tomoya (2012) carried out an experiment with 0mm and 10mm gaps between the UHF blocks in order to investigate the effect of segment spacing on the composite girder. The results showed that there were no significant change in load carrying capacity or the rigidity in the composite girder. Therefore a 10 mm gap was maintained between UHF blocks and those were filled with mortar paste having compressive strength and Youngs modulus of 90MPa and 31GPa respectively. FRP stiffeners were fixed to the both sides of the web using epoxy resin to avoid lateral buckling. Four point bending test with roller supports was carried out for all the specimens where the bending span is 700 mm and shear span is 1250 mm. During the test, load was applied from a manually operated hydraulic jack and the deflection at mid span, applied load and strain at mid span were measured until the failure of the beam.

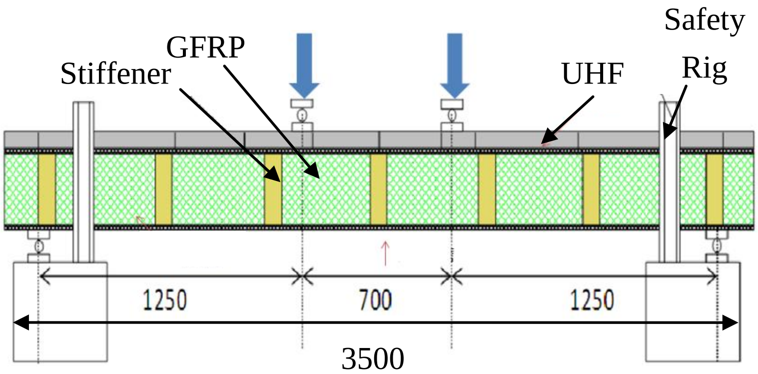


Figure 1 : Test Setup (Units in mm)

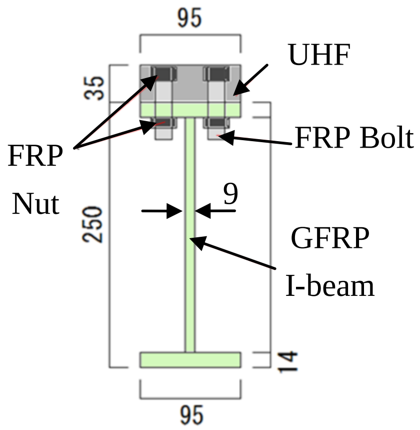


Figure 2 : Cross-section of UHF GFRP I-beam (Units in mm)

Table 4 : Test parameters of specimens

Specimen name	Bolt spacing (mm)	FRP bolt diameter (mm)	Bolt head in the UHF
G10-F16-B4	150	16	No
G10-F10-BN6	100	10	Yes
G10-F16-BN4	150	16	Yes
G10-F16-BN6	100	16	Yes

3. TEST RESULTS AND DISCUSSION

Failure patterns of each test specimen are illustrated in Figure 3. Specimens G10-F16-B4 and G10-F10-BN6 were failed due to crushing of UHF blocks in the bending span where as specimens G10-F16-BN4 and G10-F16-BN6 were failed by crushing of UHF blocks and top flange along with shear failure of web in the bending span.

(a) G10-F16-B4

(b) G10-F10-BN6

(c) G10-F16-BN4

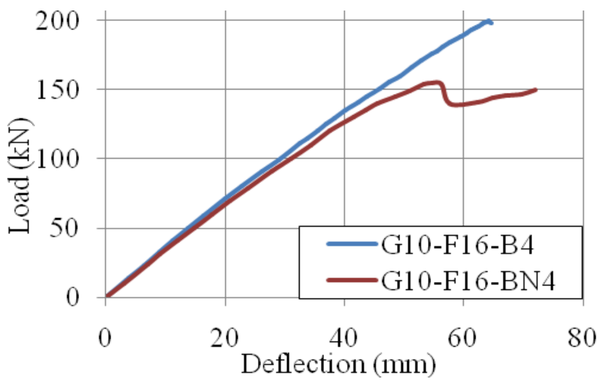
(d) G10-F16-BN6

Figure 3 : Failure patterns of specimens

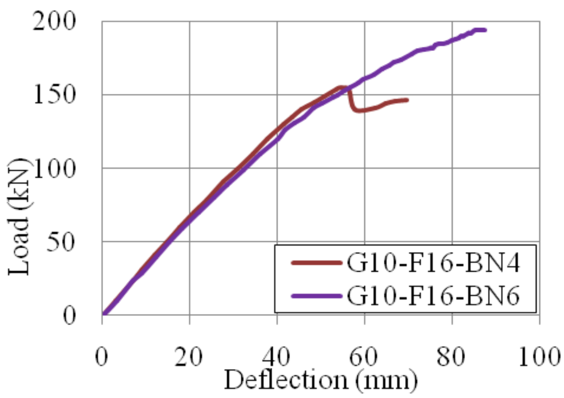
Figure 4 shows the comparison of load vs. deflection relationships of specimens with different test parameters. In this comparison mid span deflection was considered. According to the results, Figure 4(a) shows when the bolts do not have heads inside the UHF blocks, the load carrying capacity is approximately 29% higher than that of when bolts with heads in the UHF block. In the G10-F16-B4 specimen, the area of UHF material in the longitudinal direction in the UHF block is more than that of G10-F16-BN4. Because of the high rigidity of UHF compared to FRP bolt, the ductility might have increased in G10-F16-B4.

According to the results, when the number of bolts increases, the load carrying capacity also significantly increases as shown in Figure 4(b). The ultimate load carrying capacity of G10-F16-BN6 is 195kN where that of G10-F16-BN4 is 150kN. This is mainly because of better bonding between FRP beam and UHF blocks due to higher number of bolts.

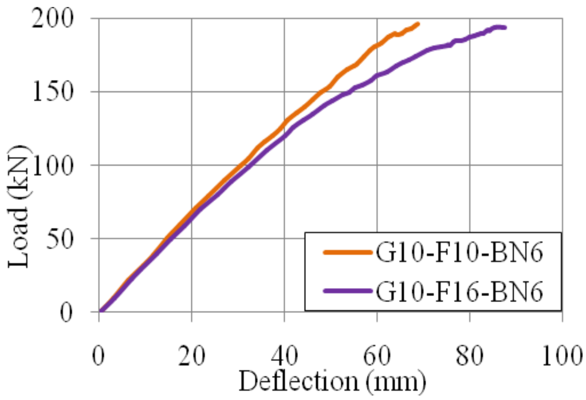
In Figure 4(c) results indicate that, when the bolt diameter varies the load carrying capacity is approximately remains same but the ductility of the beam has been increased in the specimen which has smaller diameter bolts. This may be due to high rigidity in G10-F10-BN6 specimen, resulted by smaller FRP bolt diameter, which has a higher UHF material area in the longitudinal direction in the UHF block compared to the other specimen. However in this experiment only the 10mm and 16mm diameter bolts considered. Therefore when the bolt diameter is too small, there may be low load carrying capacity due to lack of tensile strength of bolts.



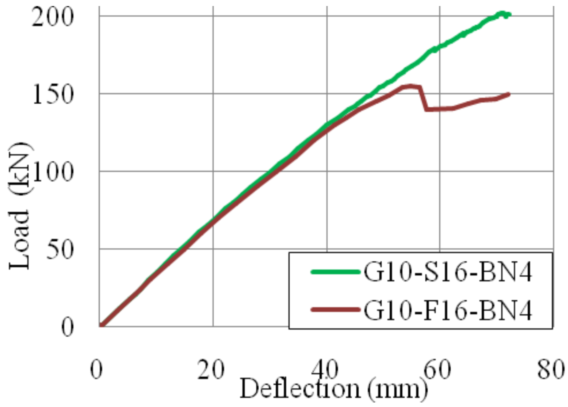
(a) Comparison of bolts having heads inside the UHF block



(b) Comparison of number of bolts



(c) Comparison of bolt diameter



(d) Comparison of bolt type

Figure 4 : Load-deflection curve

Results of a previous research study carried out with the same GFRP beam and UHF blocks with 16mm steel bolts (Perera at el. 2012) is shown in Figure 4(d). Both I-beams show similarity in stiffness and the deflection at mid span at failure. However, the ultimate load carrying capacity of steel bolts case is approximately 34% higher than beam with FRP bolts. The specimen G10-F10-BN6 showed similar performance as composite beam with steel bolts.

The load vs. strain relationship in the top and bottom flanges in the GFRP beam at mid span is illustrated in Figure 5. The results from (Tomoya 2012) also included in Figure 5 for comparison. G10-F10-BN6 specimen shows the highest stiffness and its ultimate tensile strain at bottom flange is approximately 16% less than that of G10-F16-BN6 which has the large diameter bolts. Maximum tensile strain of GFRP in longitudinal direction is approximately 2.19×10^{-2} (Arai 2012). Among the beams with FRP bolts, the maximum tensile strain is about 1.25×10^{-2} (in specimen G10-F16-BN6). Therefore, approximately 57% of ultimate tensile strain train of GFRP is utilized and hence the GFRP beam is not effectively utilized and further development need to be carried out. Specimens G10-F16-BN4 and G10-F16-BN6 show non-linearity in tensile strain at failure. This has happened due to crushing of the GFRP top flange at failure (Figure 3). However, the composite girders G10-F16-B4 and G10-F10-BN6 show good stiffness and flexural strength similar to steel bolt case (G10-S16-BN4).

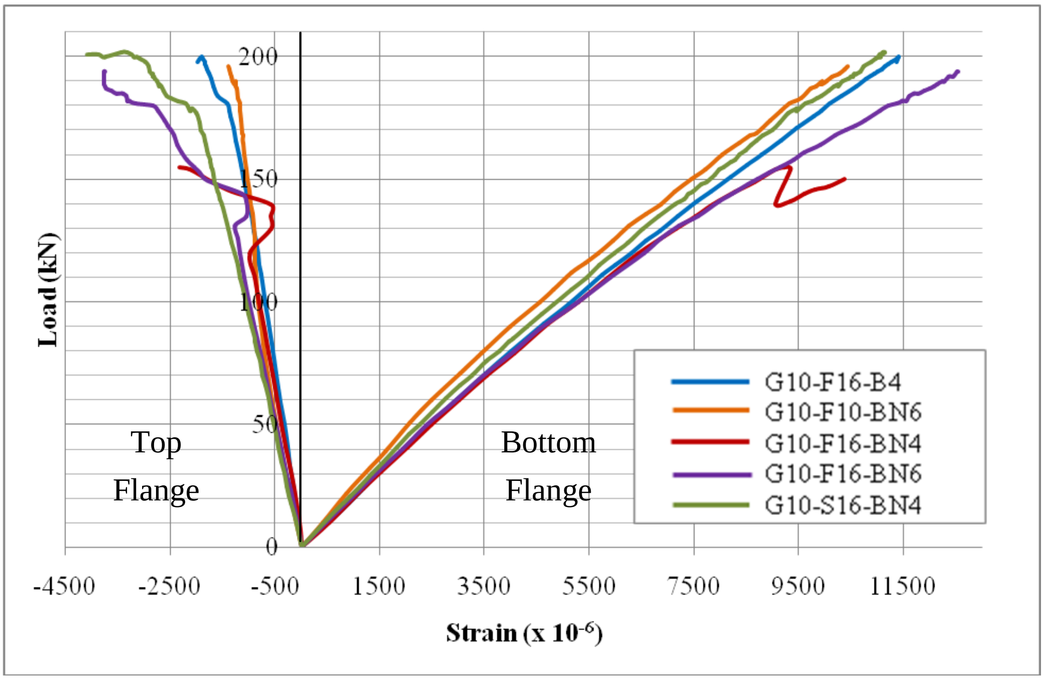


Figure 5 : Load vs. Strain relationship of composite girders at mid span

4. CONCLUSIONS

In this paper, the behavior of GFRP and UHF composite girders with FRP bolts were discussed and the following conclusions were made according to the results.

- Similar performance as GFRP and UHF composite girder with steel bolts can be achieved with with 10mm diameter FRP bolts when the bolt spacing is reduced.
- When the bolts do not have heads inside the UHF block, both ultimate load carrying capacity and stiffness of the composite beam increase.

- Significant enhancement in the ultimate load carrying capacity of the composite beam could be obtained when the number of bolts in UHF is increased.
- Better stiffness in the composite girder could be achieved when less FRP area in the longitudinal section of UHF block.

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