Novel Design of Concrete FRP Reinforcement for Fire Resistant Performance

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What is FRP?

- FRP = Fibres + Polymer
- Fibres: Strength
- Polymer: Load transfer
FRP vs. Steel

- Light weight
- High strength
- Corrosion resistance
- Chlorides resistance

Cost £££
Stiffness
Fire performance
Main motivation:

In Europe the annual cost of repair and maintenance of the infrastructure, as a result of problems associated with corrosion, is around £20 billion (Rafi et al, 2011).
Major drawback:

“’The use of FRP reinforcement is not recommended for structures in which fire resistance is essential to maintain structural integrity’” ACI 440.1R-04
Fire Performance!

- Critical temperature
  - Polymer up to 150°C
  - Carbon fibres up to 1000°C

FRP Loops!
Testing programme

Dimensions in mm
Failure mode

Loop

Hooked

Straight
Results

![Graph showing results for 500 MPa Steel](image)
Beam Tests
Beam Tests
Testing Frame:
Failure Modes:

- Short splice FRP Loops
- Straight rebars
- CFRP loops (longer splice)
Results: ambient

![Graph showing load vs. deflection for different materials under ambient conditions. The graph includes lines labeled E1, E2, F1, F2, G1, and G2. The Y-axis represents Load (kN) ranging from 0 to 40, and the X-axis represents Deflection (mm) ranging from 0 to 35. The material represented is 500 MPa Steel.]
FRP Strain
Results (High Temp.):

\[ T_g = 87^\circ C \]
Predicting Fire Performance

Develop length: Nigro et al 2012

\[ \sigma_{i,j+1} = \sigma_{i,j} - \Delta \sigma_{i,j} \]

\[ \Delta \sigma_{i,j} = \tau_{i,j} \cdot (\pi \cdot \phi \cdot \Delta z) \]

\[ s_{i,j+1} = s_{i,j} - \left( \frac{\sigma_{i,j} + \sigma_{i,j+1}}{2 \cdot E} \right) \cdot \Delta z \]
Predicting Fire Performance

Steel Bond-Slip: Yankelevsky. 1985

\[ \tau(x) = \frac{1}{\pi D} \cdot \frac{dT(x)}{dx} \]

\[ \tau(x) = \frac{ED}{4} \cdot \frac{d^2 S(x)}{dx^2} \]

\[ P_i = \frac{\alpha_1 EA}{\sinh (\alpha_1 L)} \left[ -S_i + S_i \cosh (\alpha_1 L) \right] \]

\[ P_j = \frac{\alpha_1 EA}{\sinh (\alpha_1 L)} \left[ S_j \cosh (\alpha_1 L) - S_i \right] \]

\[ \begin{bmatrix} P_i \\ P_j \end{bmatrix} = \begin{bmatrix} k_{11}^1 & k_{12}^1 \\ k_{21}^1 & k_{22}^1 \end{bmatrix} \cdot \begin{bmatrix} S_i \\ S_j \end{bmatrix} \]
Predicting Fire Performance

Slip

ΔZ
Rupture area

\[ \{ P_i \} = \begin{pmatrix} k_{11}^1 & k_{12}^1 \\ k_{21}^1 & k_{22}^1 \end{pmatrix} \cdot \{ S_i \} \]
Analytical models (ambient)
At elevated temperature
Conclusion:

- Significant improvement of fire resistance time
- Failure mode changed from pull-out to rupture
- Potential restrain of cracks opening and formation
- Analytical prediction of bond stress at ambient and elevated temperatures
THANK YOU!