BOND RESPONSE OF EMBEDDED THROUGH SECTION GFRP BARS TO CONCRETE

Chulalongkorn University Student Member ◯Linh Van Hong Bui
Hokkaido University Fellow Member Tamon Ueda
Chulalongkorn University Boonchai Stitmannaithum

1. INTRODUCTION

To enhance the longevity of the reinforced concrete (RC) structures, different techniques have been used with success in the strengthening field and rehabilitation projects. Embedded through section (ETS) method uses an adhesive to bond fiber-reinforced polymer (FRP) or steel bars embedded through pre-drilled holes into the core of the concrete members. Therefore, the bond behavior between the strengthened rods and concrete is an important factor that affects directly the mechanical performances of concrete beams strengthened with ETS bars. However, only a study of ETS pullout tests (Godat *et al.* (2012)) was found. None has ever conducted experiments of ETS bars embedded in concrete blocks with mechanical anchorage at tension ends nor investigated strain profiles of the ETS bars to see bond response.

This study presents an experimental investigation to analyze the effects of anchorage presence, embedded length, bar diameter, ETS types and anchorage length on the bond performance of the ETS GFRP bars embedded in concrete blocks.

2. EXPERIMENTAL PROGRAM

The design configuration, material properties of nine specimens and the strain gauges attachment on the ETS bar, are shown in Fig. 1, Table 1 and Table 2. The specimens are divided into five groups to investigate the effects of anchorage, embedded length, bar diameter, ETS material types and anchorage length on ETS bar bond response.

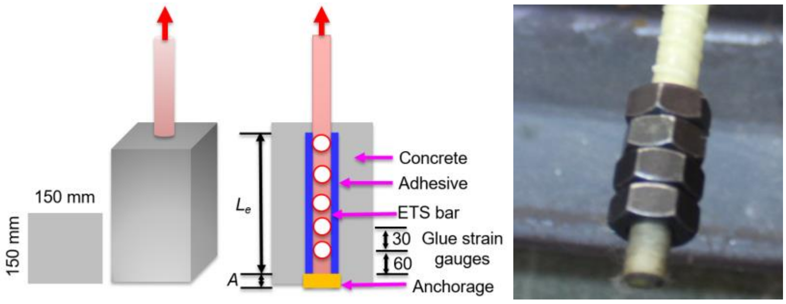

Fig. 1 Configuration of the tested specimens and the anchorage device (anchoring nuts) at end of GFRP bar

Table 1 Properties of materials of the tested specimens

Specimens	f_c (MPa)	E_r (GPa)	f_t (MPa)	$E_{adhesive.}$ (GPa)	$f_{t\_adhesive.}$ (MPa)
C1-C3, C5-C9	38	50	1076	3.1	21.0
C4	38	200	400	3.1	21.0

Table 2 Configuration, ultimate load, maximum slip and failure mode of the tested specimens

Specimens	L_e (mm)	d_b (mm)	ETS material	Anchorage	Number of anchoring nut	Ultimate force (kN)	F_t (kN)	Maximum slip (mm)	Failure mode
C1	150	10	GFRP	No	-	26.5	84.5	0.27	Pullout
C2	150	10	GFRP	Yes	4	30.3	84.5	0.42	Rupture
C3	120	10	GFRP	Yes	4	37.9	84.5	0.64	Rupture
C4	150	8	GFRP	No	-	32.1	54.1	1.16	Rupture
C5	200	10	GFRP	Yes	4	39.2	84.5	0.48	Rupture
C6	250	10	GFRP	Yes	4	37.4	84.5	0.98	Rupture
C7	120	12	Steel	Yes	4	45.4	45.2	0.12	Rupture
C8	120	10	GFRP	Yes	2	35.0	84.5	0.55	Pullout
C9	120	10	GFRP	Yes	6	37.1	84.5	0.48	Rupture

Keywords: Strengthening, ETS method, Bond mechanism, Mechanical anchorage, FRP
Contact address: Kita 13 Jo Nishi 8 Chome, Kita-ku, Hokkaido, 060-0808, Japan, Tel: +81-11-707-6582

3. RESULTS AND DISCUSSION

It is obvious from Fig. 2(a) that the initial response before the mechanical anchorage being activated is completely similar between the two specimens. From Table 2, the specimen C2 with mechanical anchorage attachment results in the significantly higher maximum pullout force and maximum slip than those obtained by the test of the specimen C1 without anchorage by 14.3 % (for pullout load) and 55.5 % (for slip). The final failure modes of the blocks C1 and C2 are the pullout of ETS bar and the rupture of ETS rod, respectively. Clearly, at the load same as the peak load of the specimen C1, where the specimen C1 failed by pullout of bar, the anchorage in the specimen C2 started to be activated, triggering the contribution of the ETS bars ultimately. Therefore, the pullout force transfer after that load was shifted from the adhesive to the anchorage, so that the failure mode of the block C2 is different from the specimen C1. Indeed, Fig. 2(b) indicates that the strain of gauge (SG1) closed to the anchorage in the specimen C2 started to increase at the peak load of the test specimen C1. This indicates that the use of anchorage enhanced drastically the tension capacity of rod at the bar end. From Fig. 2(c), generally, the ultimate pullout forces of the specimens are similar since the failure mode is the GFRP bar rupture. As shown in Table 2, the failure modes of the specimens C2, C3, C5 and C6 were the fracture of ETS GFRP bars due to the presence of anchorage at bar ends. As shown in Table 2, the ultimate pullout force is much smaller than the ultimate tensile force (F_t) based on GFRP tensile strength since the premature tension rupture at the anchorage was occurred, and the premature rupture may depend on the detailing of anchorage.

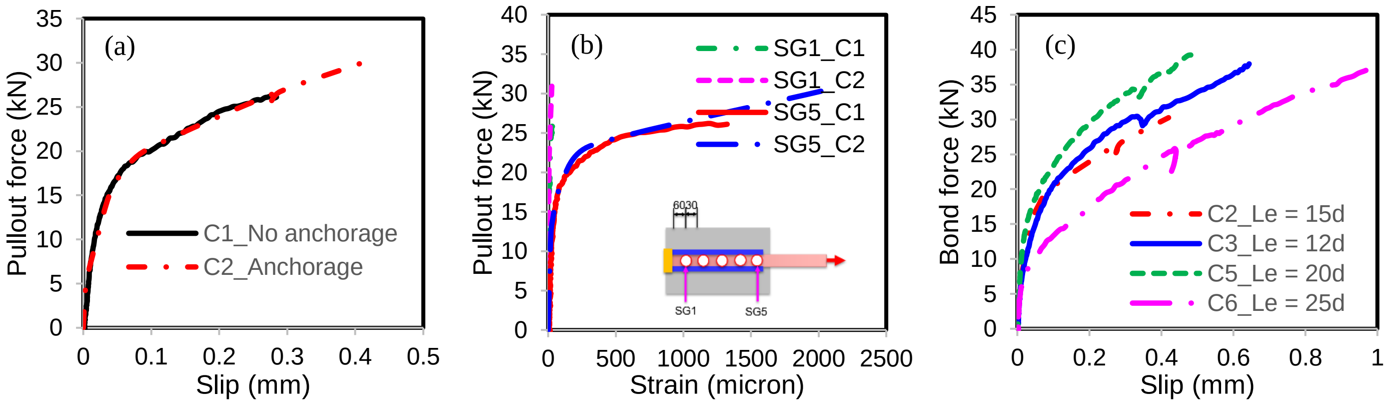

Fig. 2 Comparison in bond and strain responses between the cases with and without anchorage, and effect of ETS bar diameter

It is obvious from Table 2 that the specimen C1 with ETS GFRP bar diameter of 10 mm offers the lower ultimate pullout force and smaller maximum slip in the comparison with those of the specimen C4 with ETS GFRP bar diameter of 8 mm; 26.5 kN compared to 32.1 kN (for ultimate load) and 0.27 mm compared to 1.16 mm (for bond slip). The specimen C1 embedded by ETS GFRP bar with 10 mm of diameter induced the weak interface between the ETS bar-adhesive-concrete probably due to the poorer adhesive resin injection. While, with the smaller ETS bar size the adhesive resin was filled up more properly in C4. Hence, the ultimate pullout force of C1 was low and the maximum slip was small. On the other hand, Table 2 also reveals that ETS steel bar in C7 showed the rupture at pullout force similar to its tensile strength (F_t), meaning that there is no premature failure. For the effect of anchorage length, it is clear from Table 2 that with the longer anchorage length (or more anchoring nuts) the specimens C3 and C9 resulted in the higher pullout force than that of the specimen C8 with the short anchorage length. The failure modes of the specimen C3 and C9 were the fracture of ETS bars, while the specimen C8 with short anchored ETS bar failed by the pullout of the ETS bar leaving the nut in concrete. This fact indicates that the two nuts are not enough to assure the full tension capacity of ETS GFRP bar.

4. CONCLUSION

The test results of ETS GFRP bar indicated that the pullout force increased drastically as the anchorage was inserted at the ends. The anchorage capacity could be well increased even with two anchoring nuts. Generally, the failure mode shifted from the pullout in the non-anchored ETS bar to the bar rupture in the anchored ETS bar. The GFRP bar rupture at anchorage happened at load lower than its tensile strength of bar, indicating the necessity of improving anchorage details.

REFERENCES

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