Structural Performance of FRP in Fire

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Steel in Fire Forum
Outline

• FRP and High Temperature
• FRP Material Tests
• Recent Full-Scale Tests on Beams
• Modelling – Different Fire Scenarios
• Design Approaches
Introduction

Deterioration of structures

New construction
- Cost Environment
- FRP

Strengthening Rehabilitation
- Existing Technology
- New technologies
- FRP
- Fire concern
- Use in buildings

- Fire design criteria must be satisfied in buildings
- Little research has been performed to date
Examples of FRP

Unidirectional glass FRP bar

Carbon FRP prestressing tendon

Aramid FRP grid

Glass fibre roving

Carbon fibre roving

High strength fibres in a polymer matrix
Material Tests

- Tensile strength
- FRP to FRP bond
- FRP to concrete bond
- Steady-state temperature tests
- Transient temperature tests
- Tests up to 200 degrees C
Some tensile test results (Tyfo GFRP)

Temperature ($^\circ$C) vs. Normalized Tensile Strength

- $T_g = 75^\circ$C
- $P_R = 0.46$
- $k_m = 0.0882$
- $T_{central} = 47^\circ$C
- $R = 0.95$
- $R^2 = 0.90$
Steady State Proposed Model

\[ S(T) = \frac{S_r}{2} + \frac{S_r}{2} \left\{ \tanh(-w(T - T_c)) \right\} \]

w is 0.018

Strength (kN) vs. Temperature (°C)

- Proposed Model
- 95% confidence interval
- \(S_r\)
- \(T_c\)
- \(T_g\)
- 35°C
Full-Scale Tests
Fire Tests, T-beams

- Span 3.8 m
- FRP materials
  - Sika CarboDur S812
  - SikaWrap Hex103
  - Tyfo CFRP, GFRP
  - MBrace
- Insulation
  - Sikacrete®-213
  - Tyfo VG system
  - Other cementitious system
Figure 3-33 Flames are visible at cracks in the U-wrap location, Beam-B after 1 hour and 53 minutes of fire exposure.
Figure 3-36 T-beams after fire test in the loading frame.
Figure 3-34 Cracks at insulation surface after fire test Beam-B
Beam-B
SikaWrap® Hex 103C
40 mm of Sikacrete®
213F
Numerical Modelling
Heat Transfer

Conduction

\[ \rho c \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) \]
\[ = \frac{\partial}{\partial x} \left( k \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( k \frac{\partial T}{\partial y} \right) \]

Convection

\[ q = h_c (T_c - T_p) \]

Radiation

\[ q = \sigma \varepsilon_f \varepsilon_c (T_f^4 - T_p^4) \]
Heat Transfer FV Model

• Nonlinear Finite Volume code
• Explicit formulation
• 2D
• In MATLAB environment
• Accounts for variation in
  – Thermal properties
  – Moisture content
T-beam Temp. Predictions

- **unexposed surface**
  - Model Prediction
  - Test Data

- **centreline cover of 155 mm**
  - Model Prediction
  - Test Data

- **longitudinal steel**
  - Model Prediction
  - Test Data

- **FRP-concrete interface**
  - Model Prediction
  - Test Data
Structural Model

• Beam theory
  – Bernoulli hypothesis (plane sections remain plane)
  – Iterative solution
  – Includes Transient Creep
Different Fire Scenarios

- Fire I: 0.01 30 0.0
- Fire II: 0.05 30 0.0
- Fire III: 0.10 30 0.0
- Fire IV: 0.10 100 1.0

Temperature (°C) vs Time (hours)

- Fire I
- Fire II
- Fire III
- Fire IV
- ASTM E119
Different Fires (Strength Calculations)

- Fire I
- Fire II
- Fire III
- Fire IV
Different Fire Structural Response

- T-Beam-C

![Graph showing different deflection responses over time for different types of fires and control.]
Design for Fire Safety
Philosophy for Fire-Safety

![Diagram showing the relationship between load, temperature, and time in the context of fire safety. The diagram illustrates the time taken for fire events during the construction, service load, and retrofitted life phases.](https://example.com/diagram.png)
Conceptual design approach

- Fire resistance
- Flame spread
- Protection
- Amount of Strengthening

Protect FRP Itself

Insulation to protect original structure

Flame spread protection

- Fire resistance

Amount of Strengthening
Conceptual Model – Slabs (40 mm clear cover)

CAUTION – very preliminary – Not for use in design!!
Steel Structures?

• Structural steel can also be strengthened with FRP
• Fire performance has not been investigated
• Strategies for fire protection could be similar to that of concrete
  – Role of intumescent paints?
  – Spray-applied insulation

Photos courtesy of Prof. Amir Fam
Conclusions

• All members achieved 4 hour fire ratings
  – FRP reached its glass transition temperature fairly quickly
  – Structural contribution of FRP unknown
  – Insulation provided protection to concrete and steel

• Predictions of numerical models were consistent with experimental observations

• Conceptual design model shows promise
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