Durability and bending behaviour of concrete beams reinforced with hybrid GFRP rods and steel bars

Yanru Ren1,*

1School of Civil Engineering and Architecture, University of Jinan, China

*Corresponding author e-mail:594278575@qq.com

Abstract. It is feasible to take the place of steel bars with FRP rods as the pulled main bars in the reinforced concrete structures by many researchers. However, FRP rods concrete beams have been limited due to many reasons, such as the lower elastic modulus of FRP rods and reduced the ductility of the members owning to the fragility of FRP rods. In order to finish off these trouble, scholars have adopted a possible method that simultaneously utilizing FRP rods and steel bars in concrete members for reinforcement. The bending behaviour and durability of this new form of reinforcing member may still be problematic and this field needs further study. The bending behaviour and durability of concrete beams reinforced with hybrid GFRP rods and steel bars have been experimentally studied and some conclusions have been got.

1. Introduction

During many years, the main causes of insufficient durability and even damage to concrete are steel corrosion, freezing damage and physical and chemical effects in an erosive environment [1], and steel corrosion has become the primary factor in the ruggedness of concrete structures. FRP rods stand out among many new materials as a result of its high strength, electromagnetic insulation and corrosion resistance. It has been considered as an ideal substitute for steel bars and it fundamentally solves the problem of insufficient durability of concrete structures caused by steel corrosion [2].

The properties of FRP rods reinforced concrete structures have been inquired into by some scholars [3-6]. However, according to the survey have indicated that the failure of FRP rods reinforced concrete beams is usually abrupt, exhibiting brittle failure characteristics, cracks and deflections are relatively large under normal use conditions. Therefore, for the sake of amplify the normal capability of the beams, hybrid FRP rods and steel bars is one probable method. Hybrid bars is restrained from steel bars in the structure, and FRP rods are used to supplant the corner steel bars. Many researchers have endeavoured to look into the properties of concrete structures reinforced with hybrid reinforcing bars [7-9]. Comparatively speaking, there is less task bounded up with the durability of concrete beams reinforced with hybrid bars.

This paper inquired into the durability and bending behaviour of concrete beams reinforced with hybrid bars. Related research can improve the design and practical engineering application of concrete structures reinforced with hybrid bars.
2. Experiment

2.1. Test supplies

2.1.1. GFRP rods and steel bars. The steel bars and GFRP rods were adopted in the tension zone of the beams. The diameter of GFRP rods was the same as that of the steel bars adopted. The capability parameters of the steel bar and GFRP rod is seen in Table 1.

Table 1. The capability parameters of the steel bar and GFRP rod.

| Types         | Diameter(mm) | Elastic modulus (GPa) | Yield strength $f_y$ (MPa) | Tensile strength $f_{tu}$ (MPa) |
|---------------|--------------|-----------------------|---------------------------|-------------------------------|
| Steel bar     | 12           | 200                   | 517                       | 620                           |
| GFRP rods     | 12           | 45.7                  | Nill                      | 870                           |

2.1.2. Concrete. The design strength of the concrete is 30MPa and the mix ratio are seen in Table 2. Six concrete cubes of 150 mm diameter were prepared to fix the actual concrete strength. Three cubes were directly subjected to denseness test after 28 days. The remaining three concrete cubes were made ready for the dry-wet cycle examination.

Table 2. Concrete mix proportions.

| Water (kg/m³) | Cement (kg/m³) | Sand (kg/m³) | Stone (kg/m³) | Actual strength $f_{cu}$ (MPa) |
|---------------|---------------|--------------|--------------|-------------------------------|
| 210           | 450           | 610          | 1120         | 35.7                          |

2.2. Beam specimens design

The reinforcement form of the beam s was divided into three types, and two beams were cast in each form. Some inside information about the beam are seen in Figure 1. Each measuring is 1800mm long, 180mm wide and 300mm high. The specimens included two reinforced concrete beams and four concrete beams reinforced with hybrid bars. In addition, three specimens were tested for the dry-wet cycle to consider the durability of concrete beams reinforced hybrid bars and the others were employed for comparison.

Figure 1. Schematic diagrams of beams.

The main parameters of test beams are seen in Table 3. The equation is taken advantage of calculate the border reinforcement ratio ($\rho_b$) and the nominal reinforcement ratio ($\rho_n$).

\[
\rho_b = 0.85 \beta_1 \frac{f_c^*}{f_y} \frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{fd}}
\]

\[
\rho_n = \rho_s + \frac{f_{fd}}{f_y} \rho_t
\]

where $\beta_1$ is the coefficient, $f_c^*$ is the concrete strength ($f_c^* = 0.85 f_{cu}$), $\varepsilon_{cu}$ is the extreme strain ($\varepsilon_{cu} = 0.0033$), $\varepsilon_{fd}$ is the design tensile strain of GFRP rods ($\varepsilon_{fd} = f_{fd}/E_f$), $f_{fd}$ is the design tensile strength of FRP rods ($f_{fd} = 0.7 f_{fu}$)[10], $\rho_s$ is the steel reinforcement ratio, $\rho_t$ is the FRP reinforcement ratio.

It is worth noting that the ideal failure mode of concrete beams reinforced hybrid bars is that the steel bar is firstly yielded, and the concrete is broken when the FRP rods are not greater than the designed tensile strength, that is $\rho_b$ must be less than $\rho_n$. It can be seen from Table 3 that all six concrete beams meet this condition.
Table 3. Main parameters of beams.

| Specimen | $A_s$ (mm$^2$) | $A_f$ (mm$^2$) | $\rho_b$ (%) | $\rho_n$ (%) |
|----------|----------------|----------------|--------------|--------------|
| N1       | 452.4          | Nill           | Nill         | 0.95         |
| N2       | 226.2          | 226.2          | 0.72         | 1.10         |
| N3       | 226.2          | 226.2          | 0.72         | 1.18         |
| D1       | 452.4          | Nill           | Nill         | 0.95         |
| D2       | 226.2          | 226.2          | 0.72         | 1.10         |
| D3       | 226.2          | 226.2          | 0.72         | 1.18         |

2.3. Test environment and methods

So as to consider the durability and bending properties of concrete beams reinforced hybrid bars, the beams were tested in two different ways after the completion of the pouring of the beam specimens. The first method is to directly conduct the bending test after the completion of the beam specimen maintenance to discuss the bending behaviour of concrete beams reinforced hybrid bars (beams N1-N3). Another method is to perform the dry-wet cycle test after the beam specimen maintenance, and then perform the bending test to consider the durability of concrete beams reinforced hybrid bars (beams D1-D3). The concentration of the sodium chloride solution in the dry-wet cycle test was 5%, and each cycle was 6 days for a total of 30 cycles.

2.4. Beam test procedure

The beams were quiz by four-point bending using the 50T self-balancing system. Each beam was preloaded prior to the start of the test to adjust the strain gauges and transducers. For formal loading, graded loading is used, and each level is used to detect the deflection of the beams.

3. The experiment results analysis

3.1. Strain distribution

The measured strain values of six beams are shown in Figure 2 respectively. That the strain distribution of beams N2 and N3 is about the same beam N1, and the strain distribution of the beams D1-D3 and N1-N3 just about right.

As shown in Figure 2(a)–(c), the concrete strain produced by beam N1 is strictly increased to 2500με without the internal GFRP rods. But GFRP rods significantly changed the strain and the strain values increase to a limit of 4000με (beam N3). The same phenomenon also appeared in the beams D1-D3.

Two beams with the same reinforcement (beam N1, D1; N2, D2; N3, D3) were selected and compared. Different environments make the concrete strain of beams change. The strain of the beams which were treated by the dry-wet cycle test produce less than the uns soaked beams, and the difference is about 500με between two types of beams.
3.2. Ultimate flexural capacity

After subjected to the dry-wet cycle test, the compressive strength of the concrete was 42.5MPa, and the tensile strength of GFRP rods and steel bars all changed. The yield strength of steel bars changed from 510MPa to 500MPa. The tensile strength of GFRP rods decreased by 27%, and the tensile strength and elastic modulus were 630MPa and 44.2GPa.

| Specimen | $M_u$ (MPa) | $f_{m-max}$ (mm) | Failure mode                                      |
|----------|-------------|------------------|--------------------------------------------------|
| N1       | 59.2        | 12.77            | steel yielding and compression concrete crushing  |
| N2       | 56.3        | 14.23            | steel yielding and compression concrete crushing (GFRP rods not rupture) |
| N3       | 54.5        | 15.93            | steel yielding and compression concrete crushing (GFRP rods not rupture) |
| D1       | 49.4        | 14.84            | steel yielding and concrete crushing in compression zone |
| D2       | 52.4        | 17.67            | steel yielding and GFRP rods rupture              |
| D3       | 50.2        | 19.63            | steel yielding and GFRP rods rupture              |

Table 4 summarises the calculation results of all beams. As shown in Table 4, it was found that beams N2 and N3 are smaller a slightly ultimate bending moment than the beam N1. The possible cause of this phenomenon is that the strength of the concrete is small, and the high tensile strength characteristics of the GFRP rods cannot be further exerted. The ultimate bending moment of
reinforced concrete beam is reduced by about 15%, while hybrid reinforced concrete beams are reduced by 7~9% after subjected to the dry-wet cycle test.

Table 4 also shows the failure modes of all beams. The failure mode after the two different treatment methods is consistent for reinforced concrete beams, and the compression zone concrete is crushed after the steel bars yielding. After the two different treatment methods, the failure modes of concrete reinforced with hybrid bars change. Compared with beams N2 and N3, the failure characteristics of beams D2 and D3 are GFRP rods rupture.

In summary, it is feasible to take the place of steel bars with FRP rods, which also improves the durability of the concrete structures.

3.3. Deflection

Figure 3 plots the bending moment-deflection behaviour for all beams under normal use. In the early stage of concrete cracking, the stiffness of each test beam is similar, and they all show linear deformation characteristics. After the concrete cracked, the bending moment-deflection curves of the test beams all turned. In this process, because GFRP bars has much lower the elastic modulus, the changes of hybrid reinforced concrete beams are obvious, and the deflection increases rapidly. At the same load level, the mid-span deflection of the concrete beam reinforced with hybrid bars is greater than the reinforced concrete beam.

![Figure 3. The flexural moment-deflection curves of the beams.](image)

After the dry-wet cycle test, the bending moment-deflection curves of all beams and the other beams equally matched, but the deflection is reduced to some extent under the same load. The maximum span deflection of the beams is shown in Table 4. The deflection of the beams after the dry-wet cycle test increase.

4. Conclusion

The durability and bending behaviour of concrete beams reinforced with hybrid bars were experimentally investigated. Based on the results, the following conclusions are drawn.

1. The strain distribution of concrete beams reinforced with hybrid bars is similar to that of reinforced concrete beams. The GFRP rods significantly changed the strain of concrete, the strain of concrete beams reinforced with hybrid bars is larger than that of reinforced concrete beams. The strain of the beams which were treated by the dry-wet cycle test produce less than normal concrete beams.

2. Owing to the low strength of the concrete, the positive effect of the GFRP rods being not fully exerted, the ultimate bending moment of concrete beams reinforced with hybrid bars is smaller than reinforced concrete beams.

3. After the dry-wet cycle test, the flexural moment-deflection curves of the beams and other three unsoaked beams just about right.

4. It is feasible to take the place of steel bars with FRP rods in the reinforced concrete structures, which also improves the durability of the reinforced concrete structures.
References

[1] Gerwick B C. Concrete in the Marine Environment[J]. Cement Concrete and Aggregates, 1992, 14(1):1.
[2] Bencardino F, Condello A, Ombres L. Numerical and analytical modeling of concrete beams with steel, FRP and hybrid FRP-steel reinforcements[J]. Composite Structures, 2016, 140: 53-65.
[3] Saikia B, Kumar P, Thomas J, et al. Strength and serviceability performance of beams reinforced with GFRP bars in flexure[J]. Construction & Building Materials, 2007, 21(8): 1709-1719.
[4] Qu W, Zhang X, Huang H. Flexural behaviour of concrete beams reinforced with hybrid (GFRP and steel) bars[J]. Journal of Composites for Construction, 2009, 13(5): 350-359.
[5] Barris C, Torres L, Comas J, et al. Cracking and deflections in GFRP RC beams: An experimental study[J]. Composites Part B Engineering, 2013, 55(12): 580-590.
[6] Protchenko K, Młodzik K, Urbański M, et al. Numerical estimation of concrete beams reinforced with FRP bars[J]. MATEC Web of Conferences, 2016, 86: 78-97.
[7] Leung H Y, Balendran R V. Flexural behaviour of concrete beams internally reinforced with GFRP rods and steel rebars [J]. Structural Survey, 2003, 21(4): 146-157.
[8] Hawileh R A. Finite element modeling of reinforced concrete beams with a hybrid combination of steel and aramid reinforcement [J]. Materials & Design, 2015, 65: 831-839.
[9] Bencardino F, Condello A, Ombres L. Numerical and analytical modeling of concrete beams with steel, FRP and hybrid FRP-steel reinforcements [J]. Composite Structures, 2016, 140: 53-65.
[10] ACI Committee 440. Guide for the design and structural of concrete reinforced with Fiber-reinforced polymer (FRP) bars (ACI 440.1R-15). American Concrete Institute, Farmington Hills, MI, USA, 2015.