

Study on Hybrid Effects of FRP Anchors for Strengthening of Concrete Structures

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Abstract. FRP (Fiber Reinforced Polymers) has been widely used in structure strengthening with the advantages of high strength, light weight, corrosion resistance and so on. FRP anchor is an effective anchoring method for external strengthening FRP laminate. In order to reduce cost and improve performance, B/C HFRP (hybrid of basalt fiber/carbon fiber reinforced polymer) anchor was made through mixing the basalt fiber with conventional CFRP anchors. The shear behavior and the anchoring performance of two kinds of FRP anchors under different diameter and arrangement methods were tested by several groups of experiments. The experimental results shew that the ultimate strength, material utilization and ductility of specimens were improved in different degrees, which indicated that it was practicable in concrete structures strengthening with this hybrid method.

1. Introduction

In order to prevent or delay the debonding failure of FRP- concrete interface, and to improve the utilization ratio of materials and the effect of strengthening, the additional anchor of FRP sheets is particularly important. The commonly used anchoring methods are as follows: (1) mechanically-fastened fiber reinforced polymer (MF-FRP) [1], (2) U type hoop anchor [2], (3) near-surface mounted (NSM) FRP strengthening [3], (4) FRP anchor. Among them, FRP anchor is an emerging anchoring measure for external strengthening FRP laminate, which has aroused the concern of more and more scholars in recent years. J. G. Teng et al [4] tested on RC cantilever beams strengthened by GFRP sheets using FRP anchors. The result of experiments shew that FRP anchors could significantly improve the load capacity performance of strengthened beams, and reduce the FRP debonding speed, making full use of high-strength FRP strengthening material. H. W. Zhang et al [5] studied on the various factors which had impact on the fiber anchor. M. A. Alam et al [6] improved the FRP anchor system, using a new anchoring method which was a hybrid of multi-direction. I. S. Kim [7] applied the FRP anchor on strengthening for anti-progressive collapse. However, there are few studies on the hybrid FRP anchor, and the hybrid effects on the anchor performance remain to be further studied.

Considering the problem that the FRP anchor had relative low shear strength and the ductility of strengthened concrete structure is insufficient, B/C (basalt fiber/carbon fiber) HFRP anchor [8] was made through mixing the basalt fiber with conventional CFRP anchors. The destructive tests of a series of strengthened specimens were carried out by changing the diameter of the anchor fan, the root diameter of the FRP anchor and the arrangement of FRP anchors.



2. Experiment Study on the Performance of B/C HFRP Anchors

2.1. Preparation of B/C HFRP Anchor

In order to get relative high load carrying capacity and sufficient ductility, the approximate ratio of carbon fiber and basalt fiber was 1:2. According to the depth of pre-excavated hole (3cm depth) of concrete specimen and HFRP anchor fan diameter (1.5cm and 3cm), the length of two batches of FRP anchor was determined as 4.5cm and 6cm respectively; each bundle of basalt fiber and carbon fiber was tied with a string respectively; the diameters of the two batches of FRP anchor shall be 8 and 12 bundles of fibers; Then, a total of 8 or 12 bundles of basalt fibers and carbon fibers were tied together with strings to form a large mass of bundles.

2.2. Experimental Description

Simple shear test was conducted. The end of FRP laminate extending out of the concrete block was connected to the loading device for exerting a tensile force. To eliminate the stress concentration resulting from the uneven stress in the chuck, there must be sufficient distance between chuck and the test area. The specimens were divided into two categories, namely, control group layout (group A), single hole arrangement (group B) and four holes arrangement (group C). The specific layout of each group is shown in Table 1. The loading equipment of the test was shown in Fig. 1. In order to prevent the influence of the length error on both side, the connector and the force sensor was designed to hinged connection, which could keep the tension in the center of the FRP sheet.

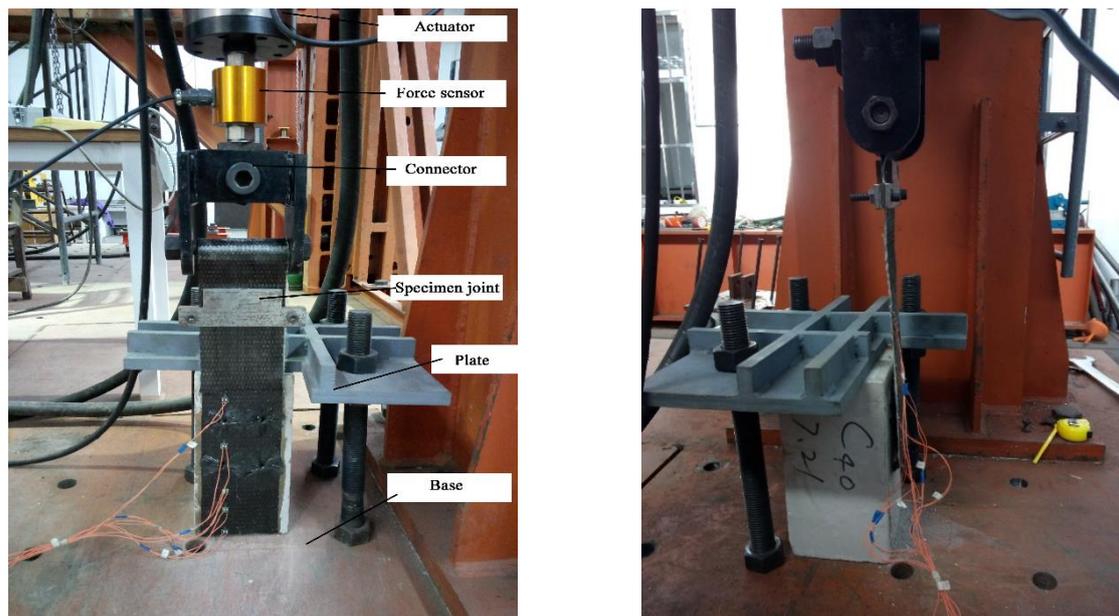


Figure 1. The loading equipment of the test

Table 1. Overview of the arrangement of each specimen

Specimen	The arrangement of FRP anchors	The diameter of FRP anchor fan [cm]	The root diameter of FRP anchors	The bond length of the FRP laminate [cm]
A-0-0-40	0	0	0	40
B-3-8-40	Single span	3	8 bundles	40
B-1.5-12-40	Single span	1.5	12 bundles	40
B-3-12-40	Single span	3	12 bundles	40
C-1.5-8-40	Four span	1.5	8 bundles	40
C-3-8-40	Four span	3	8 bundles	40
C-1.5-12-40	Four span	1.5	12 bundles	40

3. The Experimental Results

(1) For A-0-0-40 (Fig. 2a), its failure mode was the debonding of the bond end of the FRP sheet, then the specimen lost carrying capacity. Its ultimate load carrying capacity was 10.2KN.

(2) For B-3-8-40 (Fig. 2b), its failure started on the root of FRP anchors, then the FRP sheet and the anchors debonded together. Its ultimate load carrying capacity was 13.2KN.

(3) For B-1.5-12-40 (Fig. 2c), its failure started on part of FRP anchors fan torn, then the overall debonding happened in the surrounding FRP sheet of FRP anchors, but the root of FRP anchors did not break. Its ultimate load carrying capacity is 14.4KN.

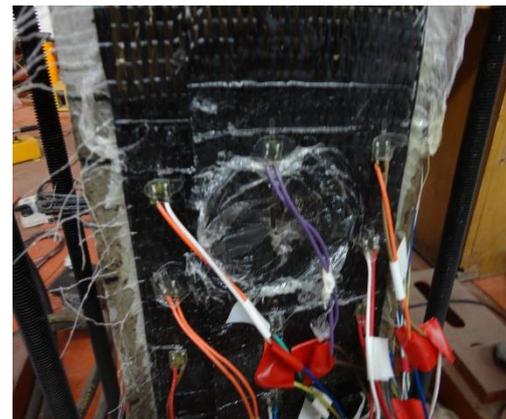
(4) For B-3-12-40 (Fig. 2d), the root of FRP anchors fractured, then the FRP sheet had the overall debonding. Its ultimate load carrying capacity was 15.4KN.

(5) For C-1.5-8-40, C-3-8-40, C-1.5-12-40, they all have the same destructive characteristics (Fig. 2e). The debonding area was extended to the rear of the two bottom FRP anchors, and the FRP fiber sheet around the four FRP anchors was completely peeled off. The ultimate load carrying capacity of C-1.5-8-40 was 19.2KN. The ultimate load carrying capacity of C-3-8-40 was 18.6KN. The ultimate load carrying capacity of C-1.5-12-40 was 19.6KN.

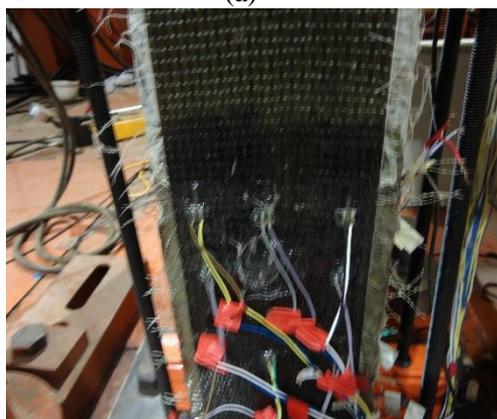
By compared between the specimens with FRP anchors and the control specimens, we could find that (Fig. 3, Fig. 4) all the ultimate load carrying capacity of the specimens with FRP anchors were raised in different degrees, and the anchoring effect was fine, so the utilization ratio of the FRP sheet was improved.



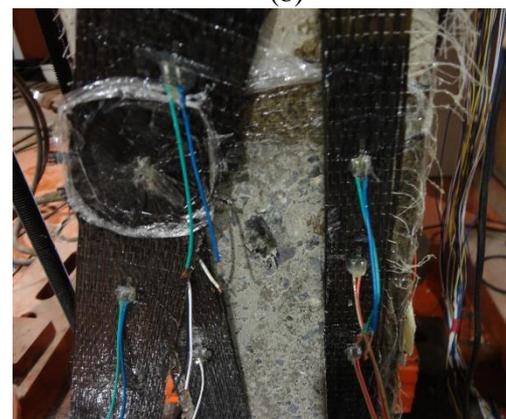
(a)



(b)



(c)



(d)



(e)

Figure 2. The failure modes of (a) A-0-0-40; (b) B-3-8-40; (c) B-1.5-12-40; (d) B-3-12-40; (e) Four Holes Arrangements

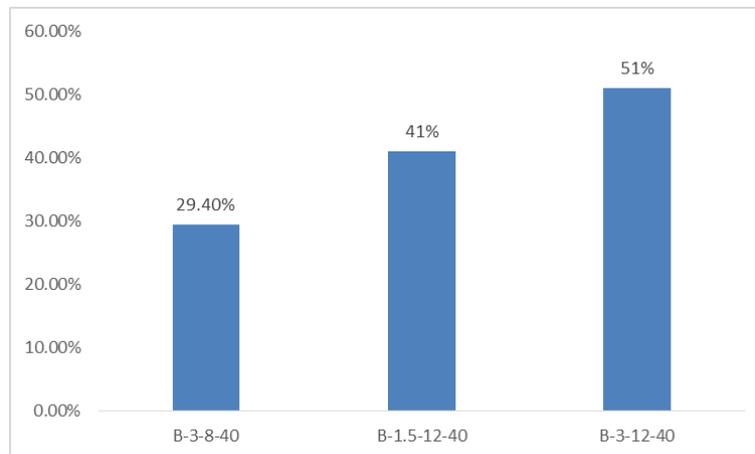


Figure 3. The performance improvement percentage of ultimate load carrying capacity of Group B

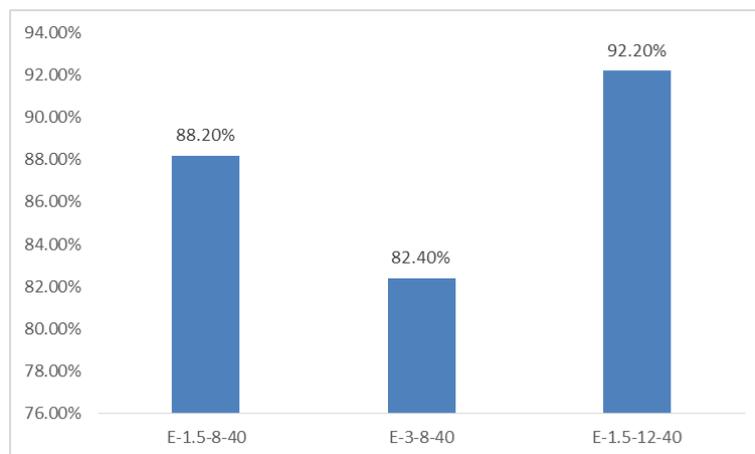


Figure 4. The performance improvement percentage of ultimate load carrying capacity of Group C

4. Conclusion

(1) Using the B/C hybrid anchors whose hybrid ratio of carbon fiber and basalt fiber was 1:2 could effectively improve the utilization of fiber fabric. At the same time, the addition of cheaper basalt fiber could greatly reduce the cost.

(2) By comparing the ultimate load capacity of the three members of E group, it could be found that the ultimate load capacity of each member is not much different and they have the same failure mode whose failure did not occur in the FRP bonding area, which indicated that the stronger constraints placed at the end of the FRP bonding area could not increase the ultimate load capacity unlimitedly.

(3) The placement of multi-pass FRP anchors on the FRP sheet could transfer the stress to the back end of the FRP bonding area, so that more FRP sheet could be involved in the force bearing, and the longitudinal utilization ratio of FRP sheet could be increased, and the overall ultimate load capacity of the component could be greatly improved.

5. Acknowledgment

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