Bond-to-Concrete Characteristic
of Basalt Fiber Reinforced Polymer Rebars

Presenter:
Tim Schneider

Raphael Kampmann, Tim Schneider, Srichand Telikapalli
Introduction

Overview

• Introduction
• Background
• Research Motivation
• Methodology
• Results and Discussion
• Closing Remarks
Introduction
Introduction

• Evaluation of alternative corrosion resistant reinforcement for concrete

• Most viable solution ⇒ Fiber reinforced polymers (FRP) rebars
Background
Background

Constituent Materials for FRP Rebars

Fibers + Resin = FRP
Background
Basalt fiber production

- Igneous rock
- Processed into continuous fiber
- No additional ingredients
Background

Advantages of basalt FRP in structural engineering

• Compared to steel rebars
  • Lower weight
  • Three times the service life
  • 20% to 30% higher tensile strength
  • 35% to 42% lower modulus of elasticity

• Compared to glass FRP rebars
  • Higher tensile strength and higher modulus of elasticity

• Compared to carbon FRP and aramid FRP rebars
  • Lower price
Research Motivation
Research Motivation

Research significance

• Demand for more resilient structures continuous to increase

• Bond-to-concrete is an important mechanical characteristic of reinforced concrete
  • Guarantees proper stress transfer between rebar and concrete

• Bond-to-concrete performance of BFRP rebars not fully analyzed yet
Research Motivation

Problem statement

• A wide range of products available in market

• Diverse surface enhancements may lead to dissimilar bond-to-concrete behavior
Research Motivation

Research objectives

• Develop more knowledge about the bond-to-concrete performance BFRP rebars

• Integrate BFRP rebars in new design guidelines
Methodology
Methodology

Bond-to-concrete test — Overview BFRP rebars #3

Type-A1

Type-A2

Type-B

Type-C

Type-D (steel)
## Methodology

Bond-to-concrete test — Test matrix

<table>
<thead>
<tr>
<th># 3 Rebar</th>
<th>Surface Treatment</th>
<th>Resin Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type-A1</td>
<td>Sand coating</td>
<td>Epoxy (HE)</td>
</tr>
<tr>
<td>Type-A2</td>
<td>Sand coating</td>
<td>Epoxy (HP)</td>
</tr>
<tr>
<td>Type-B</td>
<td>Helical wraps &amp; sand coating</td>
<td>Epoxy</td>
</tr>
<tr>
<td>Type-C</td>
<td>Sand coating</td>
<td>Vinyl ester</td>
</tr>
<tr>
<td>Type-D¹</td>
<td>Surface lugs</td>
<td>Black steel</td>
</tr>
</tbody>
</table>

¹ Control group (values from manufacturer)
Methodology

Test methods

- Bond-to-concrete strength
  - Pullout tests according to ASTM D7913

- Concrete compressive strength
  - 6x12 Cylinders according to ASTM C39
Methodology

Bond-to-concrete test — Specimen dimensions
Methodology

Bond-to-concrete test — Casting of concrete

BFRP rebar (free end)
Form divider
Formwork (combined mold)
BFRP rebar (loaded end)

Casting direction
Methodology

Bond-to-concrete test — Anchor installation
Methodology

Bond-to-concrete test — Test setup

- Elevation fixture
- Base plate
- BFRP rebar - free end
- Concrete cube
- Lock plates
- Bearing plate
- BFRP rebar - loaded end
- Bearing plate
- Lock plate
- Anchor
- Base plate

Free end LSCT
Concrete cube
Fixture for concrete cube
Loaded end LSCTs
BFRP rebar
Fixture for anchor
Anchor
Result and Discussion
Result and Discussion

Concrete compressive strength — Statistical evaluation

- Mean compressive strength of 51.00 MPa (7400 psi)
- Standard deviation of 1.39 MPa (201 psi)
- Coefficient of variation of less than 2.7%
Result and Discussion

Bond-to-concrete strength — Load-displacement behavior

<table>
<thead>
<tr>
<th>Type</th>
<th>Bond Stress, $\tau$ (MPa)</th>
<th>Slip at Free End (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All results</td>
<td>$\tau_{\text{max}}^{\text{avg}} = 13.22$ MPa</td>
<td></td>
</tr>
<tr>
<td>Type-A1 (sand coated)</td>
<td>$\tau_{\text{max}}^{\text{avg}} = 16.09$ MPa</td>
<td></td>
</tr>
<tr>
<td>Type-B (helically wrapped)</td>
<td>$\tau_{\text{max}}^{\text{avg}} = 26.00$ MPa</td>
<td></td>
</tr>
<tr>
<td>Type-C (sand coated)</td>
<td>$\tau_{\text{max}}^{\text{avg}} = 28.07$ MPa</td>
<td></td>
</tr>
<tr>
<td>Type-D (steel)</td>
<td>$\tau_{\text{max}}^{\text{avg}} = 19.23$ MPa</td>
<td></td>
</tr>
</tbody>
</table>
# Result and Discussion

Bond-to-concrete strength — Statistical evaluation

<table>
<thead>
<tr>
<th>Sample Group</th>
<th>Statistical Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Imperial</td>
</tr>
<tr>
<td></td>
<td>∧ ksi   ∨ ksi μ ksi σ ksi</td>
</tr>
<tr>
<td>Rebar Type</td>
<td>Resin Type</td>
</tr>
<tr>
<td>A</td>
<td>HE</td>
</tr>
<tr>
<td>A</td>
<td>HP</td>
</tr>
<tr>
<td>B</td>
<td>Epoxy</td>
</tr>
<tr>
<td>C</td>
<td>VinylEster</td>
</tr>
<tr>
<td>D</td>
<td>Steel</td>
</tr>
</tbody>
</table>
Result and Discussion

Bond-to-concrete strength — Specimen failure
Result and Discussion

Bond-to-concrete strength — Specimen failure

Loaded-end

Free-end

Type-A1

Type-A2

Type-B

Type-C

Type-D (steel)
Result and Discussion

Bond-to-concrete strength — Analysis & discussion

• Concrete dust was observed for steel rebars only
  • Steel rebars ⇒ Pullout strength limited by concrete properties
  • BFRP rebars ⇒ Pullout strength limited by rebar properties

• Helically wrapped rebars were squeezed through concrete
  • Due to low transverse stiffness

• Delamination of sand coated rebars (without surface deformation)
  • Limited by resin shear strength
Result and Discussion

Bond-to-concrete strength — Analysis & discussion

• Bond behavior measurably affected by two aspects:
  1. Surface enhancement properties
  2. Resin type

• Deformed rebars (helically wrapped) provide additional interlocking
  • Bond performance similar to traditional steel rebars
  • May be preferred due to longevity of bond (e.g.: temperature variations)
Closing Remarks
Closing Remarks

Conclusions

• Steel rebars provided higher bond strength than (sand coated) BFRP rebars

• The pullout failure mechanism differs between BFRP and traditional steel rebars

• Surface enhancements highly influenced the bond-to-concrete behavior and performance

• Resin type impacted bond-to-concrete performance
Closing Remarks

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Closing Remarks

Questions?

Raphael Kampmann
kampmann@eng.famu.fsu.edu

Tim Schneider
tim.schneider@fh-muenster.de