Sustainable MBC Bonder to Eliminate Epoxies during Retrofit

Vasudeva Upadhyaya Raghavendra
School of Engineering & Technology
Central Queensland University
Rockhampton, Australia
Introduction

• Damages to concrete structures are inevitable
• Causes may be natural (weathering, earthquakes, corrosion, etc.) or man-made (explosion, design error, increase in service loads, etc.)
• Damage results in cracks, loss of strength, structural failure, etc.

Chemical attack in sewers
Corrosion in reinforcing steel
Honeycomb due to improper filling
Spalling in bridge decks
Retrofitting

- A structural rehabilitation process, where the damaged components are strengthened to achieve the desired degree of safety operational efficiency of the structure

- Some commonly used retrofitting techniques
  - Grouting or Guniting
  - Span shortening
  - External post-tensioning
  - Bonded steel elements
  - FRP retrofit

- Fibre Reinforced Polymer (FRP) retrofit involves applying a coat of binder material over the damaged portion and wrap it with fibrous sheets
FRP Strengthening

• FRP is a composite material consisting of high tensile-strength fibre strands woven together. The strength, durability of FRP sheets are exceptional.

• FRPs are bonded to the concrete surface using an epoxy resin.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (kg/m³)</th>
<th>Tensile Strength (MPa)</th>
<th>Elastic Modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-glass</td>
<td>2.55</td>
<td>2000</td>
<td>80</td>
</tr>
<tr>
<td>Alumina</td>
<td>3.28</td>
<td>1950</td>
<td>297</td>
</tr>
<tr>
<td>Carbon</td>
<td>2</td>
<td>2900</td>
<td>525</td>
</tr>
<tr>
<td>Kevlar29</td>
<td>1.44</td>
<td>2850</td>
<td>64</td>
</tr>
</tbody>
</table>
**FRP–Concrete Bonding**

**Epoxy resin** is commonly used for bonding purpose

- The resin and hardener are mixed in proportion of 100 : 35 by weight and mixed continuously for 5 minutes to have a uniform mixture.
- Significant health impacts for people working or living with them.

**Mineral Based Composites (MBC) are recent development**

- FRP grids are externally bonded to the concrete surface by replacing part of the cement hydrate binder of conventional mortar.
- This mortar can result in high performance and could be used as a sustainable replacement for epoxy.
Epoxy vs. MBC
In MBC, the traditional epoxy resin will be replaced by a cement mortar containing suitable admixtures like superplasticizers, viscous modifying agents etc.

<table>
<thead>
<tr>
<th>Epoxy Resin</th>
<th>Mineral Based Composites (MBC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditionally used</td>
<td>Innovative and sustainable</td>
</tr>
<tr>
<td>Harmful to work with because of toxic fume emission in high temperatures.</td>
<td>No significant health effects</td>
</tr>
<tr>
<td>Volatile, can harden or evaporate</td>
<td>Non-volatile, readily available</td>
</tr>
<tr>
<td>Cannot be used over wet surfaces</td>
<td>Can be used in all weather conditions</td>
</tr>
<tr>
<td>Low temperature resistance (55-60°C)</td>
<td>High temperature resistance (850°C)</td>
</tr>
<tr>
<td>Vulnerable to freeze-thaw condition</td>
<td>Not affected</td>
</tr>
</tbody>
</table>
MBC Strengthening Technique

• Concrete mix design
  • Grade 30
  • W/C ratio = 0.37

• Compressive test result
  • 14 days – 28.5 MPa
  • 28 days – 38.5 MPa
Experimental Program

• Total of 54 samples were tested

• Configuration of the specimens
  • Control specimen
  • Uncracked specimen with single GFRP wrap
  • Uncracked specimen with double GFRP wrap
  • Partially cracked* specimen with single GFRP wrap
  • Partially cracked* specimen with double GFRP wrap
  • Full failure specimen with single GFRP wrap
  • Full failure specimen with double GFRP wrap

* Partially cracked specimen – preloaded up to 70% of failure load
Casting and Surface Preparation

- Concrete was casted in standard moulds and cured for 28 days.
- After curing, specimen was dried for a day to ensure the surface is free of any moisture.
- Surface was made smooth using a sand paper and all loose particles were removed.
- One coat of epoxy/MBC is applied on the surface of specimens.
- Specimens were wrapped with GFRP sheet having an overlap of 75 mm to avoid failure in overlap region.
- Second layer of epoxy/MBC is to be applied and specimen were allowed to cured for 7 days.
- Later specimens were tested until their failure
Uncracked Specimens with Epoxy

![Graph showing stress-strain relationship for different types of wraps.](image-url)
Pre-cracked Specimens with Epoxy

![Graph showing stress-strain relationship for different specimens with Epoxy.](image-url)
Failed Specimens with Epoxy

Stress [MPa] vs. Strain

- **DD-wrap**
- **1st-DW**
- **FF-DW**
# Test Results – Epoxy Bonding

<table>
<thead>
<tr>
<th>No.</th>
<th>Specimen Description</th>
<th>Maximum Load (kN)</th>
<th>Compressive Strength (MPa)</th>
<th>Strength Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control specimen</td>
<td>431.5</td>
<td>24.4</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Control specimen single wrapping</td>
<td>712.4</td>
<td>40.3</td>
<td>65.1</td>
</tr>
<tr>
<td>3</td>
<td>Control specimen double wrapping</td>
<td>1,148.5</td>
<td>65.0</td>
<td>166.2</td>
</tr>
<tr>
<td>4</td>
<td>First cracked specimen</td>
<td>340.2</td>
<td>19.2</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>First cracked specimen single wrapping</td>
<td>495.3</td>
<td>28.8</td>
<td>48.8</td>
</tr>
<tr>
<td>6</td>
<td>First cracked specimen double wrapping</td>
<td>518.9</td>
<td>32.9</td>
<td>71.0</td>
</tr>
<tr>
<td>7</td>
<td>Full failure specimen</td>
<td>431.5</td>
<td>24.4</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>Full failure specimen single wrapping</td>
<td>454.1</td>
<td>26.4</td>
<td>8.4</td>
</tr>
<tr>
<td>9</td>
<td>Full failure specimen double wrapping</td>
<td>505.4</td>
<td>28.6</td>
<td>15.3</td>
</tr>
</tbody>
</table>
Epoxy Bonded Specimens

- **FIRST CRACK APPEARANCE**
- **FULLY CRACKED SPECIMEN**
- **WRAPPED SPECIMEN**
- **FAILED SPECIMEN**
MBC Admixtures and Mix Details

For one cylinder wrapping

- Cement: 750g
- W/C ratio: 0.38
- Metakaolin: 10% of cement
- Super plasticizer: 3% of cement
- Viscous Modifying Agent: 0.04% of cement
Uncracked Specimens with MBC

![Graph showing stress-strain relationship for uncracked specimens with MBC with different types of wraps: CONTROL, SNG-wrap, and DD-wrap. The graph plots stress in MPa against strain on a scale from 0 to 60 for stress and 0 to 100 for strain.](image-url)
Pre-cracked Specimens with MBC

![Graph showing stress-strain relationship for different specimens: 1st crk-SW, FF-SW, SNG-wrap.](image)

- **1st crk-SW**
- **FF-SW**
- **SNG-wrap**
Failed Specimens with MBC

- DD-wrap
- 1st-DW
- FF-DW

Stress [MPa] vs. Strain
## Test Results – MBC Bonding

<table>
<thead>
<tr>
<th>No</th>
<th>Specimen Description</th>
<th>Maximum Load (kN)</th>
<th>Compressive Strength (MPa)</th>
<th>Strength Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control specimen</td>
<td>422.0</td>
<td>23.9</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Control specimen single wrapping</td>
<td>647.0</td>
<td>36.6</td>
<td>53.3</td>
</tr>
<tr>
<td>3</td>
<td>Control specimen double wrapping</td>
<td>963.5</td>
<td>54.5</td>
<td>128.4</td>
</tr>
<tr>
<td>4</td>
<td>First cracked specimen</td>
<td>324.5</td>
<td>18.4</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>First cracked specimen single wrapping</td>
<td>504.5</td>
<td>28.5</td>
<td>55.5</td>
</tr>
<tr>
<td>6</td>
<td>First cracked specimen double wrapping</td>
<td>554.8</td>
<td>31.4</td>
<td>71.0</td>
</tr>
<tr>
<td>7</td>
<td>Full failure specimen</td>
<td>422.0</td>
<td>23.9</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>Full failure specimen single wrapping</td>
<td>476.4</td>
<td>26.9</td>
<td>12.9</td>
</tr>
<tr>
<td>9</td>
<td>Full failure specimen double wrapping</td>
<td>531.4</td>
<td>30.1</td>
<td>25.9</td>
</tr>
</tbody>
</table>
MBC Bonded Specimens

MBC mortar preparation

Specimen wrapped with MBC binder

Failure region
## Comparison: Epoxy Vs. MBC Binder

<table>
<thead>
<tr>
<th>No</th>
<th>Specimen Description</th>
<th>Strength Increase (%)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Epoxy bonder</td>
<td>MBC bonder</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Control specimen single wrapping</td>
<td>65.1</td>
<td>53.3</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Control specimen double wrapping</td>
<td>166.2</td>
<td>128.4</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>First crack specimen single wrapping</td>
<td>48.8</td>
<td>55.5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>First crack specimen double wrapping</td>
<td>71.0</td>
<td>71.0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Full failure specimen single wrapping</td>
<td>8.4</td>
<td>12.9</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Full failure specimen double wrapping</td>
<td>15.3</td>
<td>26.0</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

• In most cases the MBC performances are comparable with epoxy resins
• Only in the case of control specimens epoxy resins yields a slightly better performance compared with MBC bonder
• By considering other aspects such as health, cost effectiveness and environmental protection MBC bonders proves to be better replacement for epoxy in FRP retrofit.
Thank you....

Q & A