Investigation of Connection method of FRP Rods using Turnbuckle body

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1. Introduction

Carbon Fiber Reinforced Polymer Rods (CFRPRs) have been increasingly used in civil infrastructure applications due to advanced properties such as high specific strength, lightweight and high corrosion resistance. They are used as tendon in new construction of reinforced concrete and also used for rehabilitation of concrete structures[1]. However, it is important that CFRPRs should be connected suitably to transfer the force and useful connecting methods are required. This paper focuses on the bond strength of CFRPRs connected with three different methods using turnbuckle body under tensile tests, and the present method simplify the connecting to steel members. Moreover, stress distribution of CFRPR surface is investigated by finite element analysis (FEA).

2. Experimental method

In this study, three experimental parameters are adopted; the first method uses expansive cement to connect CFRPRs, second method uses epoxy resin, and the third uses both epoxy and 1.2mm diameter steel balls into the turnbuckle bodies. A total of 8 specimens were tested in this study as shown in Table 1. The used CFRPRs were manufactured by pultrusion technique and had a diameter of 5mm. The process connection of specimens EPSB1, EPSB2, and EPSB3 with the turnbuckle bodies was followed into two steps. The volumes of epoxy and steel balls were calculated equal together, 50% of the hollow volume inside the turnbuckle bodies. Firstly, the epoxy was inserted to the vertical turnbuckles, and then steel balls were inserted later. Steel balls can automatically down under the gravity weight. After finishing the insertion of epoxy and steel balls, specimens were maintained at least 24 hours before testing. Fig. 1 shows one of the specimens.

Table 1 Specimens

Specimen name	Filled material	Embedding Length	Turnbuckle body	Number of Specimen
EC	Expansive Cement	125 mm	M10 (JIS A 5541)	2
EP	Epoxy			3
EPSB	Epoxy and Steel balls			3

Fig 1. Example of specimen, CFRPR connected with turnbuckle bodies

Tensile tests were performed using a 1000kN Universal Testing Machine. The specimens were set-up across the two cross-heads of the machine and aligned with the axis of the grips of the machine. The turnbuckles were fixed at the top and bottom cross-head of the machine (see Fig 2a).

3. Experimental results and discussions

Table 1 shows the maximum loads obtained from experiments. Debonding occurred in specimens in all specimens except for specimen EPSB2. The bond strength much increased by steel balls and got the highest bond strength in specimen EPSB2. Fig. 2b shows the breaking failure of specimen EPSB2. Therefore, the bond strength was most effective in this case. Fig. 3 shows the cutting sections of specimen EPSB2 after the experiment. The steel balls were perfectly inserted between epoxy and CFRPR. From the experimental results, the small steel balls can increase effectively the bond strength of the connections. Steel ball can increase more than 3 times the bond strength of specimens using only epoxy and more than twice for used expansive cement.

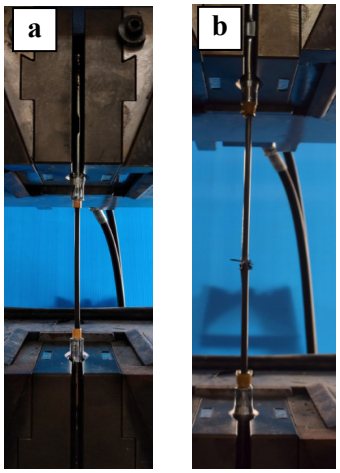

Fig 2. Test setup (a) and breaking failure of specimen EPSB2 (b)

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Table 1. Maximum load of specimens

Specimen	EC1	EC2	EP1	EP2	EP3	EPSB1	EPSB2	EPSB3
Maximum load (kN)	16.87	17.71	12.67	9.08	10.54	35.75	39.06	36.88
Average load (kN)	17.29		10.76			37.23		

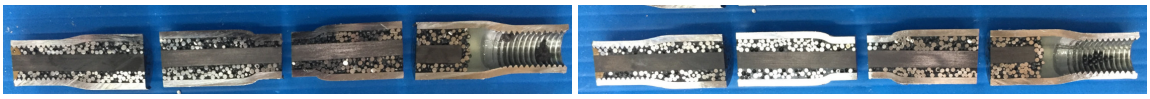

Fig 3. Inside condition of specimen EPSB2

4. Finite element analysis

Two-dimensional models were carried out in FEA (LUSAS software) to survey the effects of steel balls on the increase of bonding strength of specimens. Two cases of specimens were analyzed: specimen EP with the only epoxy inside the turnbuckles and specimen EPSB with both epoxy and steel balls inside the turnbuckles. The maximum sectional area of the turnbuckle with unit thickness 1mm was used for analysis and subjected to tension load that have a value of 1000 N. Boundary conditions and dimension of specimens are shown in Fig. 4 and models in FEA are shown in Fig. 5.

Fig. 6 shows the transverse stress S_y and shear stress S_{xy} of the contact line between epoxy and CFRPR.

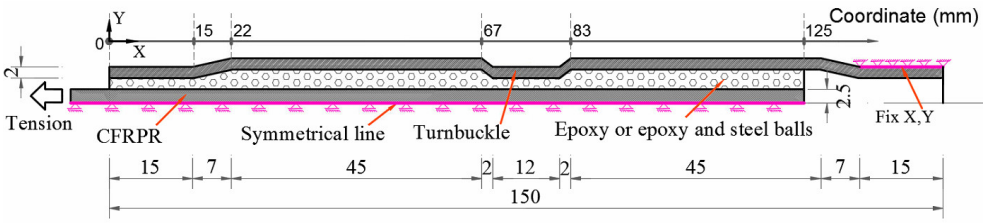

Fig 4. Boundary conditions and dimensions of specimens

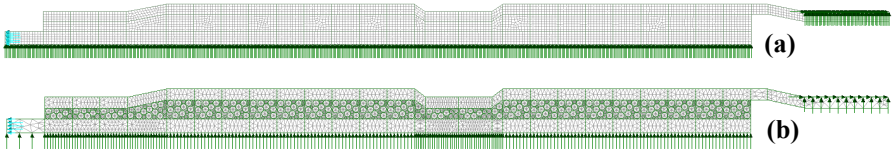

Fig 5. Models in FEA: specimen EP (a) and specimen EPSB (b)

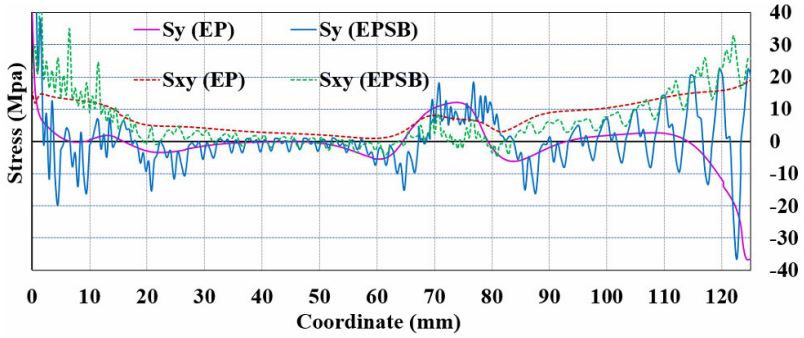

Fig 6. Stress distributions in specimens

It can be seen that transverse stress S_y of specimen EPSB had higher negative values than specimen EP. This proves that compression stress occurred much higher in specimen EPSB, leading to an increase of bonding strength. Moreover, shear stress of specimen EPSB is lower than specimen EP in the main coordinates. This also proves that bonding strength is better in specimen EPSB.

5. Conclusions

The use of small steel balls for the connections between CFRPRs and turnbuckles was an effective method to increase the bond strength of the connections. In addition, because this method is very simple, it can be easily applied for the real connection of structural design of steel structures, bridges, etc. More experiments with larger diameter turnbuckles and other types of CFRPRs will be carried out to investigate the bond strength behaviors in the future to develop this application in real construction.

Acknowledgements

Epoxy resin, E2300, was provided by Konishi Co.

References

1) 建設用先端複合材技術協会：連続繊維補強材を用いたコンクリート構造物設計・施工マニュアル（案），2015