ROUND ROBIN TESTING INITIATIVE FOR FIBER REINFORCED POLYMER (FRP) REINFORCEMENT

A. Palmieri[1], S. Matthys[1], A. Seberscu[2], M. Guadagnini[2], J. Barros[3], I. Costa[3], A. Bilotta[4], F. Ceroni[5], E. Nigro[4], C. Czaderski[6], S. Olia[6], Z. Szabo[7], G. Balazs[7], G. Sas[8], B. Taljsten[8], C. Mazzotti[9], N. Taranu[10], V. Munteanu[10], V. Tamuzs [11]

[1] Ghent University, Belgium [2] University of Sheffield, UK [3] University of Minho, Portugal [4] University of Naples, Italy [5]University of Sannio, Italy [6]Laboratory EMPA, Switzerland [7] University of Budapest, Hungary [8] University of Lulea, Sweden [9] University of Bologna, Italy [9] University Iasi ,Romania [11] University of Latvia, Latvia

Summary

An international Round Robin Testing (RRT) programme on FRP reinforcement was conducted within the framework of the Marie Curie Research Training Network, EN-CORE, and with the support of Task Group 9.3 of the International Federation for Structural Concrete (fib). Eleven laboratories and six manufacturers and suppliers participated in this exercise. As part of this extensive experimental endeavour, one or more of the following tests were performed by the participating laboratories: 1) tensile tests on FRP bars and strips; 2) tensile tests on FRP laminates; 3) double bond shear tests on FRP laminates (Externally Bonded Reinforcement, EBR) and FRP bars/strip (Near Surface Mounted reinforcement, NSM). This paper will discusses the results of the RRT initiative, among which the experimental results of bond tests on concrete specimens strengthened with EBR and NSM FRP.

Keywords: RRT, FRP, bond test, EBR, NSM

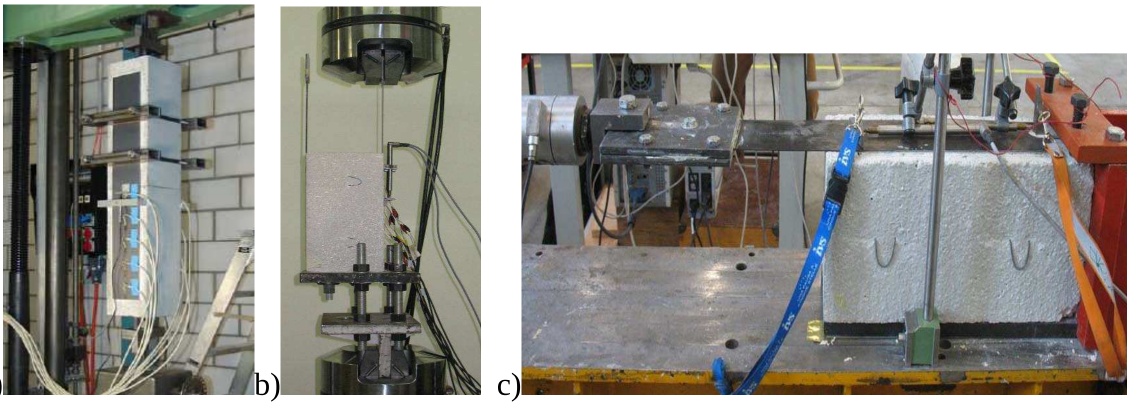
1 Introduction

In recent years, strengthening technologies for reinforced concrete structures using FRP composites have been gaining widespread interest and growing acceptance in the civil engineering industry. The most common strengthening technique are respectively the EBR technique, that consist of bonding, with a high strength adhesive, a laminate/textile onto the surface of the concrete element, and the NSM technique, that consist of placing the FRP reinforcing bars into grooves pre-cut into the concrete members and embedding the bars with a high strength adhesive.

A Round Robin Testing initiative was conducted to investigate the feasibility of the adopted test methods and to investigate the mechanism of bond between FRP reinforcement and concrete. In this paper focus is given to the RRT bond tests.

2 Experimental program

A total of 95 bond tests on EBR FRP strengthening system and 102 bond tests on NSM FRP strengthening system were carried out in the RRT initiative. Three different test set up methodologies, namely a double bond shear test set up (DB), and two single shear test set ups (SB type A and SB type B) have been adopted by the participating laboratories (all the configurations were mainly based considering bond testing in a tension-tension situation) as shown in figure 1. The same test set up methodology was used for testing specimen strengthened with NSM. Further details on the whole test programme, properties of FRP and reinforcement application are described elsewhere [1-3]. Concrete blocks were prepared by the laboratories and the mean compressive cylinder strength, f_{cm} was respectively ≈30 MPa for tests type DB and ≈20 MPa for tests type SB.



a) b) c)

Fig. 1. Specimen details a) DB test b) SB test type A c) SB test type B

Table 1 and 2 list the details of the FRP strengthening system respectively for the EBR and NSM application. Three specimens for each product have been tested.

Name	Width [mm]	Thickness [mm]	f_f [MPa]	E_f [GPa]
C1A	100	1,2	3100	165
C1B	100	1,4	3100	210
C1C	60	1,3	3100	165
C2	100	1,0	2850	175
C3	100	1,2	2900	165
C4	100	1,4	3100	170

* f_f (FRP tensile strength) and E_f (modulus of young) are according to manufacturers values.

Table 1- EBR Laminates

Name	Bar Type	D_f [mm]	Groove [mm]	f_f [MPa]	E_f [GPa]
C-6-SC	Sand coated CFRP	6.0	12x12	2068	124
B-6-SC	Sand coated BFRP	6.0	12x12	1413	50
B-8-SC	Sand coated BFRP	8.0	14x14	1208	50
G-8-R	Ribbed GFRP	8.0	14x14	1500	60
C-2.5x15-S	Smooth CFRP	2.5x15	8x25	3100	165
C-8-S	Smooth CFRP	8.0	14x14	2800	155
G-8-SW	Spirally Wound GFRP	8.0	12x12	1333	52
C-10x10-S	Smooth CFRP	10x10	15x15	2000	155

Table 2- NSM FRP bars

3 Test results EBR strengthening system

Failure at the adhesive-concrete interface with a thin layer of concrete attached to the FRP laminate was the predominant failure mode for all the test specimens (fig 2 give an example as reference). Experimental results in terms of average value of ultimate load F_u

are shown in figure 3. The experimental results are divided in terms of type of FRP laminate, testing laboratory and test set up adopted for testing.

Fig. 2. Failure mode

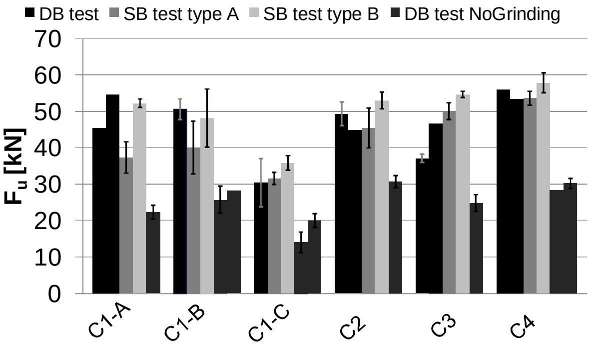


Fig. 3. Ultimate load one laminate

The difficulties in aligning the two concrete prisms for the double bond shear tests, can explain the differences of failure load values obtained for the specimens tested with the same test set-up method (see fig 3). For the specimens whose surface was not roughened (no grinding of concrete surface) the ultimate load values were systematically lower than that of specimens whose surface was grinded, no matter what test set up was adopted. The difference of concrete strength (20 MPa for SB test and 30MPa for DB test) seems to have a limited influence on the FRP performance for the RRT test range. The difference of about 10% observed in terms of failure loads in the test set up SB type A and SB type B is probably due to the different restrain condition of the specimen in the two test set-ups (in the SB test type B the horizontal base contrast provides for proper reaction to the bending moment produced by the load eccentricity).

4 Test results NSM strengthening system

Different failure modes were observed during testing (failure at concrete/epoxy interface fig 4a–b and failure at epoxy/bar interface fig 4b-c) mainly related to the different variables such as the type and shape of FRP bars and the FRP bars surface configuration. For some products different failure modes were observed by the labs for the specimens tested with the same or different test set-up method. Hence some inconsistencies in failure aspect were observed between labs. Experimental results in terms of average value of ultimate load F_u are shown in figure 5. The experimental results are divided in terms of type of FRP rods/strips, testing laboratory and test set up adopted for testing. Experimental outcomes, in terms of ultimate load, seems to be in agreement for the two different test set up adopted, excluding some differences caused by unexpected failure mode.
For the DB test the alignment of specimens was, for some cases, difficult to achieve and the occurrence of bending effect was observed during testing. For both test set-ups the stresses developed along the embedded steel bars, in addition to the stresses at the bond interface (induced by the FRP reinforcement bars) can cause a premature failure of the concrete specimen by splitting. This was especially the case for high strength strips and bars with high bond capacity.

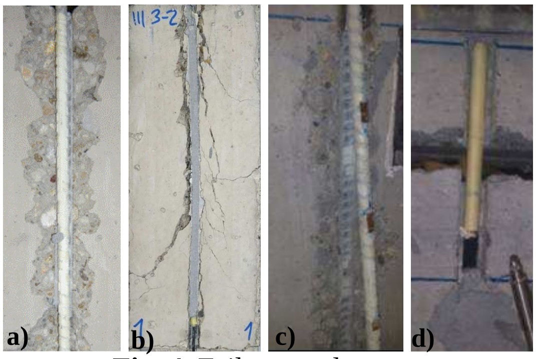


Fig. 4. Failure mode

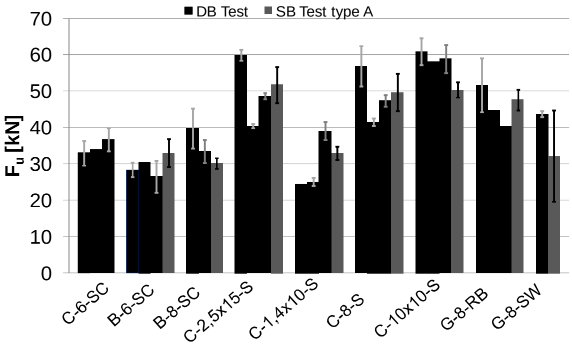


Fig. 5. Ultimate load

5 Conclusions

In this paper, as part of an extensive research in the framework of a round robin testing initiative, the experimental results of different bond tests set up on concrete specimens strengthened with EBR and NSM FRP are described. An initial comparison in terms of ultimate load seems to give acceptable agreement in between the different test set-ups adopted. Experimental results confirm that the ultimate load is marginally affected by the concrete strength (for the RRT test range) while significantly dependent on the concrete surface preparation (as tested for the EBR). More detailed analysis of the test results is ongoing.

6 Acknowledgement

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Ir. Aniello Palmieri,Ph-d student
✉ Ghent University Magnel Laboratory for Concrete Research
Technologiepark-Zwijnaarde 904
B-9052 Gent, Belgium
☎ +32 264 55 25
+32 9 264 58 45
☺ Aniello.Palmieri@Ugent.be

Prof. Dr. Ir. Stijn Matthys.
✉ Ghent University Magnel Laboratory for Concrete Research
Technologiepark-Zwijnaarde 904
B-9052 Gent, Belgium
☎ +32 264 55 20
+32 9 264 58 45
☺ Stijn.Matthys@ugent.be