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Verification Experiments on Bond Behaviour of Near Surface Mounted Strengthened Concrete Structure

Xiaodong Zhang

School of Environmental Arts and Architectural Engineering, Heilongjiang University of Technology, No.99 South Heping Street, Jixi City, Heilongjiang Province, China

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Abstract: Fibre-reinforced polymer (FRP)-the currently produced materials are now widely used for bridges and the strengthening and retrofitting of concrete structures. Early on 1982, externally bonded FRP sheets have been successfully applied to strengthen concrete structures. Now the technology of Near-Surface Mounted Fibre-reinforced polymer (FRP) is widely used. Lots of experiments were carried out to characterize the way of properly use of this technology. Finally it was observed that the longest embedded lengths gave the most consistent results. Although there are always problems related to long-embedded length case in real situation. Research on the case of short-embedded length is desirable to highlight any weaknesses in the test method which is used in the research on long-embedded length case. The experiments carried in this paper are aimed to verify the conclusion which previous researchers have made.

1. Introduction

During the last decade, conventional materials such as steel have been replaced by fibre-reinforced polymer (FRP) material for the strengthening of the concrete structures. Although externally bonded FRP reinforcement performed extremely well in practice, premature debonding failure was observed and identified by many researchers. Several details were proposed to avoid this type of failure, which is unacceptable from the point of view of structural safety. On 1997, Cosenza, G. Manfredi and R. Realfonzo carried out a series of tests in which the influence of type of fibre, outer surface (shape and type of concrete matrix), and other significant parameters (i.e., confining pressure, bar diameter, compressive concrete strength) on bond performance was investigated [1]. In the paper of Francesco Focacci, Antonio Nanni and Charles E. Bakis (2000) named "Local Bond-Slip Relationship for FRP Reinforcement in Concrete", a method for the determination of the parameters of a local $\tau=\tau(s)$ relationship from results of pull-out tests that take into account the distribution of slip and bond shear stress along the embedded portion of the bar was proposed. [2] This method was applied to some pull-out test results corresponding to different embedded lengths, and local $\tau=\tau(s)$ relationships were found [3].

Among large amounts of different types of bond tests, the direct pull-out test and the beam pull-out test are the most common ones. In the experiments of this paper, the direct pull-out test of short-embedded length CFRP rod was adopted. Four concrete cubes of which the four sides are cut into different dimensions of grooves are used. The 8 mm diameter smooth surface CFRP rods (MBT MBAR®) were bonded into the grooves. The bonds with different sizes of cross-sections and different embedded lengths were tested separately. Sixteen tests were carried out, and behaviours of the bonds and CFRP reinforcements in different dimension of grooves with different embedded lengths are evaluated by carrying out the Pull-out tests. The experimental results are analysed and used to verify the conclusions which pervious researchers have made.

2. Experiments

2.1 Test 1.1

Date and time of the test: 02/02/2005 @ 12:50pm
Date of the bonding: 20/01/2005
Size of the groove: 16×21 mm^2
Embedded length: 80mm
ℓ_{TG} : 18mm

Figure 1: Experimental specimen

Reading of the load cell and top gauge during the test:

Initially, load increased rapidly with little increase of the displacement. When load was 22KN, displacement became to reduce as the load still going up. The displacement kept reducing to negative value until the load increased to about 27KN, then, it started to increase with the load. When displacement increased to about 0mm, a loud noise “BANG” was heard; load reduced to about 8.5KN suddenly (CFRP rod had been pulled out through bond). Test stopped when displacement increased to 5mm. Neither the concrete nor the bond cracked during the test; the failure mode is “pull-out of the rod”. Figure 2 shows how load and displacement changed during the test. Figure 1 shows the specimen after being tested. It is believed that something strange happened during the test (may be the displacement arm of the top strain gauge was stuck).

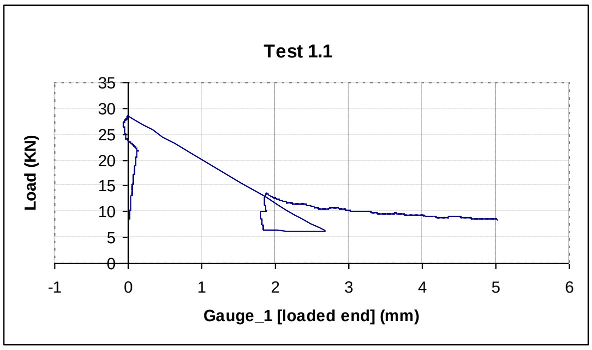

Figure 2: Load-Slip curve

2.2 Test 1.2

Date and time of the test: 15/02/2005 @ 13:50pm
Date of the bonding: 08/02/2005
Size of the groove: $18\times 20mm^2$
Embedded length: 80mm
ℓ_{TG}: 35mm

Figure 3: Experimental specimen

Reading of the load cell and top gauge during the test:

Initially, load increased rapidly with little increase of the displacement. When displacement increased to about 0.48mm, load started to reduce at the same time, a noise “Klick” was heard (possibility is the bond failure). Then the load reduced quickly with the increasing of the displacement. Test stopped when displacement increased to 5mm. The concrete cracked at the surface after the test (Figure 3), and the CFRP rod was pulled-out through the bond. The relationship between the load and reading of the top gauge are shown in Figure 4.

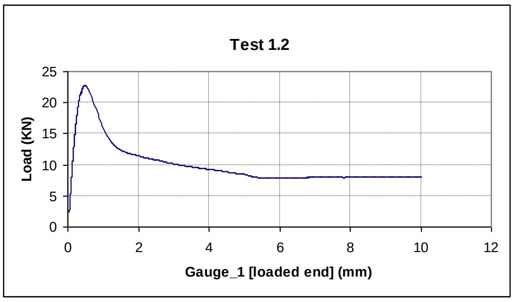

Figure 4: Load-Slip curve

2.3 Test 1.3

Date and time of the test: 02/02/2005 @ 13:55pm
Date of the bonding: 20/01/2005
Size of the groove: $14\times 20mm^2$
Embedded length: 160mm
ℓ_{TG} : 12mm

The test had been stopped twice because of the failure of the cross-head grip (the grip of the cross-head could not hold the CFRP rod properly and the CFRP rod was pulled out through the grip of the cross-head).

Figure 5: Experimental specimen

Part 1

Reading of the load cell and top gauge during the test:

The load increased rapidly with very little increase of the displacement. When load increased to about 22.5KN, a noise “Tint” was heard (possibility is the failure of the cross-head grip); the load kept increasing to 26.3KN and then decreased to 26.04KN, and increased again (two more noises were heard separately when load increased to 27.32KN and 29.06KN); the load decreased to 27.68KN after increasing to 29.06KN and then increased back up once more. The load kept increasing this time, and noises were heard frequently. When it increased to 35.9KN, a loud noise “BANG” was heard (the CFRP rod was pulled out through the grip of the crosshead). Test was stopped. After the test, the CFRP rod crashed at the top end which was holded by the grip of the crosshead during the test (Figure 5). The plot of load versus reading of top gauge during the test is shown in Figure 6.

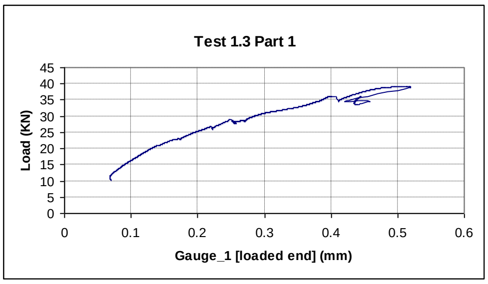

Figure 6: Load-Slip curve

Part 2

In the test, the grip of the crosshead failed again (CFRP rod was pulled out through the grip of the crosshead). Test was stopped again a short time after beginning in case of the crosshead grip being damaged. The plot of load against reading of top gauge is shown in Figure 7.

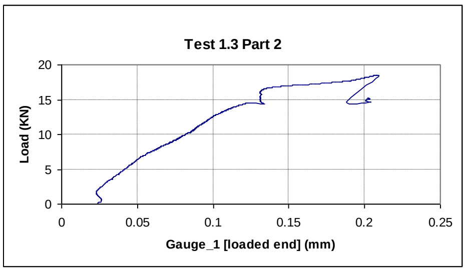

Figure 7: Load-Slip curve

Part 3

Reading of the load cell and top gauge during the test:

The load increased rapidly with little increase of the displacement. At about 22KN, the load dropped a little (possibly the grip of the crosshead failed), then went up again. At about 30KN, a nose “Dang” was heard and the load dropped little (possibly the grip of the crosshead failed again) and then increased again. When load increased to around 40KN, in suddenly fall down quickly to about 15KN and then decreased gradually. Test stopped when displacement increased to 10mm. No cracks on the concrete and the bond; the failure mode is “pull-out of the rod” (Figure 5). The relationship between load and reading of top gauge is shown in Figure 8.

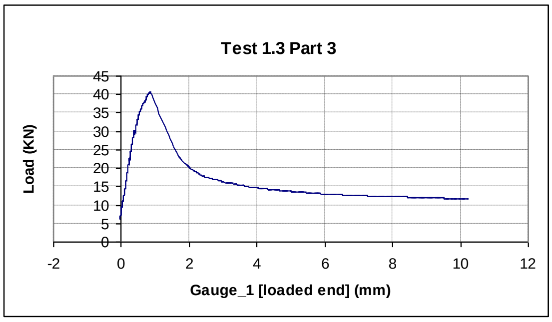

Figure 8: Load-Slip curve

2.4 Test 1.4

Date and time of the test: 15/02/2005 @ 14:50pm

Date of the bonding: 08/02/2005

Size of the groove: 18×20 mm^2

Embedded length: 120mm

ℓ_{TG} : 32mm

Figure 9: Experimental specimen

Reading of the load cell and top gauge during the test:

Load increased rapidly with little increase of the displacement. After reaching a peak value of about 15KN, the load started to dropped down quickly to about 9KN, and then decreased gradually. No noise was heard during the test. Test stopped when the slip increased to 10mm. No significant cracks formed on the concrete and the bond; failure mode is “pull-out of the bond” (Figure 9). Figure 10 shows how load and displacement changed during the test.

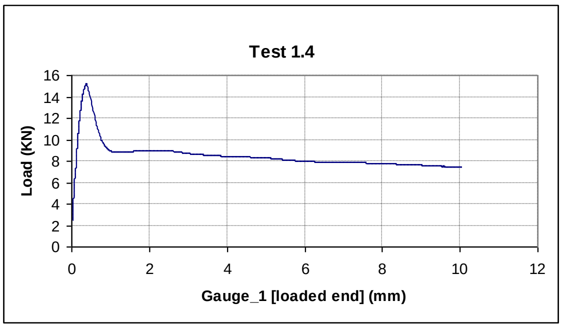

Figure 10: Load-Slip curve

2.5 Test 2.1

Date and time of the test: 01/02/2005 @ 10:30am
Date of the bonding: 20/01/2005
Size of the groove: 20×20 mm^2
Embedded length: 160mm
ℓ_{TG} : 18mm

Figure 11: Experimental specimen

Reading of the load cell and top gauge during the test:

Initially, both load and displacement increased quickly. At about 27.5KN, load suddenly decreased to about 25KN, but displacement did not change as the load was dropping. Then load went up back to about 27.5KN, but the displacement did not change while the load was going up. When load increased to 27.5KN, displacement started to increased with it. When load increased to a peak value of about 35.02KN, a noise “Tint” was heard (possibility bond failure) and load started to drop quickly to 20KN, and then decreased gradually. Although small cracks on the concrete and the bond were observed after the test (Figure 11), it is believed that the failure mode is still “pull-out of the rod”. The plot of load against reading of top gauge is shown in Figure 12.

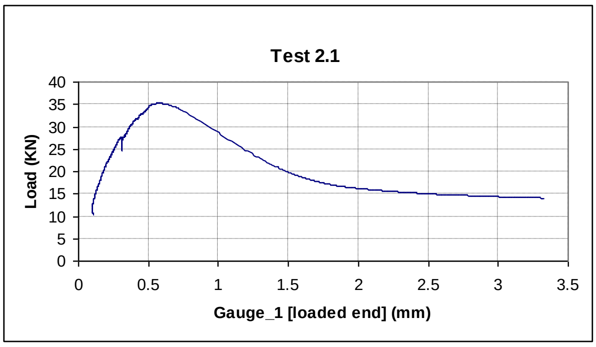

Figure 12: Load-Slip curve

2.6 Test 2.2

Date and time of the test: 15/02/2005 @ 11:00am
Date of the bonding: 08/02/2005
Size of the groove: 23×20 mm^2
Embedded length: 120mm
ℓ_{TG} : 30mm

Figure 13: Experimental specimen

<u>Part 1</u>

Reading of the load cell and top gauge during the test:

At the beginning, load increased rapidly with little increase of displacement. When load increased to 15KN, a noise "Klick" was heard (the grip of the crosshead failed), and load started to fall down. After fluctuating between 14.3Kn and 14.2KN for several times, load started to increase again. When load increased to 16KN, both load and displacement started to decrease (grip of the crosshead failed and the CFRP rod was pulled out through the grip). Test was stopped after a short time. The plot of load against reading of top gauge is shown in Figure 14.

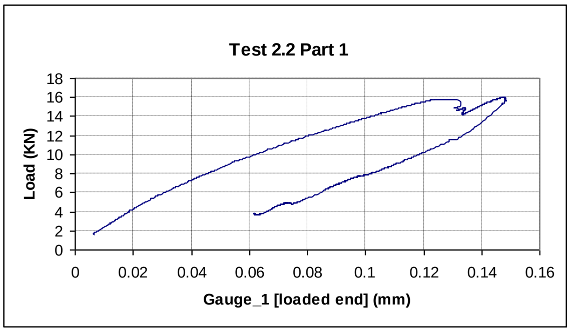

Figure 14: Load-Slip curve

<u>Part 2</u>

Reading of the load cell and top gauge during the test:

Initially, load increased rapidly with little increase of displacement. When load increased to 17KN, it started to fall down to 15KN, and then increased again. When load increased to 27KN, it stayed for s short time, but slip kept increasing and a noise "Klick" was heard (grip of the crosshead failed). Load started to increase again after a short time (noise was heard when load was 28.5KN). When load increased to 29.5KN, it stayed for a moment and then went up. When load increased to 30KN, the rate at which load increase became to slow down. A loud noise "BANG" was heard when load is about 31.5KN (bond failed) and load went down rapidly with a large increase of slip. Test stopped when slip increased to 10mm. Failure mode is "pull-out of the rod" (Figure 13). The plot of load versus reading of top gauge is shown in Figure 15.

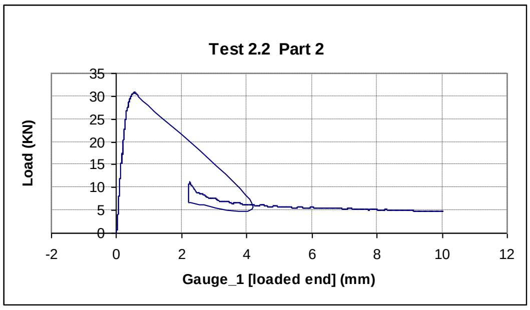

Figure 15: Load-Slip curve

2.7 Test 2.3

Date and time of the test: 27/01/2005 @ 14:50pm
Date of the bonding: 20/01/2005
Size of the groove: 24×19 mm^2
Embedded length: 80mm
ℓ_{TG} : 40mm

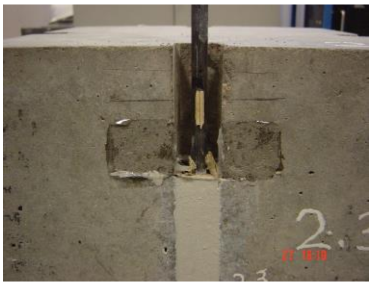

Figure 16: Experimental specimen

Part 1

Reading of the load cell and top gauge during the test:

Load initially increased rapidly with little increase of displacement. A loud noise “BANG” was heard when load is 8.385KN, but load kept increasing. When load increased to about 15.5KN, the rate at which load increased became to slow down. When load increased to about 17KN, both load and displacement started to fall down. When load decreased to 16.5KN, it stayed, but displacement kept decreasing. When displacement decreased to 0.15mm, both load and displacement started to went up (Figure 17). When load increased to 25.7KN, it stopped increasing but displacement started to go up rapidly. Test was stopped because one of the four steel rods which were used to hold the concrete was pulled out.

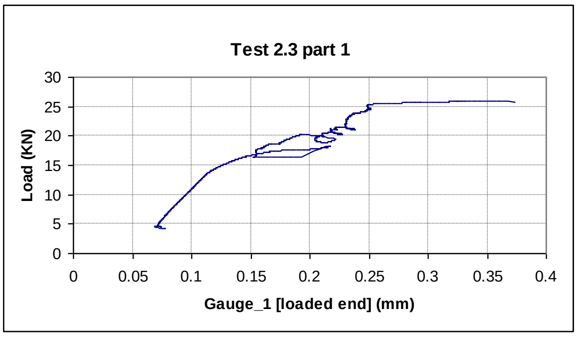

Figure 17: Load-Slip curve

Part 2

Reading of the load cell and top gauge during the test:

Test was started again. When load increased to 4.5KN, a noise "Ding" was heard. Test stopped when displacement is 5mm. No cracks on concrete and bond; the failure mode is "pull-out of the rod" (Figure 16). The plot of load against reading of top gauge is shown in Figure 18.

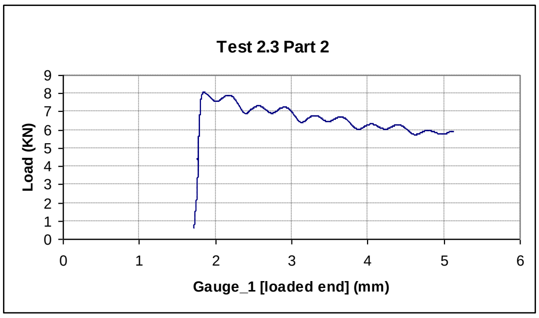

Figure 18: Load-Slip curve

2.8 Test 2.4

Date and time of the test: 15/02/2005 @ 12:05pm

Date of the bonding: 08/02/2005

Size of the groove: 25×20 mm^2

Embedded length: 40mm

ℓ_{TG} : 40mm

Figure 19: Experimental specimen

Reading of the load cell and top gauge during the test:

Load increased to a peak value of 8.9KN and then fall down rapidly to 4.4KN. Test stopped when displacement increased to 5mm. No noise was produced during the test. Although a crack is observed at the top end of the bond (Figure 19), it is believed that the failure mode is still "pull-out of the rod". The graph of load against reading of top gauge is shown in Figure 20.

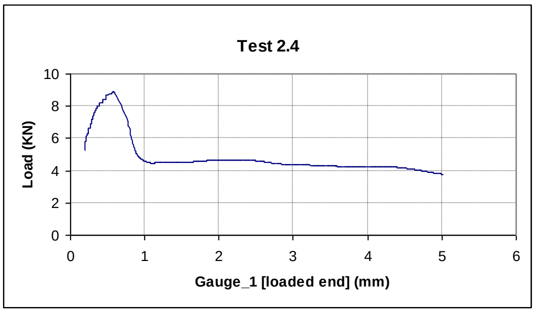

Figure 20: Load-Slip curve

2.9 Test 3.1

Date and time of the test: 01/02/2005 @ 12:20pm
Date of the bonding: 20/01/2005
Size of the groove: 21×20 mm^2
Embedded length: 40mm
ℓ_{TG} : 72mm

Figure 21: Experimental specimen

Part 1
Reading of the load cell and top gauge during the test:
Test was stopped about 40 seconds after being started because nothing appeared on the graph of load versus loaded end slip (displacement decreased from 0mm to negative value as load kept increasing) [Figure 22].

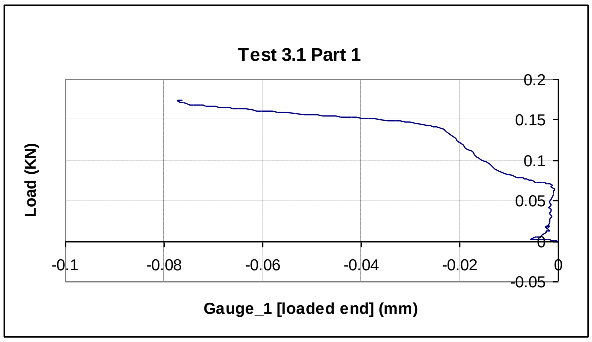

Figure 22: Load-Slip curve

Part 2
Reading of the load cell and top gauge during the test:
Test was started again. After about 40 seconds, the test was stopped again because still nothing appeared on the graph. It was at the time the test was stopped, a loud noise “BANG” was head (bond failed). The plot of load against reading of top gauge is shown in Figure 23.

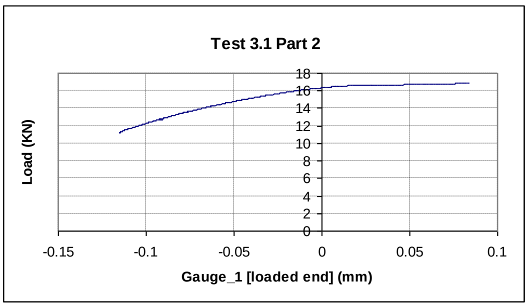

Figure 23: Load-Slip curve

Part 3

Reading of the load cell and top gauge during the test:

Test was started the third time. Initially, load increased to about 7KN without ant changing of the displacement. After reaching the peak value, load started to fall down rapidly and displacement started to increase too (Figure 24). Test stopped when displacement increased to 10mm. No cracks on concrete or bond (Figure 21). Failure mode is “pull-out of the rod”.

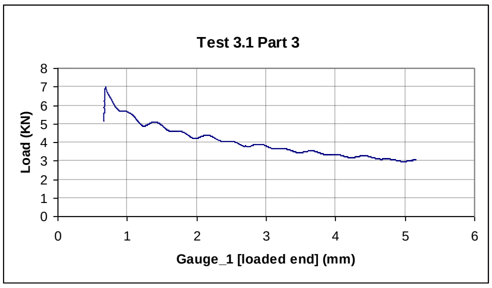

Figure 24: Load-Slip curve

2.10 Test 3.2

Date and time of the test: 16/02/2005 @ 14:50pm

Date of the bonding: 08/02/2005

Size of the groove: 19×19 mm^2

Embedded length: 160mm

ℓ_{TG} : 11mm

Figure 25: Experimental specimen

Reading of the load cell and top gauge during the test:

Initially, both load and displacement increased slowly. Load kept increasing to a peak value and then falls down slowly. Noises “Klick, Klick” were heard when load increased to the peak value. There was no crack on concrete or bond; failure mode is “pull-out of the rod” (Figure 25). The plot of load against reading of top gauge is shown in Figure 26.

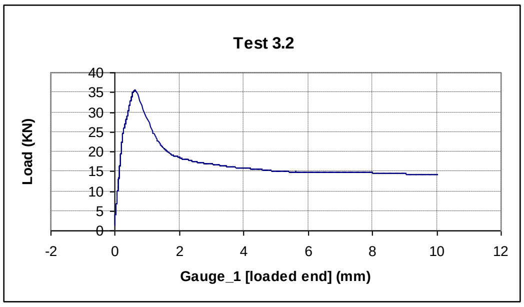

Figure 26: Load-Slip curve

2.11 Test 3.3

Date and time of the test: 02/02/2005 @ 10:13am
Date of the bonding: 20/01/2005
Size of the groove: 20×20 mm^2
Embedded length: 160mm
ℓ_{TG} : 19mm

Figure 27: Experimental specimen

Reading of the load cell and top gauge during the test:

Initially, load increased rapidly with little increase of displacement. After increased to 24.19KN, the load stayed for a while and then increased slowly. When load is 27KN, noises "Tint….Tint" was heard and load started to decrease quickly to 25KN without any changing of displacement and two noises were heard separately when load was 26.12KN and 25.8KN (possibly grip failed). Load started to went up after falling down to 25KN. When load increased to 38.74KN, a loud noise "BANG" was heard (bond failed). Test stopped before displacement reached to 10mm. Neither concrete nor bond cracked during the test; failure mode is "pull-out of the rod" (Figure 27). The plot of load against reading of top gauge is shown in Figure 28.

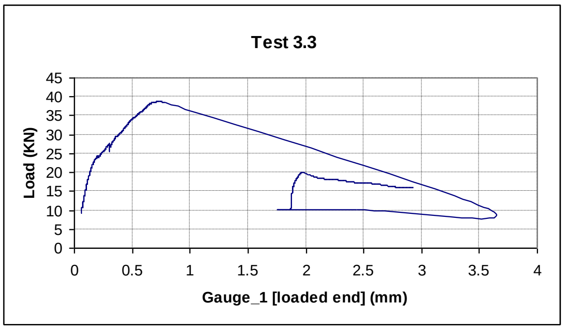

Figure 28: Load-Slip curve

2.12 Test 3.4

Date and time of the test: 16/02/2005 @ 13:50pm
Date of the bonding: 08/02/2005
Size of the groove: 20×20 mm^2
Embedded length: 80mm
ℓ_{TG} : 47mm

Figure 29: Experimental specimen

Reading of the load cell and top gauge during the test:

Initially, load increased rapidly with little increase of displacement. From 22KN, load started to increase slowly. When load is 24.75KN, a loud noise “BANG” (bond failed) was heard and load started to fall down rapidly to 5KN and then went up to 8.3KN. Load started to fall down to again after increasing to 8.3KN. Test stopped when displacement increased to 10mm. The plot of load versus reading of top gauge is shown in Figure 30. No cracks on concrete or bond; failure is “pull-out of the rod” (Figure 29)

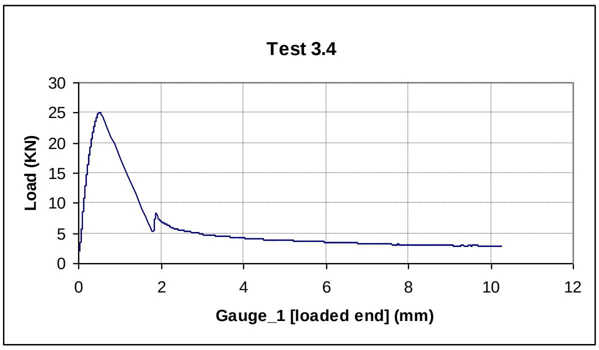

Figure 30: Load-Slip curve

2.13 Test 4.1

Date and time of the test: 31/01/2005 @ 13:10pm

Date of the bonding: 20/01/2005

Size of the groove: 19×22 mm^2

Embedded length: 40mm

ℓ_{TG} : 72mm

Reading of the load cell and top gauge during the test:

Initially, both load and displacement increased rapidly. Load started to decrease rapidly to about 6.05KN after reaching a peak value of about 13KN, and then decreased very slowly to about 6KN. Test stopped when displacement increased to 5mm. The plot of load against reading of top gauge is shown in Figure 31. Failure mode is “pull-out of the rod”.

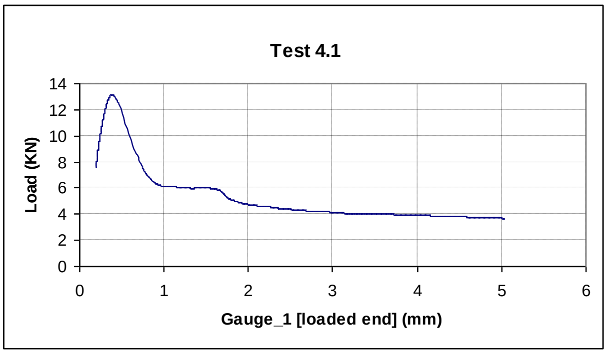

Figure 31: Load-Slip curve

2.14 Test 4.2

Date and time of the test: 15/02/2005 @ 13:05pm
Date of the bonding: 08/02/2005
Size of the groove: 18×19 mm^2
Embedded length: 40mm
ℓ_{TG} : 44mm

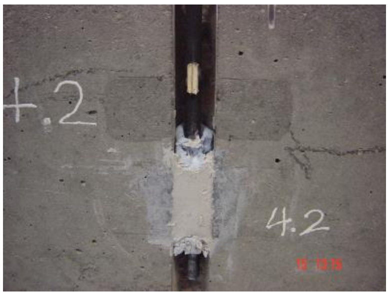

Figure 32: Experimental specimen

Reading of the load cell and top gauge during the test:

Initially, load increased rapidly with little increase of displacement. After reaching a peak value of about 9KN, load started to fall down to 3.5KN rapidly, and then fall down slowly. Test stopped when displacement increased to 5mm. No sufficient noise was heard during the test. The plot of load against reading of top gauge is shown in Figure 33. No crack formed during the test; failure mode is "pull-out of the rod" (Figure 32)

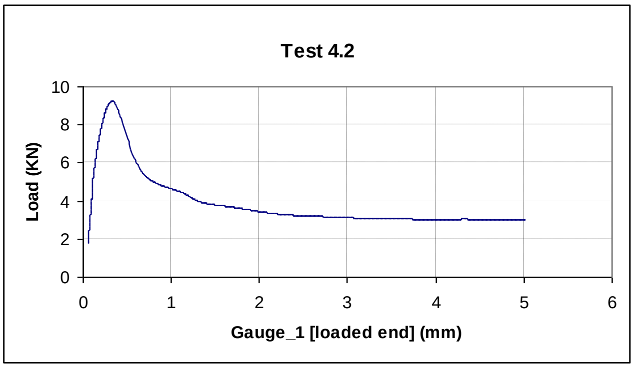

Figure 33: Load-Slip curve

2.15 Test 4.3

Date and time of the test: 02/02/2005 @ 11:36am
Date of the bonding: 20/01/2005
Size of the groove: 15×20 mm^2
Embedded length: 120mm
ℓ_{TG} : 14mm

Figure 34: Experimental specimen

Reading of the load cell and top gauge during the test:

Initially, load increased without any increase of displacement. When load increased to 12KN, displacement started to increase. When load was 22KN, a noise "Tint" was heard (bond failed) and load started to fall down to 13.89KN rapidly and then kept falling down but very slowly. Test stopped when displacement increased to 5mm. Although a small crack was observed at the top end of the bond (Figure 34), it is believed that the mode of failure is still "pull-out of the rod". The plot of load against reading of top gauge is shown in Figure 35.

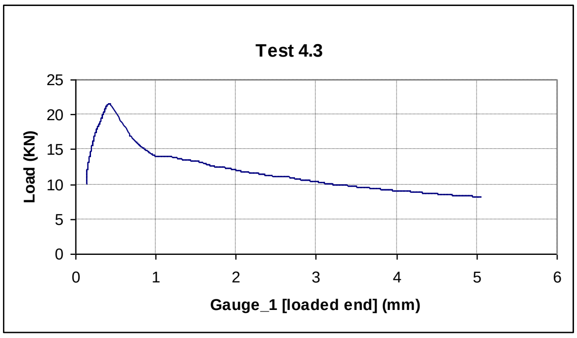

Figure 35: Load-Slip curve

2.16 Test 4.4

Date and time of the test: 15/02/2005 @ 15:45am
Date of the bonding: 08/02/2005
Size of the groove: 20×20 mm^2
Embedded length: 120mm
ℓ_{TG} : 28mm

Figure 36: Experimental specimen

Reading of the load cell and top gauge during the test:

Initially, load increased rapidly with little increase of displacement. Load stayed at 19.3KN for a while and then increased. When load increased to 20KN, a noise "Klick" was heard (possibly grip failed) and load fluctuated up and down for a while and then went up again. When load increased to 22KN, a noise "Klick" was heard. Load kept increasing to 25KN, and fluctuated up and down at 25KN for a while and then started to fall down. The plot of load against reading of top gauge is shown in Figure 37. Neither concrete nor bond cracked during the test; failure mode is "pull-out of the rod" (Figure 36).

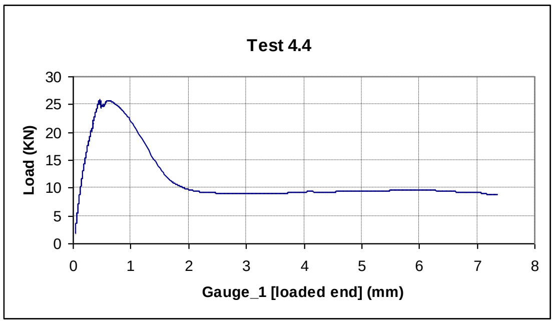

Figure 37: Load-Slip curve

3. Test Results

During the test, the tensile load and the slip (relative displacement between the rod and bond) at the loaded and free end were recorded.

The tensile deformation of the part of the CFRP rod between the displacement arm of the top gauge and the top end of the bond can be obtained from the following relationship [4-5]:

$$\delta = \frac{F \ell_{TG}}{E_{FT} A_F} \tag{1}$$

Where: δ - The tensile deformation of the CFRP rod

F - The tensile load applied to the CFRP rod

A_F - The sectional area of the CFRP rod

E_{FT} - The tensile modulus of the CFRP rod

ℓ_{TG} - The distance between the displacement arm of the top gauge and the top end of the bond.

The tensile deformation of the rod has been calculated using equation (1) [6] and it is believed that it does have significant effect on the top gauge, so the loaded end slip (*s*) is calculated using the following equation [7]:

$$s = r_1 - \delta \qquad (2)$$

Where: δ - tensile deformation of the CFRP rod

r_1- reading of the top strain gauge

To obtain the experimental bond-slip curve, an average shear stress (τ_{AV}) between the bond and CFRP rod is calculated from the applied tensile load F (assuming that the distribution of the average shear stress along the rod's lateral surface is constant) as follows:

$$\tau_{AV} = \frac{F}{\pi \phi \ell_E} \qquad (3)$$

The peak value of the average shear stress (τ_1) is calculated using equation (3) [8] once the peak pull out load is known.

The peak pull out load (F_1), peak value of the average shear stress (τ_1) and the corresponding loaded end slip (s_1), the mode of failure and the bond length of each test are summarized in Table 1 below.

Table 1: The test results

Test			F_1 (KN) [Peak]	τ_1 (MPa) [peak]	s_1 (mm)	Mode of Failure
1 1	10 ø	80	28.56793	14.209		Pull-out of the rod
1 2	10 ø	80	22.79015	11.335	0.484369	Pull-out of the rod & large concrete cracks
1 3	20 ø	160	40.71161	10.84	0.849319	Pull-out of the rod
1 4	15 ø	120	15.23561	5.052	0.372394	Pull-out of the rod & epoxy is not hard enough
2 1	20 ø	160	35.24572	8.765	0.574298	Pull-out of the rod & concrete cracks
2 2	15 ø	120	30.83143	10.183	0.548020	Pull-out of the rod
2 3	10 ø	80	25.99158	12.927	0.334365	Pull-out of the rod
2 4	5 ø	40	8.91845	8.871	0.575907	Pull-out of the rod
3 1	5 ø	40	16.86483	16.776		Pull-out of the rod
3 2	20 ø	160	35.56578	8.845	0.602735	Pull-out of the rod
3 3	20 ø	160	38.84027	9.659	0.729644	Pull-out of the rod
3 4	10 ø	80	25.03758	12.453	0.506548	Pull-out of the rod
4 1	5 ø	40	13.16189	13.092	0.380421	Pull-out of the rod
4 2	5 ø	40	9.26306	9.214	0.326578	Pull-out of the rod
4 3	15 ø	120	21.61675	7.168	0.418601	Pull-out of the rod & concrete cracks
4 4	15 ø	120	25.92588	8.596	0.455981	Pull-out of the rod

The curves of shear stress versus loaded end slip are plotted according to the test results of each embedded lengths (Table 1), using which the linear regression curve is plotted in the same diagram (Figure 38).

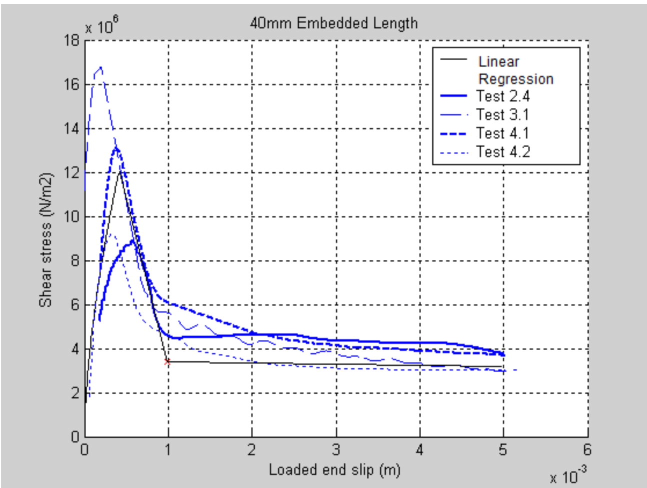

Figure: 38 (a): The experimental τ-*s* curve and linear regression curve of 40mm embedded length specimens

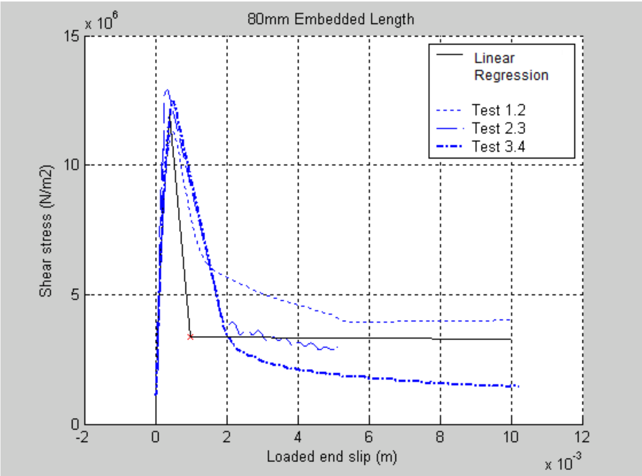

Figure: 38 (b): The experimental τ-s curve and linear regression curve of 80mm embedded length specimens

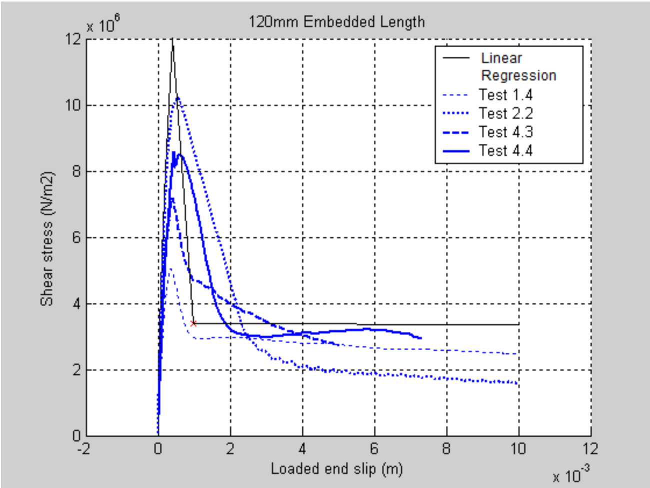

Figure: 38 (c): The experimental τ-s curve and linear regression curve of 120mm embedded length specimens

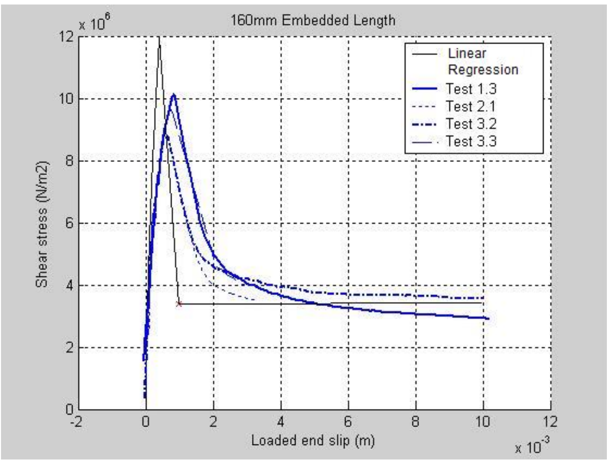

Figure: 38 (d): The experimental τ-s curve and linear regression curve of 160mm embedded length specimens

Figure: 38: The experimental τ-s curve and linear regression curve

4. Conclusions

Most of the models which have been suggested by researchers to represent the relationship between the short-embedded-length shear stress and the slip have three different zones (Figure 38): the primary bond mechanism (the primary zone), degradation of the primary bond mechanism (the degradation zone), and the secondary bond mechanism (the secondary zone) [9-10].

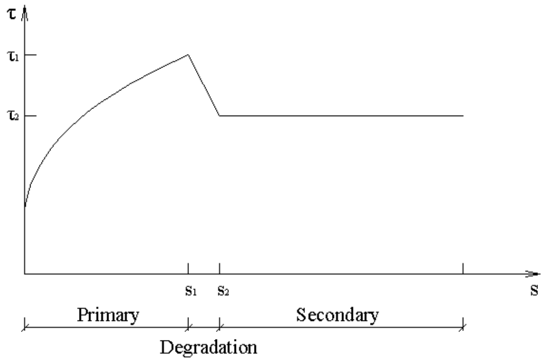

Figure 39: General model suggested by researchers

As we can see from Figure 39 that the linear regression curves of all embedded lengths match the conclusions most of the previous researchers suggest.

The following conclusions can also be drawn according to the experimental results:

• Two different modes of failure were experienced during the experimental rests, namely, pull-out of the rod and concrete cracks. In some cases, combined failure modes were registered. For most of the test, the rod was pull-out through bond without any cracks generating on the concrete or bond, which means that the cover thickness used in these tests (around 6mm) is sufficient to prevent cracks.

• The peak pull-out load and the corresponding loaded end slip increased with the embedded length of the CFRP rod.

• The shear stress at which the free end of the CFRP rod starts to move revealed a tendency to decrease with the increase of the embedded length, and was practically not reasonable.

• The bond strength (peak value of average shear stress τ_1) revealed a prone to decrease with increase of the embedded length.

• For those grooves of which the depth is deep enough to prevent failure occurs on the concrete surrounding the bond, the groove width has no significant effect on the bond strength.

References

[1] Tarek Hassan, Sami Rizkalla, 2003, Investigation of Bond in Concrete Structures Strengthened with Near Surface Mounted Carbon Fibre Reinforced Polymer Strips, ASCE Journal of composites for construction

[2] Chen. J.F., and Teng. J.G., 2001, Anchorage Strength Model for FRP and Steel Plates Bonded to concrete, Journal of Structural Engineering, ASCE, Vol.127, No.7, July, pp.784-791.

[3] Laura De Lorenzis, Antonio Nanni, 2001, Characterization of FRP Rods as Near-Surface Mounted Reinforcement, Journal of Composites for Construction

[4] Cosenza E., Manfredi G., Realfonzo R., 1997, Behavior and modelling of bond of FRP rebars to concrete, ASCE Journal of composites for construction, 1/2, 40-51

[5] AbdelJaber Ma'en et al. Influence of Compressive Strength of Concrete on Shear Strengthening of Reinforced Concrete Beams with Near Surface Mounted Carbon Fiber-Reinforced Polymer. Buildings, 2021, 11(11): 563-563.

[6] Alaa Hassoon and Ammar Aljanabi. Improvement of flexural capacity of hybrid, reinforced concrete spliced girders using steel fiber concrete in splice region and near surface mounted carbon fiber-reinforced polymer bars:

experimental investigations. Innovative Infrastructure Solutions, 2020, 5(1): 12-19.
[7] Tamer Eljufout and Houssam Toutanji. Fatigue behavior of prefatigued reinforced concrete beams rehabilitated with near surface mounted carbon fiber reinforced polymer reinforcement. Structural Concrete, 2020, 21(2): 533-547.
[8] Ahmed H. Abdel-Kareem. Punching Strengthening of Concrete Slab-column Connections Using Near Surface Mounted (NSM) Carbon Fiber Reinforced Polymer (CFRP) Bars. Journal of Engineering Research and Reports, 2020, 1-14.
[9] Tony Martin et al. Arching in concrete slabs strengthened with near surface mounted fibre reinforced polymers. Engineering Structures, 2019, 184:257-277.
[10] Laraba et al. Experimental evaluation of damaged rectangular reinforced concrete beams repaired with near surface mounted carbon fibre reinforced polymer. Materials Research Innovations, 2014, 18(sup6): S6-10-S6-13.