Flexural Strength and Behavior of Inverted-T Precast Concrete Beam Reinforced with Modified Smooth CFRP Bars

Sunday, March 24, 2024
8:00 a.m. to 10:00 a.m.
Session 10: Behavior and Design of Prestressed Concrete Structures

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Presented by: John J. Myers, Ph.D., P.E., Missouri S&T
Introduction
Introduction – Research Background

- Disintegration
- Excessive deflection
- Spalling & delamination
- Leakage
- Cracks

Steel reinforcement corrosion leads to serious structural failure
Application of carbon fiber reinforced polymer (CFRP) bars as a flexural reinforcement in the RC structures to overcome the corrosion issues.
Introduction – Problem Statement

Various types of deformed and non-deformed CFRP bars are offered in the industries.

Smooth (non-deformed) CFRP bar is not recommended to be applied as flexural reinforcement (poor bond strength with concrete).

Limited research on smooth CFRP bar contribute to the gap of knowledge.

To improve the bond strength on smooth CFRP bar with new technique.

To apply the modified smooth CFRP bars as flexural reinforcement in precast beam.

Various types of surface treatment of CFRP bars
MAIN OBJECTIVE: To determine the flexural strength and behavior of precast concrete beam reinforced with modified smooth CFRP bars

SPECIFIC OBJECTIVE 1
To ascertain the bond behavior of modified smooth CFRP bars and concrete

SPECIFIC OBJECTIVE 2
To evaluate the flexural responses of inverted-T precast concrete beam reinforced with modified smooth CFRP bars
Literature review
(Achillides & Pilakoutas, 2004; Benmokrane et al., 2002; Hao et al., 2009; Okelo & Yuan, 2005): concern about insufficient bond behaviors of FRP bars in concrete with relatively lower bond strength than steel bars under similar conditions.

In general, bonding mechanism of CFRP bars mainly consists of chemical adhesion, friction and mechanical interlocking.

Bonding mechanism for non-deformed CFRP (smooth) bars, however, only consists of chemical adhesion, frictional resistance. Hence, smooth CFRP bars are not recommended to be utilized as flexural reinforcement unless there are provided with adequate anchoring systems.

In this study, a new anchorage system together with modified surface treatment is proposed to enhance the bond properties of smooth CFRP bars in concrete.
Factors affecting bond strength of CFRP bar in concrete

**Bond strength**
- Surface treatment
  - Deformed bar
  - Non-deformed bar
- Bar diameter
- Embedment length
- Concrete compressive strength
- Modulus of elasticity
- Bar casting position
- Confinement pressure

**Notes:**
- Common variables that have been investigated in literature
- New variables to be investigated in this study

Epoxy-coated, additional anchorage system for smooth CFRP bars
<table>
<thead>
<tr>
<th>RESEARCHER (S)</th>
<th>VARIABLES</th>
<th>METHOD OF TESTING</th>
<th>FINDINGS</th>
</tr>
</thead>
</table>
| Ashour and Habeeb (2008) | Reinforcement ratio              | Flexural test with 3 and 4 point loads. | a) Increase CFRP reinforcement ratio at bottom layer: enhance load capacity and controlling deflection;  
b) **De-bonding of CFRP bars from concrete** was an important issue that needs further investigation. |
| ZY Sun et al. (2012)    | Different reinforcement types (FRPs and steel). | Flexural test with 4 point loads | a) Loading process (FRP) divided into 3 stages: elastic stage before cracking, service stage after cracking and stage after the rupture of FRP; 
b) **Diameter of FRP influences bonding behavior** of FRP bar to concrete. |
| Lin & Zhang (2013)      | Bar types and surface treatment: a) smooth surface of CFRP and GFRP bars; b) spiral wrapped of BFRP bars. | Flexural test with 4 point loads | a) **Poor bonding between the bar with smooth surface and concrete**: CFRP RC beams show large increases in deflection and very low in load bearing capacities;  
b) Bond–slip is proven to exert great influence on flexural behaviour of FRP RC beams; 
c) **Very poor structural performance and bond condition** are observed on CFRP RC beam with smooth bar surface. |
<table>
<thead>
<tr>
<th>RESEARCHER (S)</th>
<th>VARIABLES</th>
<th>METHOD OF TESTING</th>
<th>FINDINGS</th>
</tr>
</thead>
</table>
| Eugenijus Gudonis et al. (2013) | Structural applications using CFRP bars | Paper review | Main attention should be paid to the following factors for designing FRP RC structures:  
a) Proper selection of FRP material under severe environmental conditions; and,  
b) Bond properties as the governing criteria for deformational analysis. |
| Suzan A.A. Mustafa et al. (2017) | RC beams reinforced with different reinforcement types (FRPs and steel). | Simulation on flexural test using finite element software | a) Replacing steel bars by CFRP bars in RC beam shows 1.32 higher than ultimate capacity of the conventional beams;  
b) Higher FRP reinforcement ratio: Less rate in increasing ultimate moment capacity. |
| Ahmed et al. (2020) | a) Reinforcement ratio;  
b) Concrete compressive strength (20, 35 & 50 MPa);  
c) Concrete types (GPC & OPC) | Flexural test with 4 point loads | a) 4 different types of failure observed: (1) Tension failure, (2) tension–compression failure, (3) compression failure and (4) debonding failure;  
b) Reinforcement ratio: Beam stiffness (beams with low reinforcement ratio recorded significant deflection);  
c) Compressive strength: Significant effect on the first crack, crack width and deflection; |
Factors affecting the aspects of behavior of RC beams reinforced with CFRP bars

- **Flexural performances**
  - Surface treatment
    - Deformed bar
    - Non-deformed bar
  - Reinforcement ratio
  - Strain behaviour
  - Concrete compressive strength
  - Deflections and cracks (width, spacing & numbers)

**Notes:**
- Common variables that have been investigated in literatures
- New variables to be investigated in this study

Epoxy-coated, additional anchorage system for smooth CFRP bars
Throughout the literature review, it can be observed that:

a) Bond strength between CFRP bars and concrete:
   1. The poorest bond performance with concrete: smooth CFRP bar;
   2. Smooth CFRP bars are not recommended to be applied in structural applications;
   3. New technique need to be investigated and documented in order to enhance the bond strength.

b) CFRP reinforcement in RC beams
   1. Non-rectangular beams have not been tested in the literatures.
   2. CFRP RC beam experiences 4 different types of failure modes: (1) Tension failure for under-reinforced beam; (2) Tension-compression; (3) Compression failure for over-reinforced beam; (4) De-bond failure of CFRP from concrete.
   3. Researchers were concerning with the de-bond failure of CFRP from concrete as this failure is sudden and catastrophic.
   4. Over-reinforced limit state is more preferable in designing the CFRP RC beams.

In this study, precast concrete beams are designed as under-reinforced limit state. The bond performance of modified smooth CFRP bars are vital to avoid any de-bond failure of CFRP bars with concrete. The tensile strength of CFRP bars will be fully utilized as the precast beams are fail by tension failure.
Materials and methods
## Materials and methods

<table>
<thead>
<tr>
<th>STAGE</th>
<th>VARIABLE</th>
<th>METHODS OF TESTING</th>
<th>NUMBERS OF SPECIMEN</th>
<th>CODE OF PRACTICE</th>
</tr>
</thead>
</table>
| Stage 1 | Bonding strength between CFRP bars and concrete                        | Pull-out test using 150 x 150 150 mm cube.                                         | 21 specimens         | 1. ACI 440.3R-12  
           |                                                           |                                                                                     |                      | 2. CSA S806-12   |
| Stage 2 | Flexural performances of precast concrete reinforced with modified smooth CFRP bars | Flexural test with 4 point loads:  
           | Full-scale of 9 sets precast inverted T-shaped beam specimens with size *400 mm x  
           | 600 mm x 5000 mm (according to the JKR IBS Catalogue Version 2:2020)               | 9 beam specimens     | ACI 440.1R-15        |
## Pull-out test details

<table>
<thead>
<tr>
<th>Set*</th>
<th>Notation</th>
<th>Surface Treatment</th>
<th>Concrete Cover (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Smooth (S)</td>
<td>1 mm Sikadur-30 Coated (EC)</td>
</tr>
<tr>
<td>1</td>
<td>C1-S-C</td>
<td>✓</td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td>C2-EC-C</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>C3-EC-E</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>C4-DE-C</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5</td>
<td>C5-DE-E</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>6</td>
<td>C6-AA-C</td>
<td>X</td>
<td>✓</td>
</tr>
<tr>
<td>7</td>
<td>C7-AA-E</td>
<td>X</td>
<td>✓</td>
</tr>
</tbody>
</table>

Note: * Each set encompass of three identical specimens.

Specimen notations: 1) C1 – represents specimen numbering; 2) S – smooth (no treatment) surface; 3) EC – epoxy coated (average of 1 mm thickness); 4) DE – deep embedment; 5) AA – Additional anchorage by using aluminum tube; 6) C – centric position; 7) EC – eccentric position.
CFRP bars: smooth bar and coated with Sikadur-30 (average of 1 mm thickness)

CFRP bars: coated with Sikadur-30 (average of 1 mm thickness) and additional anchorage

Aluminum tube = 6 mm (thickness), 25.4 mm (outer diameter), 30 mm (length)

Casting works

Specimens curing

Pullout test

CFRP bars: deep embedment
Pull-out test details

Pullout test set up in the laboratory

Schematic diagram
### Flexural Test Details

<table>
<thead>
<tr>
<th>Beam#</th>
<th>Beam size</th>
<th>Top reinforcement</th>
<th>Bottom reinforcement</th>
<th>Links</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Beam size</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>W (mm)</td>
<td>W_{ub} (mm)</td>
<td>H_T (mm)</td>
<td>H_C (mm)</td>
</tr>
<tr>
<td>BT-400600-4ST</td>
<td>400 200 600 500 400</td>
<td>4500</td>
<td>2H12</td>
<td>2H12</td>
</tr>
<tr>
<td>BT-400600-4CFRP</td>
<td>400 200 600 500 400</td>
<td>4500</td>
<td>2H12</td>
<td>2H12</td>
</tr>
<tr>
<td>BT-400600-6CFRP</td>
<td>400 200 600 500 400</td>
<td>4500</td>
<td>2H12</td>
<td>2H12</td>
</tr>
</tbody>
</table>

Notes: * - Each set encompass of three identical specimens.

# - Average compressive strength for each beam at 28-days = 42.5 MPa

Specimen notations:
1) BT – Inverted-T beam;
2) 400600 – beam’s width and depth;
3) 4ST – 4 steel bars reinforcement;
4) 4CFRP – 4 CFRP bars reinforcement;
5) 6CFRP – 6 CFRP bars reinforcement.
Inverted-T precast beam

ELEVATION OF PRECAST BEAM

SECTION 1-1
Inverted-T precast beam

Aluminum tubes at both ends:
- 6 mm (thickness),
- 25.4 mm (outer diameter),
- 450 mm (length)

CFRP bars: coated with Sikadur-30 (average of 1 mm thickness) and installed with additional anchorage (aluminum tube)

The reinforcement of inverted-T precast beams
Inverted-T precast beam

Precast beam ready to concrete

Concreting works
Inverted-T precast beam

Four points flexural test set up in the laboratory

Schematic diagram
Results and Discussions
## Pull-out test results

<table>
<thead>
<tr>
<th>Notation</th>
<th>Surface Type</th>
<th>$f_c$ (MPa)</th>
<th>$\sqrt{f_c}$ (MPa)</th>
<th>Bonded Length, $L_d$ (mm)</th>
<th>Diameter, $d_b$ (mm)</th>
<th>Bond Strength, $\tau$ (MPa)*</th>
<th>Normalised Bond Strength, $\tau/\sqrt{f_c}$ (MPa$^{0.5}$)*</th>
<th>Loaded-end Slip, $s_m$ (mm)*</th>
<th>Failure Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1-S-C</td>
<td>Smooth</td>
<td>48.22</td>
<td>6.94</td>
<td>150</td>
<td>8</td>
<td>0.51</td>
<td>0.07</td>
<td>0.11</td>
<td>Bar pulled-out</td>
</tr>
<tr>
<td>C2-EC-C</td>
<td>Epoxy coated</td>
<td>48.22</td>
<td>6.94</td>
<td>150</td>
<td>8</td>
<td>5.22</td>
<td>0.75</td>
<td>2.54</td>
<td>Bar pulled-out</td>
</tr>
<tr>
<td>C3-EC-E</td>
<td>Epoxy coated</td>
<td>48.22</td>
<td>6.94</td>
<td>150</td>
<td>8</td>
<td>4.93</td>
<td>0.71</td>
<td>2.16</td>
<td>Bar pulled-out</td>
</tr>
<tr>
<td>C4-DE-C</td>
<td>Deep embedment</td>
<td>42.30</td>
<td>6.50</td>
<td>150</td>
<td>8</td>
<td>11.11</td>
<td>1.71</td>
<td>4.24</td>
<td>Bar pulled-out</td>
</tr>
<tr>
<td>C5-DE-E</td>
<td>Deep embedment</td>
<td>42.30</td>
<td>6.50</td>
<td>150</td>
<td>8</td>
<td>10.17</td>
<td>1.56</td>
<td>3.84</td>
<td>Bar pulled-out</td>
</tr>
<tr>
<td>C6-AA-C</td>
<td>Epoxy coated + AA</td>
<td>42.30</td>
<td>6.50</td>
<td>150</td>
<td>8</td>
<td>12.27</td>
<td>1.89</td>
<td>2.21</td>
<td>Bar pulled-out</td>
</tr>
<tr>
<td>C7-AA-E</td>
<td>Epoxy coated + AA</td>
<td>42.30</td>
<td>6.50</td>
<td>150</td>
<td>8</td>
<td>10.47</td>
<td>1.61</td>
<td>1.20</td>
<td>Bar pulled-out</td>
</tr>
</tbody>
</table>

Note: * - The average results are based on three identical specimens.

The average bond strength results of the specimen of C6-AA-C have achieved the minimum requirement of 12 MPa in bond strength for these modified smooth CFRP bars to be applied as flexural reinforcement (Benmokrane et al., 2002).
1) Summary of flexural strength test;
2) Ultimate loads;
3) Cracking moment and flexural moment capacity;
4) Failure mode;
5) Load-deflection behavior;
6) Neutral axis to depth ratio;
7) Cracking pattern and crack width;
8) Strain in concrete and CFRP bars.
<table>
<thead>
<tr>
<th>Group</th>
<th>Beam notation</th>
<th>First crack load, $P_{cr}$ (kN)</th>
<th>Ultimate load, $P_u$ (kN)</th>
<th>Deflection, $\Delta$ at $P_{cr}$ (mm)</th>
<th>$P_{35%}$ (mm)</th>
<th>$P_u$ (mm)</th>
<th>Reinforcement ratio (ACI), $\rho_f (\rho_f/\rho_{fb})$</th>
<th>Mode of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A – 4 steel bars reinforcement</td>
<td>BT-400600-4ST-1</td>
<td>64.87</td>
<td>281.05</td>
<td>2.60</td>
<td>5.08</td>
<td>36.15</td>
<td>0.0038 (0.22)</td>
<td>Tension failure</td>
</tr>
<tr>
<td></td>
<td>BT-400600-4ST-2</td>
<td>70.17</td>
<td>288.37</td>
<td>3.04</td>
<td>6.26</td>
<td>36.03</td>
<td>0.0038 (0.22)</td>
<td>Tension failure</td>
</tr>
<tr>
<td></td>
<td>BT-400600-4ST-3</td>
<td>61.71</td>
<td>304.90</td>
<td>2.71</td>
<td>7.37</td>
<td>33.29</td>
<td>0.0038 (0.22)</td>
<td>Tension failure</td>
</tr>
<tr>
<td>Group B – 4 CFRP bars reinforcement</td>
<td>BT-400600-4CFRP-1</td>
<td>65.25</td>
<td>160.91</td>
<td>1.91</td>
<td>6.28</td>
<td>33.91</td>
<td>0.00093 (0.66)</td>
<td>Tension failure</td>
</tr>
<tr>
<td></td>
<td>BT-400600-4CFRP-2</td>
<td>57.29</td>
<td>188.92</td>
<td>2.56</td>
<td>9.45</td>
<td>44.52</td>
<td>0.00093 (0.66)</td>
<td>Tension failure</td>
</tr>
<tr>
<td></td>
<td>BT-400600-4CFRP-3</td>
<td>58.29</td>
<td>157.37</td>
<td>1.48</td>
<td>10.84</td>
<td>44.19</td>
<td>0.00093 (0.66)</td>
<td>Tension failure</td>
</tr>
<tr>
<td>Group C – 6 CFRP bars reinforcement</td>
<td>BT-400600-6CFRP-1</td>
<td>65.29</td>
<td>233.47</td>
<td>2.02</td>
<td>7.06</td>
<td>45.69</td>
<td>0.00139 (0.99)</td>
<td>Tension failure</td>
</tr>
<tr>
<td></td>
<td>BT-400600-6CFRP-2</td>
<td>65.58</td>
<td>246.85</td>
<td>2.45</td>
<td>7.28</td>
<td>43.87</td>
<td>0.00139 (0.99)</td>
<td>Tension failure</td>
</tr>
<tr>
<td></td>
<td>BT-400600-6CFRP-3</td>
<td>62.59</td>
<td>225.03</td>
<td>1.29</td>
<td>10.55</td>
<td>*</td>
<td>0.00139 (0.99)</td>
<td>Tension failure</td>
</tr>
</tbody>
</table>

Note: * - The LVDT was not working properly towards the end of the test.
Observations:

1) Increase CFRP reinforcement ratio: enhance ultimate load (45% - 55%) and control deflection.
2) Lower modulus of elasticity: Reduce the ultimate load of CFRP precast beams
<table>
<thead>
<tr>
<th>Beam</th>
<th>Experiment (kNm)</th>
<th>Prediction (ACI) (kNm)</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M&lt;sub&gt;cr&lt;/sub&gt;</td>
<td>M&lt;sub&gt;n&lt;/sub&gt;</td>
<td>M&lt;sub&gt;cr&lt;/sub&gt;</td>
</tr>
<tr>
<td>BT-400600-4ST-1</td>
<td>56.8</td>
<td>170.6*</td>
<td>74.4</td>
</tr>
<tr>
<td>BT-400600-4ST-2</td>
<td>61.4</td>
<td>187.9*</td>
<td>74.4</td>
</tr>
<tr>
<td>BT-400600-4ST-3</td>
<td>54.0</td>
<td>188.3*</td>
<td>74.4</td>
</tr>
<tr>
<td>BT-400600-4CFRP-1</td>
<td>57.1</td>
<td>140.8</td>
<td>74.4</td>
</tr>
<tr>
<td>BT-400600-4CFRP-2</td>
<td>50.1</td>
<td>165.3</td>
<td>74.4</td>
</tr>
<tr>
<td>BT-400600-4CFRP-3</td>
<td>51.0</td>
<td>137.7</td>
<td>74.4</td>
</tr>
<tr>
<td>BT-400600-6CFRP-1</td>
<td>57.1</td>
<td>204.3</td>
<td>74.4</td>
</tr>
<tr>
<td>BT-400600-6CFRP-2</td>
<td>57.4</td>
<td>216.0</td>
<td>74.4</td>
</tr>
<tr>
<td>BT-400600-6CFRP-3</td>
<td>54.8</td>
<td>196.9</td>
<td>74.4</td>
</tr>
</tbody>
</table>

Note: *Moment corresponding to steel yielding
Failure mode (BT-400600-4ST beam)

Tensile failure with numerous flexural cracks at pure bending moment region
Failure mode (BT-400600-4CFRP beam)

Tensile failure with several flexural cracks at pure bending moment region
Tensile failure with several flexural cracks at pure bending moment region
Load-deflection behavior (beam-1 series)
Load-deflection behavior (beam-2 series)
Load-deflection behavior (beam-3 series)
Load-deflection behavior (combined all beams)
Load-deflection behavior (BT-400600-6CFRP-1)

1st crack

2nd crack

3rd crack

4th crack

5th crack

6th crack
### Neutral axis to depth ratio and curvature

<table>
<thead>
<tr>
<th>Beam notation</th>
<th>Neutral axis to depth ratio (c/d)</th>
<th>Neutral axis at $M_n$ (c/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1$^{\text{st}}$ crack (before/after)</td>
<td>2$^{\text{nd}}$ crack (before/after)</td>
</tr>
<tr>
<td>BT-400600-4CFRP</td>
<td>0.55/0.24</td>
<td>0.21/0.17</td>
</tr>
<tr>
<td>BT-400600-6CFRP</td>
<td>0.47/0.44</td>
<td>0.41/0.32</td>
</tr>
</tbody>
</table>
## Cracking numbers, spacing and width

<table>
<thead>
<tr>
<th>Beam notation</th>
<th>Number of cracks</th>
<th>Average crack spacing (mm)</th>
<th>Average crack width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT-400600-4ST-1</td>
<td>11</td>
<td>260</td>
<td>2.0</td>
</tr>
<tr>
<td>BT-400600-4ST-2</td>
<td>12</td>
<td>263</td>
<td>2.3</td>
</tr>
<tr>
<td>BT-400600-4ST-3</td>
<td>13</td>
<td>255</td>
<td>2.5</td>
</tr>
</tbody>
</table>

BT-400600-4ST-1
# Cracking numbers, spacing and width

<table>
<thead>
<tr>
<th>Beam notation</th>
<th>Number of cracks</th>
<th>Average crack spacing (mm)</th>
<th>Average crack width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT-400600-4CFRP-1</td>
<td>3</td>
<td>1200</td>
<td>14.5</td>
</tr>
<tr>
<td>BT-400600-4CFRP-2</td>
<td>2</td>
<td>1100</td>
<td>14.0</td>
</tr>
<tr>
<td>BT-400600-4CFRP-3</td>
<td>3</td>
<td>1000</td>
<td>16.0</td>
</tr>
</tbody>
</table>

![Diagram showing cracking pattern for BT-400600-4CFRP-1]
<table>
<thead>
<tr>
<th>Beam notation</th>
<th>Number of cracks</th>
<th>Average crack spacing (mm)</th>
<th>Average crack width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT-400600-6CFRP-1</td>
<td>6</td>
<td>670</td>
<td>7.06</td>
</tr>
<tr>
<td>BT-400600-6CFRP-2</td>
<td>7</td>
<td>590</td>
<td>10.2</td>
</tr>
<tr>
<td>BT-400600-6CFRP-3</td>
<td>5</td>
<td>710</td>
<td>9.0</td>
</tr>
</tbody>
</table>

**Cracking numbers, spacing and width**

![Crack diagram](BT-400600-6CFRP-1)
Strain in concrete and CFRP bars (beam-1 series)
Conclusions

✓ Prior to 1\textsuperscript{st} crack: CFRP precast beams are stiffer than steel precast beams;
✓ Cracking load: All beams have recorded nearly the same load;
✓ At cracking load:
  a) CFRP precast beams have exhibited sudden drop. The crack numbers can be easily identified from the graph (refer to load-deflection curve for the beam BT-400600-6CFRP-1; 
  b) The sudden drop has negatively affected the beam stiffness, which increases the deflection, and the neutral axis moves deeply into the compression zone.
✓ Deflection:
  a) CFRP reinforced beams deflected more than steel reinforced beams after cracking.
  b) However, after steel yielded, deflection rate in steel reinforced beams are more than CFRP specimens;
✓ Reinforcement ratio: Precast beam reinforced with 6 CFRP bars recorded lower deflection as compared to the beams reinforced with 4 CFRP bars;
✓ Failure mode: No de-bond failure between CFRP bars and concrete. Hence, it is proven that this type of surface modification provide sufficient bond and anchorage so that smooth CFRP bars can be applied as flexural reinforcement;
✓ Compressive strength: Higher concrete strength potentially increase the first cracking load.
THANK YOU