Mechanical Performance of Curved FRP Rebars

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Outlines

- Introduction
- Performance of Bent FRP’s
- Experimental Programme/Results
- Analytical study
- Conclusions
Introduction

• End anchorages

• Element connection

• Shear reinforcement
Introduction

Standardised shapes (BS 8666)

R ≥ 2d
Cold Bent FRP’s

Maximum strain induced in cold bent bars (R/d=2)

Typical range of strain for FRP products
Pre-bent FRP’s

• Thermosetting FRP’s: can only be pre-bent at the factory

• Thermoplastic FRP’s: could offer a valid solution for on-site bending of reinforcement
Performance of Bent FRP’s

The tensile strength of FRP bars can be largely reduced when subjected to a biaxial state of stress.

Premature failure at bent portion
Code Provisions

Design equation (JSCE)

\[ f_{fb} = \left( \alpha \frac{r_b}{d_b} + 0.3 \right) f_{fu} \leq f_{fu} \]

- \( r_b \) is the radius of the bend in the bar
- \( d_b \) is the nominal diameter of the FRP bar
- \( f_{fu} \) is the design strength of a straight portion of the bar
Code Provisions

\[ f_{fb} = \left( \alpha \frac{r_b}{d_b} + 0.3 \right) f_{fu} \leq f_{fu} \]

Bend geometry
- r/t

Composite make-up
- type of fibres
- type of resin
- volume fractions
Experimental Testing Programme

GFRP thermoplastic strip (10x3mm)

<table>
<thead>
<tr>
<th>Properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength (MPa)</td>
<td>720</td>
</tr>
<tr>
<td>Tensile modulus (GPa)</td>
<td>28</td>
</tr>
<tr>
<td>Ultimate strain (%)</td>
<td>1.9</td>
</tr>
<tr>
<td>Glass content (%v/v)</td>
<td>35</td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>1.48</td>
</tr>
</tbody>
</table>
Experimental Testing Programme

Parameters (47 specimens)

- \( R/t \) (2 – 5)
- Embedment length (60mm, 145mm)
- Tail length \( (t/t = 5 – 15) \)
- \( f_{cu} \) (45MPa, 95MPa)
- Surface treatment (smooth, sand coated)

Type 2

Type 3
Experimental Results

Strain distribution in specimens Type 2
Experimental Results

Strain distribution in specimens Type 3
Experimental Results

![Graph showing experimental results for different types of FRP configurations. The graph plots the ratio of applied force to ultimate force (f/fu) against the ratio of FRP thickness to plate thickness (r/t). Different symbols represent different types of FRP configurations: Type 2, SM, N; Type 2, SC, N; Type 2, SM, H; Type 2, SC, H; Type 3, SM, N; Type 3, SM, H. The JSCE line is also plotted for comparison.]
A Macromechanical approach

- Force equilibrium
  \[ \sigma_2 = \sigma_1 \frac{t}{r} \]

- Failure criterion
  \[ \frac{\sigma_1^2}{\sigma_{1,max}^2} - \frac{\sigma_1 \sigma_2}{\sigma_{1,max}^2} + \frac{\sigma_2^2}{\sigma_{2,max}^2} = 1 \]
A Macromechanical approach

• Predictive model

\[
\frac{\sigma_1}{\sigma_{1,\text{max}}} = \frac{1}{\sqrt{1 + \left(\frac{h}{R}\right) + \left(\frac{h}{R}\right)^2}} \cdot \beta^2
\]

• Material testing

• Micromechanics

\[
\sigma_{2,\text{max}} = \frac{1}{k_\sigma} \left( f_{mc} + \sigma_{rm} \right)
\]

\[
\beta = \frac{\sigma_{1,\text{max}}}{\sigma_{2,\text{max}}}
\]
A Macromechanical approach

\[ \beta = 7 \]

\[ \sigma_{2,\text{max}} = 90 \text{ MPa} \]
Model Validation (Yang et al. 2004)

- **Proposed model**
- **JSCE, $\alpha=0.05$**
- **Nakamura et al.**
- **Ueda et al.**

![Graph showing model validation for different models against bend capacity and r/t ratio.](image)
Conclusions

• The capacity of the bent portion is not only a function of its geometry

• Values of r/t > 3-4 guarantee the development of 40% of the ultimate strength

• The macromechanical based model adequately captures strength degradation of bent bars