RELIABILITY ASSESSMENT OF BRAIDED FRP REINFORCEMENT FOR CONCRETE STRUCTURES

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Outline

- Background and Motivation
- General Research Idea
- Research Progress
- Results
- Conclusions
Background and Motivation

Deterioration of global infrastructure

Degradation of reinforced concrete structures due to corrosion of steel

affects long-term durability, total service life, structural safety of RC elements

Estimated global cost of corrosion $2.5 trillion
Background and Motivation

Replacement of steel as internal concrete reinforcement by FRP composites

Fibre Reinforced Polymers consist of
- High strength fibres
- Polymer matrices

Advanced properties of FRP
- Corrosion resistance
- High strength-to-weight ratio
- Reduced life-cycle costs

Main disadvantage of FRP ➔ Brittle failure without warning
Background and Motivation

Degradation mechanisms
Moisture, Alkalinity, Temperature, Fatigue

Durability of FRPs strongly dependent on
- Type of fibre & matrix
- Fibre content
- Fibre-matrix interface
- Orientation of fibres

Expected lifetime of reinforced concrete structure

Limited information on FRP long-term durability in civil engineering applications \(\Rightarrow\) Real, in-situ data are needed
Background and Motivation

Manufacture methods of FRP:
- **Pultrusion** → low cost & continuous process
- **Braiding** → additional ductility & increased bond with concrete

Design guidelines for the efficient use of FRPs in construction:
- **ACI-440.1R**
- **CSA-S806-02**
Background and Motivation

Basic principle of braiding:
Interlacing of yarns in a diagonal direction -
Multiaxial Orientation

Braiding Angle:
Affects mechanical properties of braids
Background and Motivation

Sensitivity analysis → How design variables influence the optimisation cost function

Braided FRP reinforcement
Cost factor is related to geometrical & manufacturing parameters like braiding angle, number of layers, elastic modulus.

Design Optimisation through Sensitivity Analysis Methods
General Research Idea

**Aim of the project:**
Design, Development, Optimisation & Performance Evaluation of Basalt Fibre Reinforced Polymer composites, for internal concrete reinforcement, using braiding as a manufacturing technique

**Main goal:**
Explore the potential of braided BFRP reinforcement in infrastructure applications
Research Progress

Manufacturing design & process of braided BFRP preforms

Materials
- Basalt fibres
- PET fibres
- Epoxy resin

<table>
<thead>
<tr>
<th>Material Property</th>
<th>Basalt</th>
<th>PET</th>
<th>Epoxy resin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>2.7</td>
<td>1.39</td>
<td>1.15</td>
</tr>
<tr>
<td>Linear density (TEX)</td>
<td>300/600</td>
<td>97</td>
<td>-</td>
</tr>
<tr>
<td>Yarn diameter (mm)</td>
<td>0.38/0.53</td>
<td>0.3</td>
<td>-</td>
</tr>
<tr>
<td>Elastic modulus (GPa)</td>
<td>87/89</td>
<td>10</td>
<td>2.65</td>
</tr>
</tbody>
</table>
Manufacturing design & process of braided BFRP preforms

Braided BFRP preforms changing braiding parameters (angle, no of layers)

10 different braid configurations:
- 5 mm OD
- 8 mm OD
- 10 mm OD
Results

Laboratory manufactured BFRP preforms & rebars using braiding & vacuum assisted resin infusion technique
Research Progress

Numerical analysis

Classical Lamination Theory (CLT) numerical approach

Evaluation of elastic properties of braided composites

Calculate each layer’s properties & define:

- Thickness
- Poisson’s ratio
- Fibre volume fraction

Estimate the effective longitudinal in-plane modulus $E_{x}^{FRP}$ of BFRP rebars
Results

Direct relation between braiding parameters & rebar’s properties

![Numerically determined elastic moduli using CLT](image)

<table>
<thead>
<tr>
<th>BFRP sample</th>
<th>Ex (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36.64</td>
</tr>
<tr>
<td>2</td>
<td>30.62</td>
</tr>
<tr>
<td>3</td>
<td>34.03</td>
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<tr>
<td>4</td>
<td>33.02</td>
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<tr>
<td>5</td>
<td>43.13</td>
</tr>
<tr>
<td>6</td>
<td>41.54</td>
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<tr>
<td>7</td>
<td>33.98</td>
</tr>
<tr>
<td>8</td>
<td>35.36</td>
</tr>
<tr>
<td>9</td>
<td>43.05</td>
</tr>
<tr>
<td>10</td>
<td>40.96</td>
</tr>
</tbody>
</table>

* OD: Outer diameter (mm); Braid yarns: Basalt (tex), PET Monofilament; Angle (°)
Research Progress

**Sensitivity Analysis**

**Sensitivity analysis** on parameters affecting elastic modulus of braided rebars

- Evaluations of fundamental processing parameters: TEX, Material modulus, Poisson’s ratio, Braiding angle
- Influence of fibre & epoxy properties: 10% coefficient of variation
- Monte Carlo approach using CLT analysis
Results

The effect of braiding process is to reduce the variation arising from the material input properties.
Conclusions

- Direct relation between braiding parameters & rebar’s properties.
- Pultruded FRP reinforcement Variation in input properties is directly reflected in rebar’s properties
  Braided FRP More complex situation due to interaction between the layers
- Further development of sensitivity analysis for braided BFRP rebars based on CLT numerical approach, using PSOM.
- Include braiding angle parameter, cost function & a heuristic approach for high quality designs.
THANK YOU!

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Training in Reducing Uncertainty in Structural Safety 2015 - 2018

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