COMPARATIVE PERFORMANCE OF FRP & FRCM SYSTEMS AT ELEVATED TEMPERATURE

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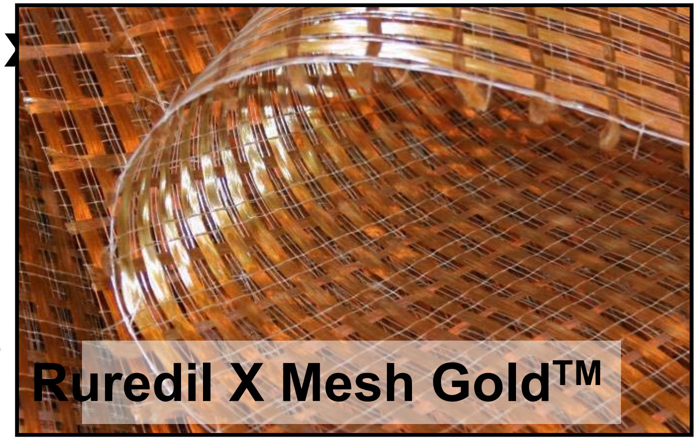
Introduction

- **Externally-Bonded FRP Strengthening Systems**
  - Widely accepted, method of choice, **polymer-based (concerns in fire)**

- **Textile Reinforced Mortar (TRM) Strengthening Systems:**
  - Emerged in last 5-10 years
  - Repairing damaged or deficient **concrete or masonry** (axial, shear, flexure)
  - Open-weave **carbon fibre fabrics** applied using **inorganic mortars**
  - Comparatively **low strength, stiffness, adhesion properties**

- **Fibre Reinforced Cementitious Matri**
  - Emerged in last 5 years
  - Non-woven **PBO fibre grids** applied using **modified inorganic mortars**
  - Repairing **damaged or deficient concrete**
  - **Superior strength, stiffness, adhesion**



Research Motivation

- **Thermal & mechanical performance in fire**
  - A key issue in the application of any structural strengthening system
- **Fire-rated, insulated externally bonded FRP strengthening systems are available**
  - Current **design guidance ignores the FRP during fire (even with insulation)**
  - Ability of FRP strengthening systems to maintain structural effectiveness **under load at high temperature** remains unproven
  - Applications of FRPs are hindered
- **It has been suggested that TRM/FRCM systems may outperform FRP systems during fire or in elevated temperature service environments**

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Background

- **FRCM:**
  - Advantages over externally bonded FRP systems:
    - Installation and aesthetics
    - Breathability
    - **Non-combustibility, zero flame spread**
    - **Mechanical performance at high temperature?**

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- **Current presentation:**
  - Pilot study into comparative performance of FRCM systems
  - Tests at **ambient & elevated temperatures**
  - **Comparison against externally-bonded carbon/epoxy FRP** strengthening systems

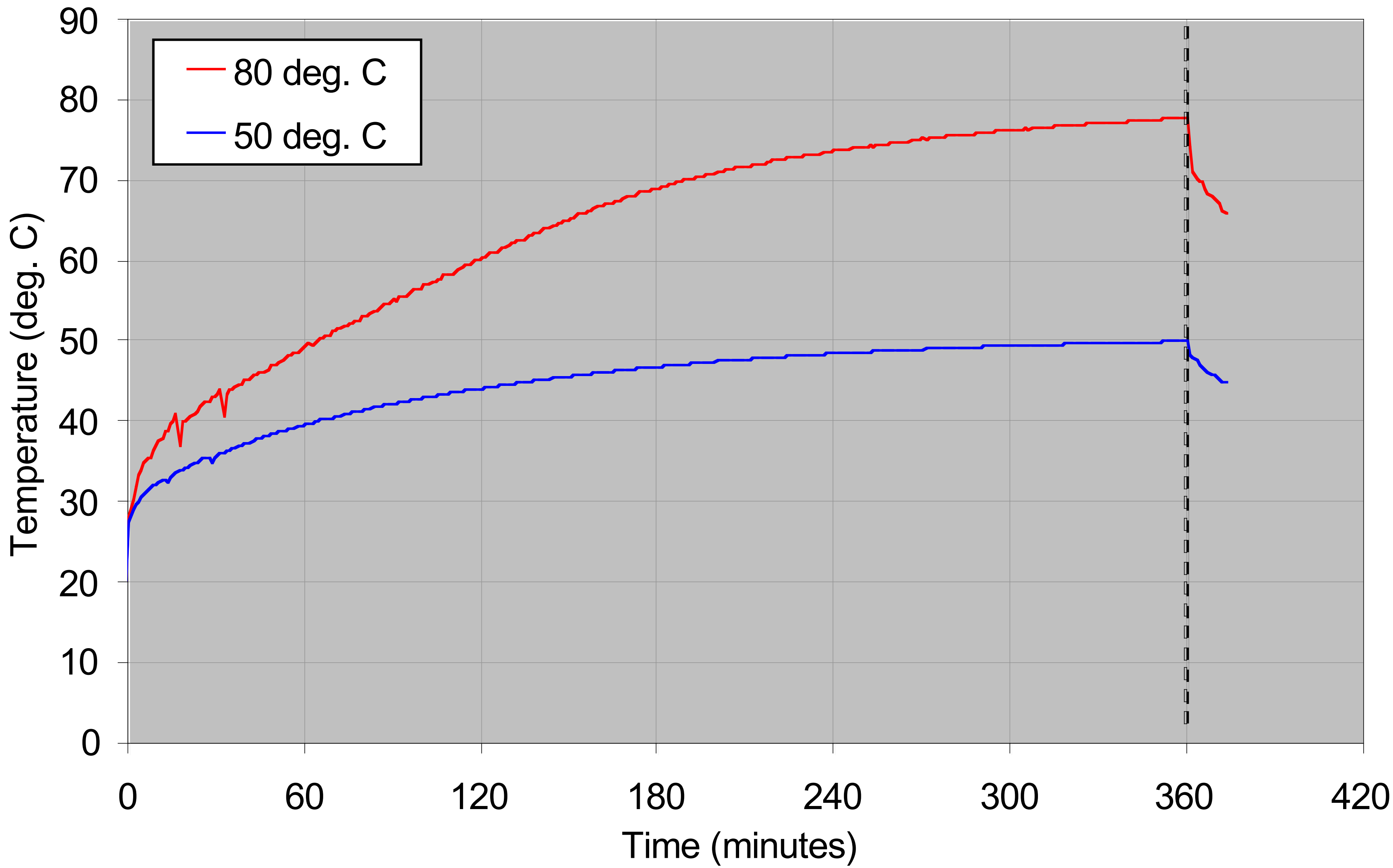
QUESTION: How does FRCM compare with FRP?

OBJECTIVES:

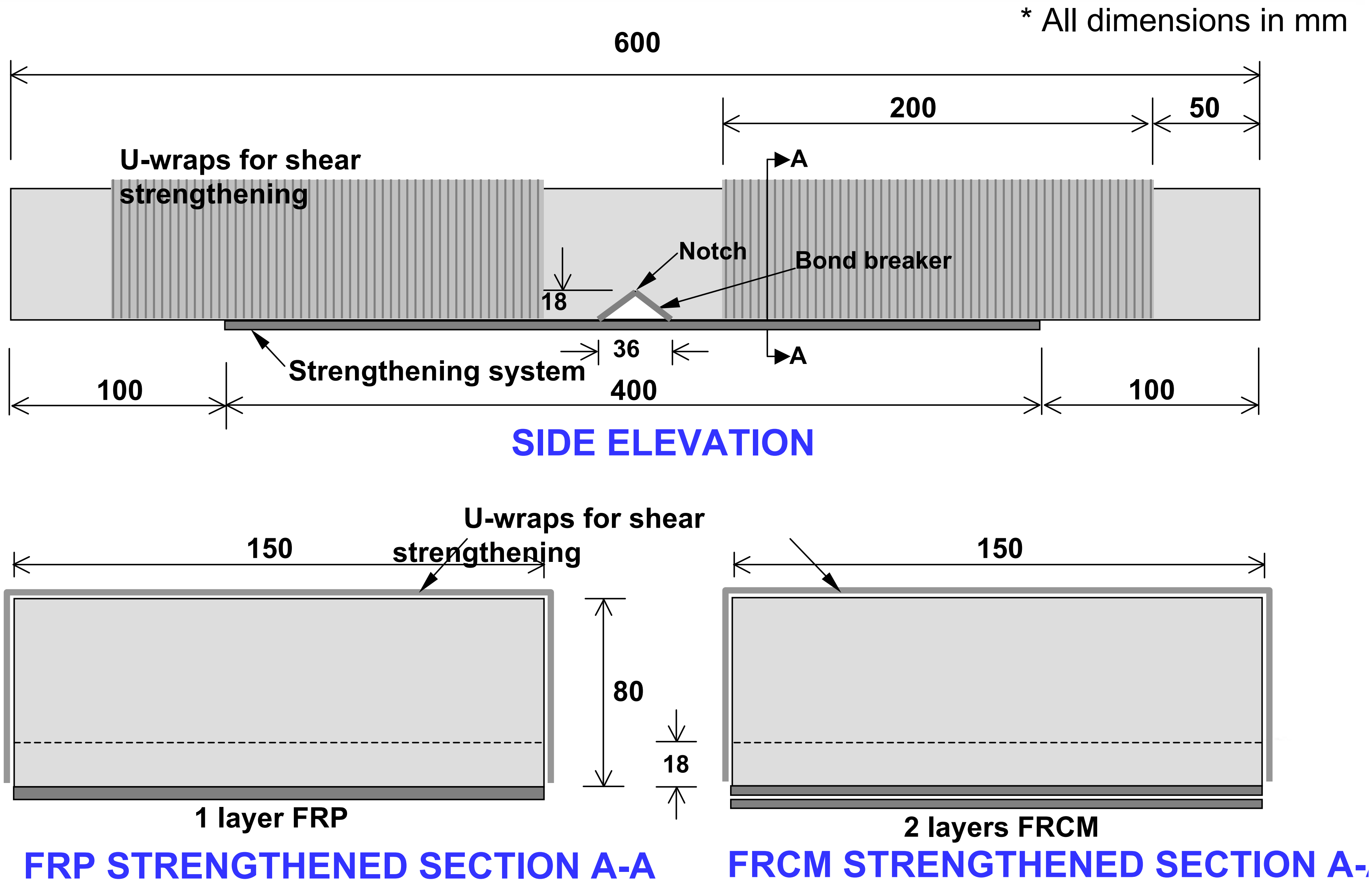
1. Experimentally **investigate the performance of FRCM flexural strengthening systems** for reinforced concrete structures
   - **In comparison with externally-bonded FRP systems**
   - **In bond-critical applications without supplemental anchors**
   - **At temperatures that they might experience if insulated and exposed to a standard fire scenario, or in elevated temperature service environments**

2. Investigate the **hypothesis that FRCM systems may provide superior retention of mechanical properties at elevated temperature** as compared with externally-bonded FRP

Experimental Programme

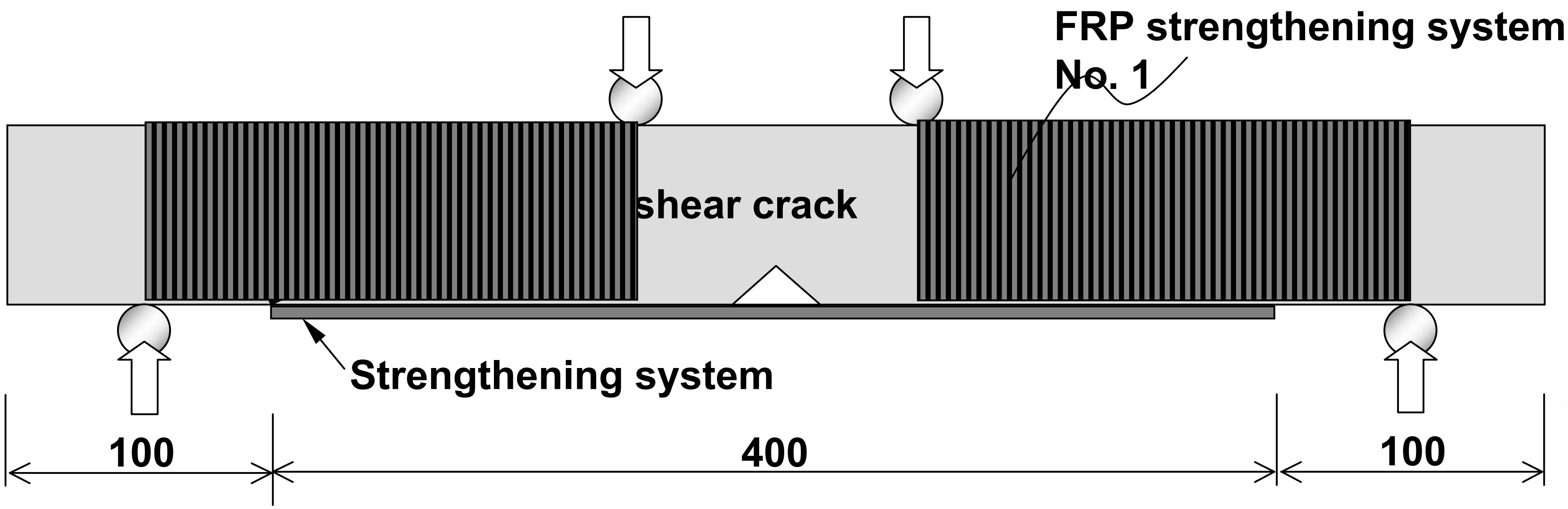


Beam Specimens



Shear Strengthening Scheme

- Pilot tests demonstrated **shear failures**
- Remedial **shear strengthening** was required
  - Inverted U-wraps
  - shear strengthening without supplemental anchorage
  - Does not significantly affect the flexural strengthening

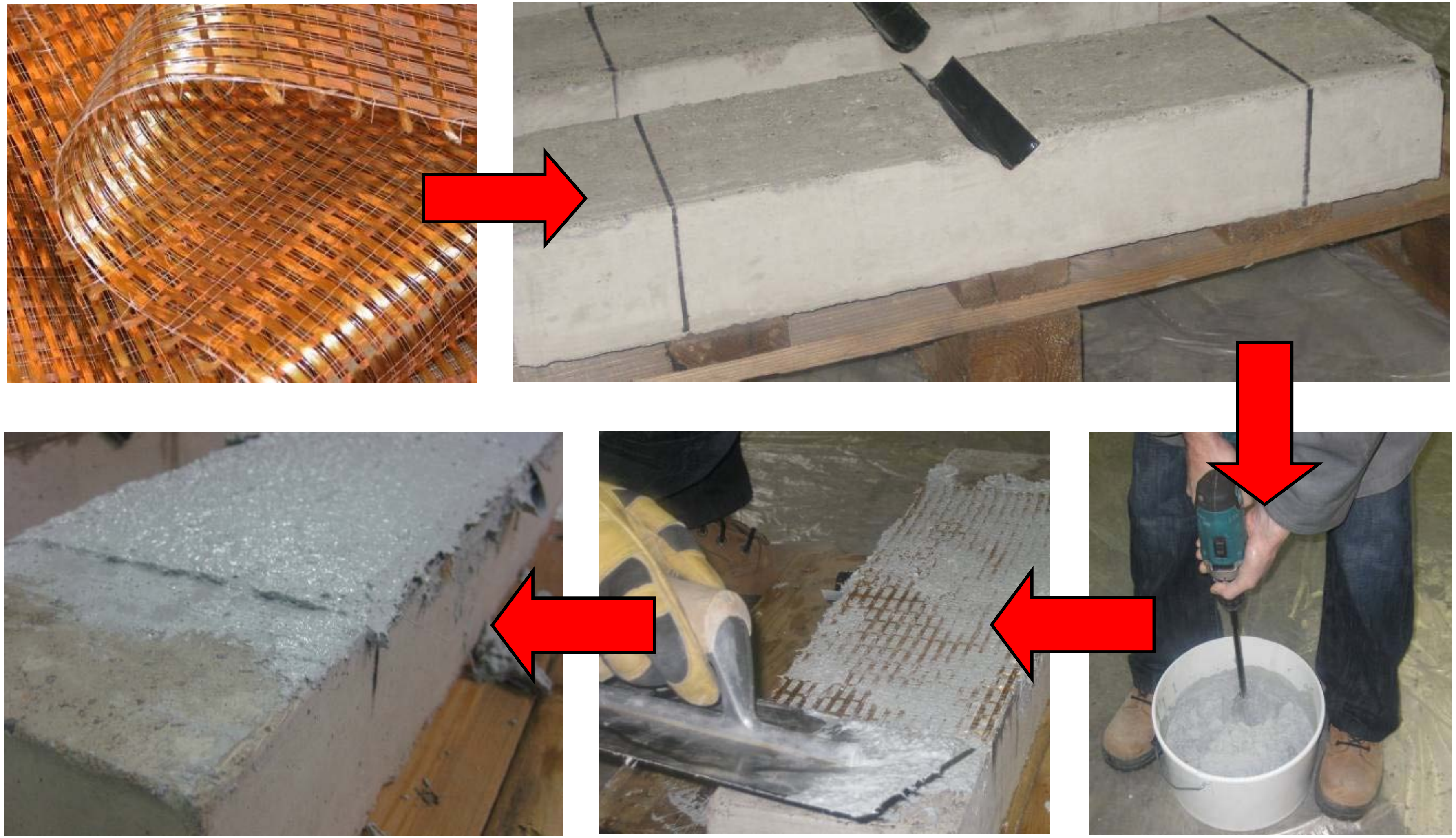


Testing Matrix

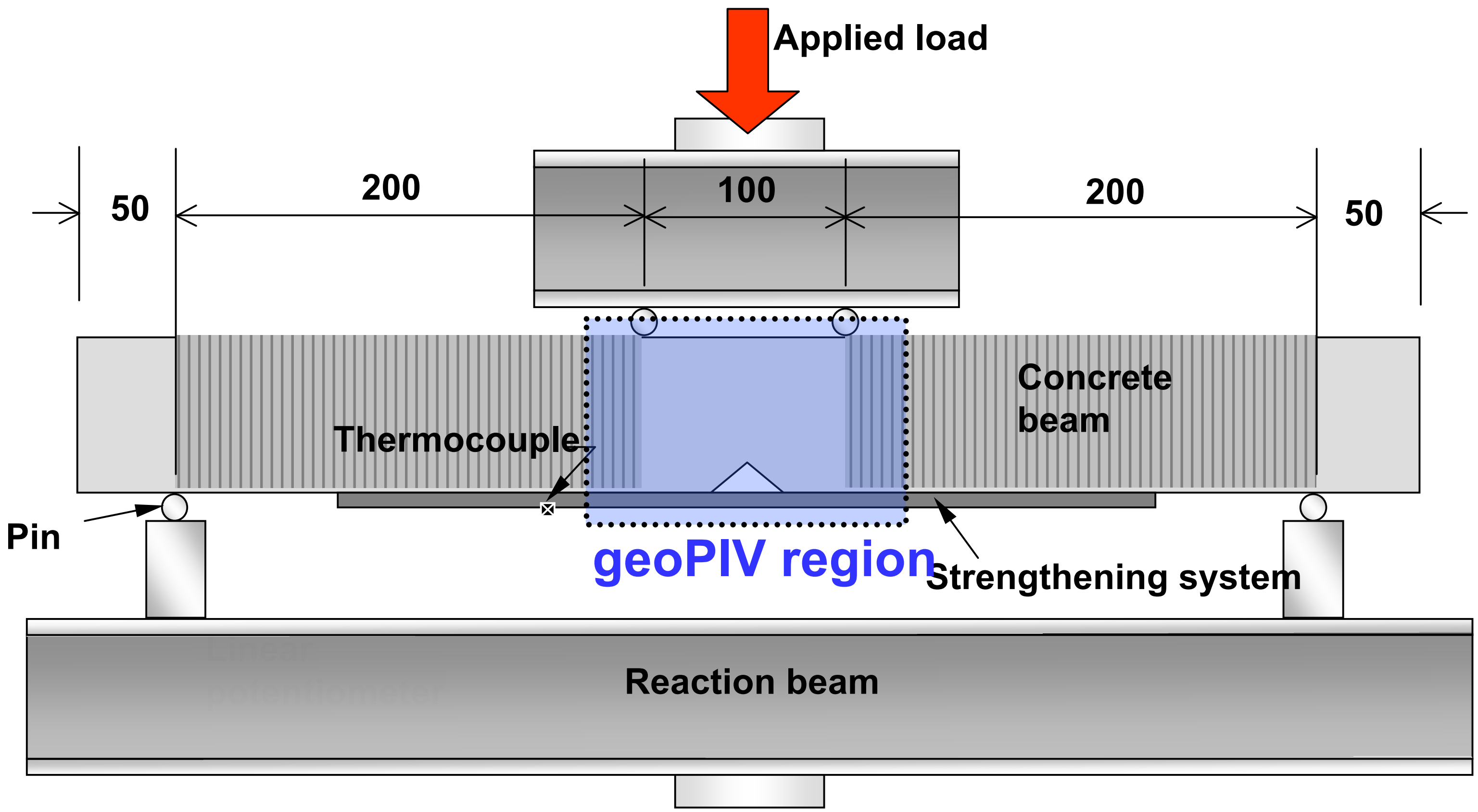
Specimen ID	Primer	Fibre system	Adhesive system	Target test temp. (°C)	Duration of heating (hrs)	No. of beams
PC 20	--	--	--	20	--	3
FRP Nº1 20	Primer Nº1[1]	Carbon fibre[3]	Saturant Nº1[1]			3
FRP Nº2 20	Primer Nº2[2]	Carbon fibre[3]	Saturant Nº2[2]			3
FRCM 20	--	X Mesh Gold	X Mesh M750			3
PC 50	--	--	--	50	6	3
FRP Nº1 50	Primer Nº1[1]	Carbon fibre[3]	Saturant Nº1[1]			3
FRP Nº2 50	Primer Nº2[2]	Carbon fibre[3]	Saturant Nº2[2]			3
FRCM 50	--	X Mesh Gold	X Mesh M750			3
PC 80	--	--	--	80	6	3
FRP Nº1 80	Primer Nº1[1]	Carbon fibre[3]	Saturant Nº1[1]			3
FRP Nº2 80	Primer Nº2[2]	Carbon fibre[3]	Saturant Nº2[2]			3
FRCM 80	--	X Mesh Gold	X Mesh M750			3

[1] Commercially available epoxy primer and saturant system currently selling in Italy.
[2] Commercially available epoxy primer and saturant system currently selling globally.
[3] Commercially available unidirectional carbon fibre fabric currently selling in Italy.

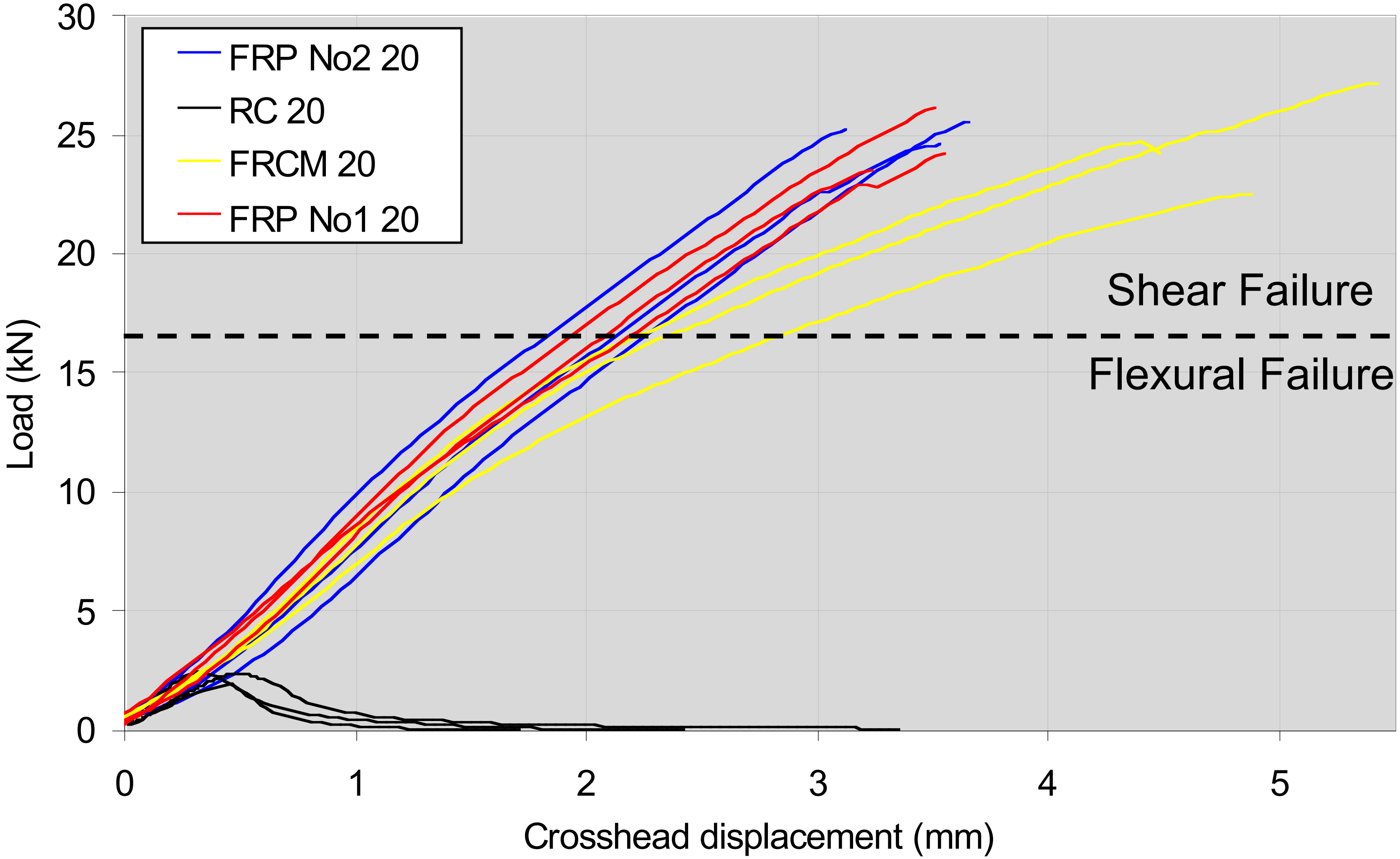
FRCM Installation



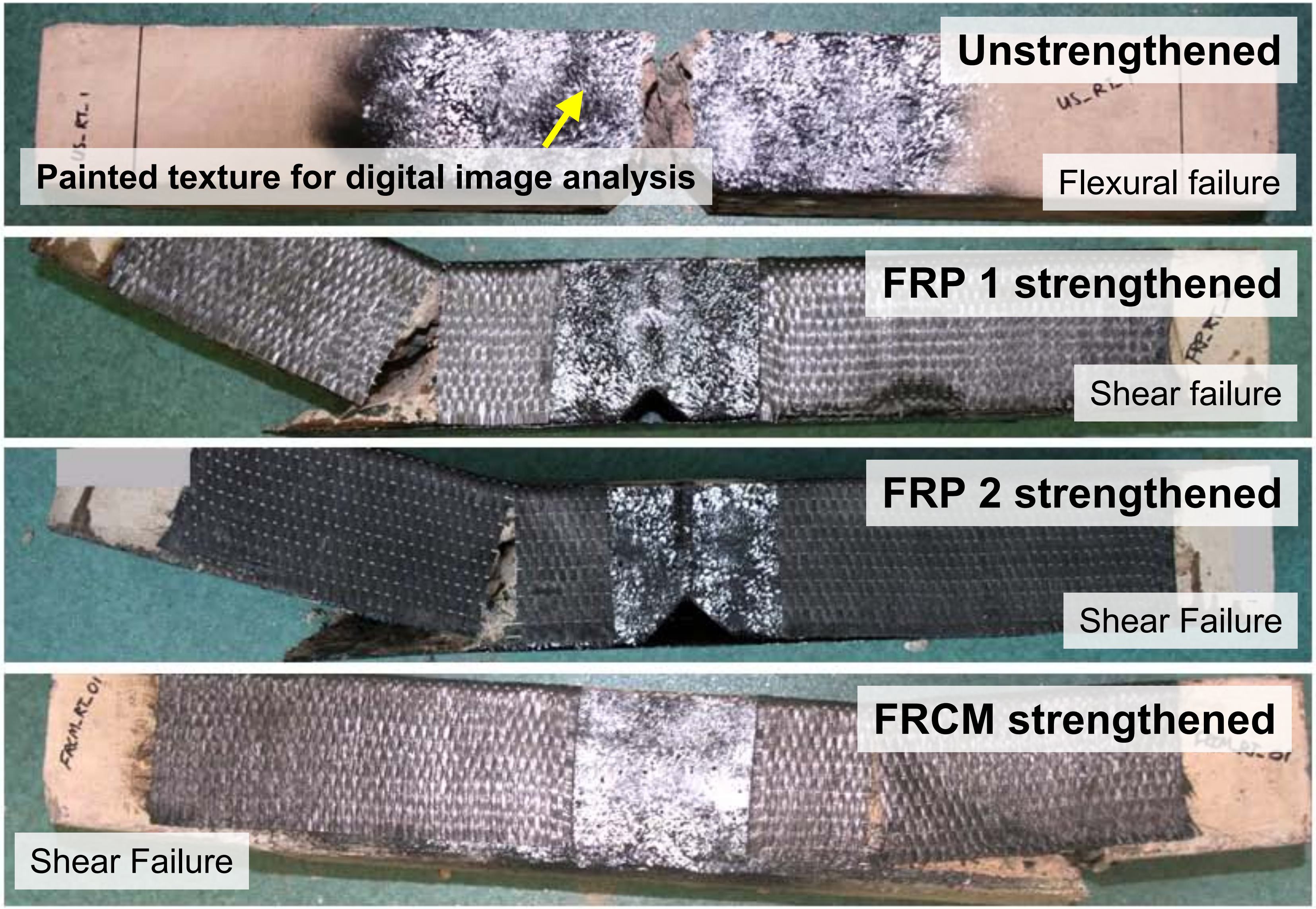
Testing Methodology



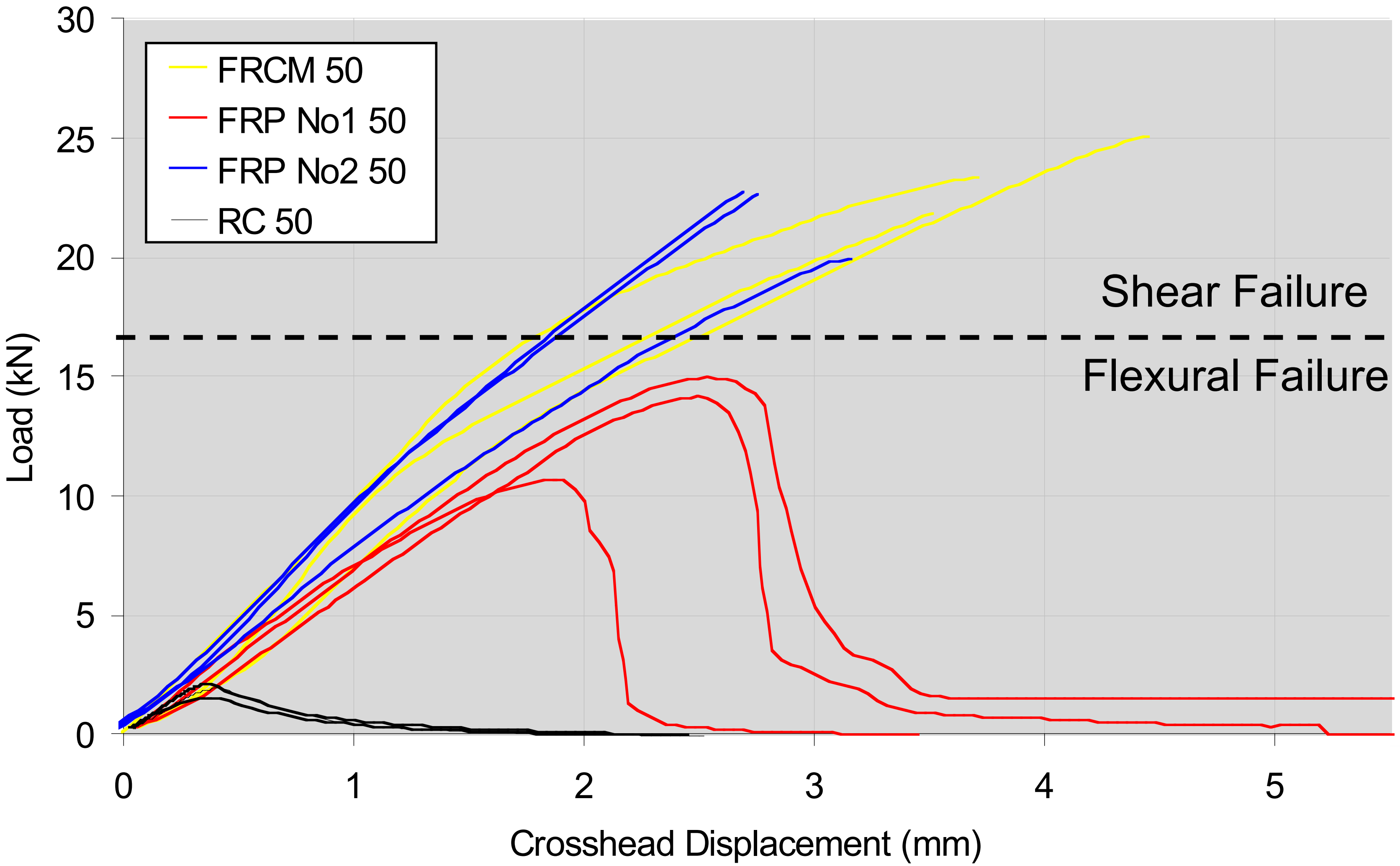
Load vs. Displacement: Tests @ 20°C



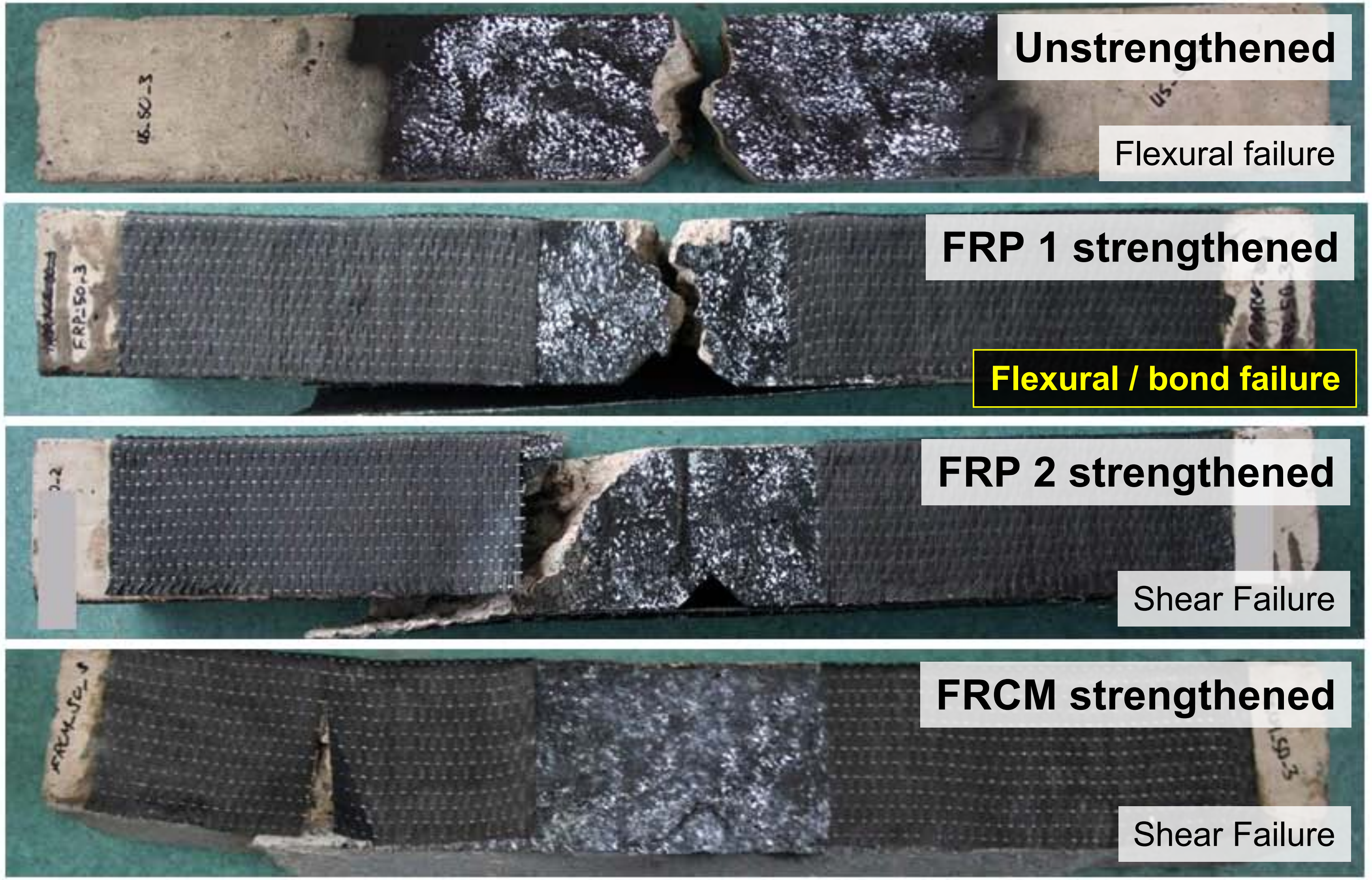
Failure Modes: 20°C



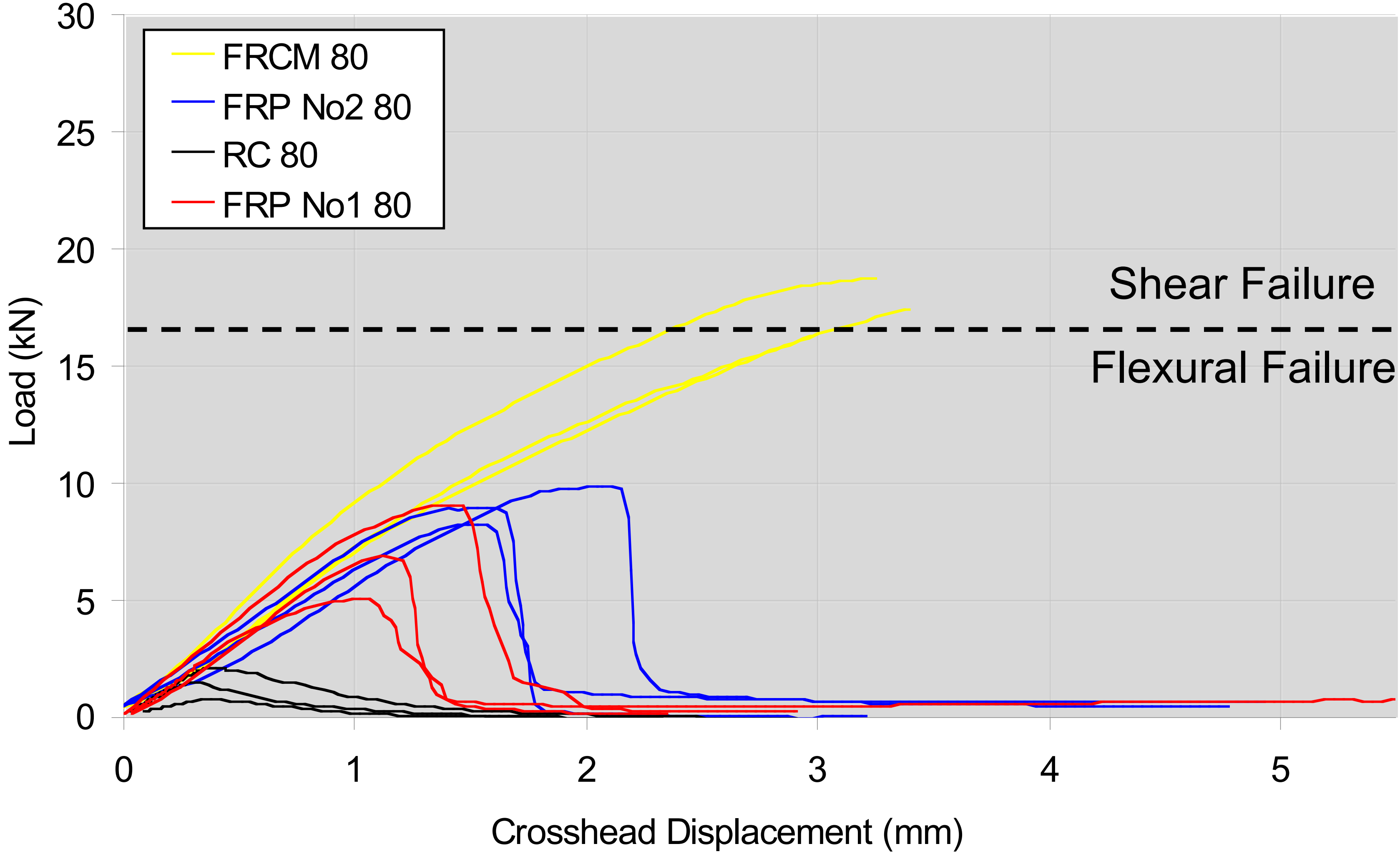
Load vs. Displacement: Tests @ 50°C



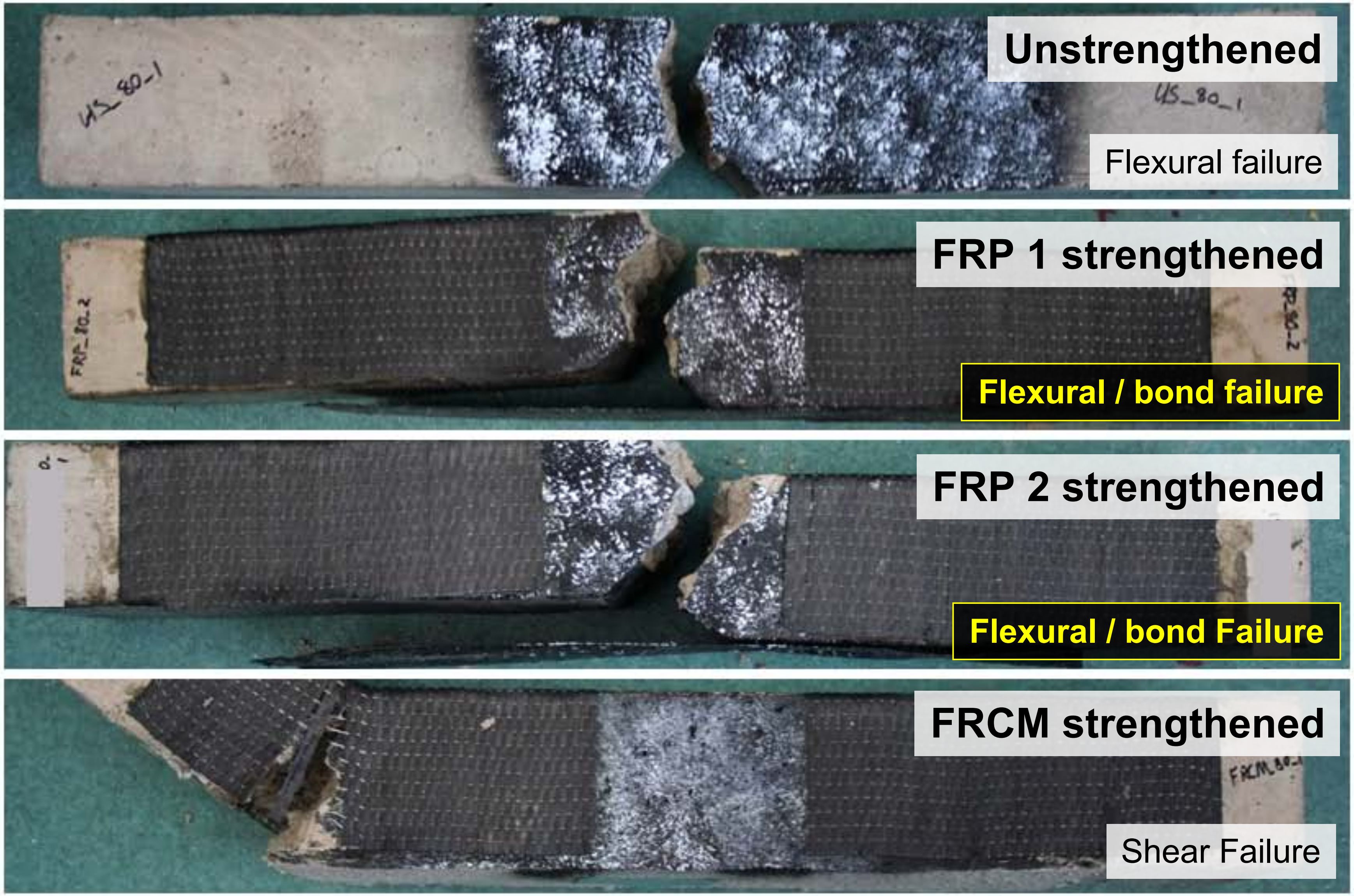
Failure Modes: 50°C



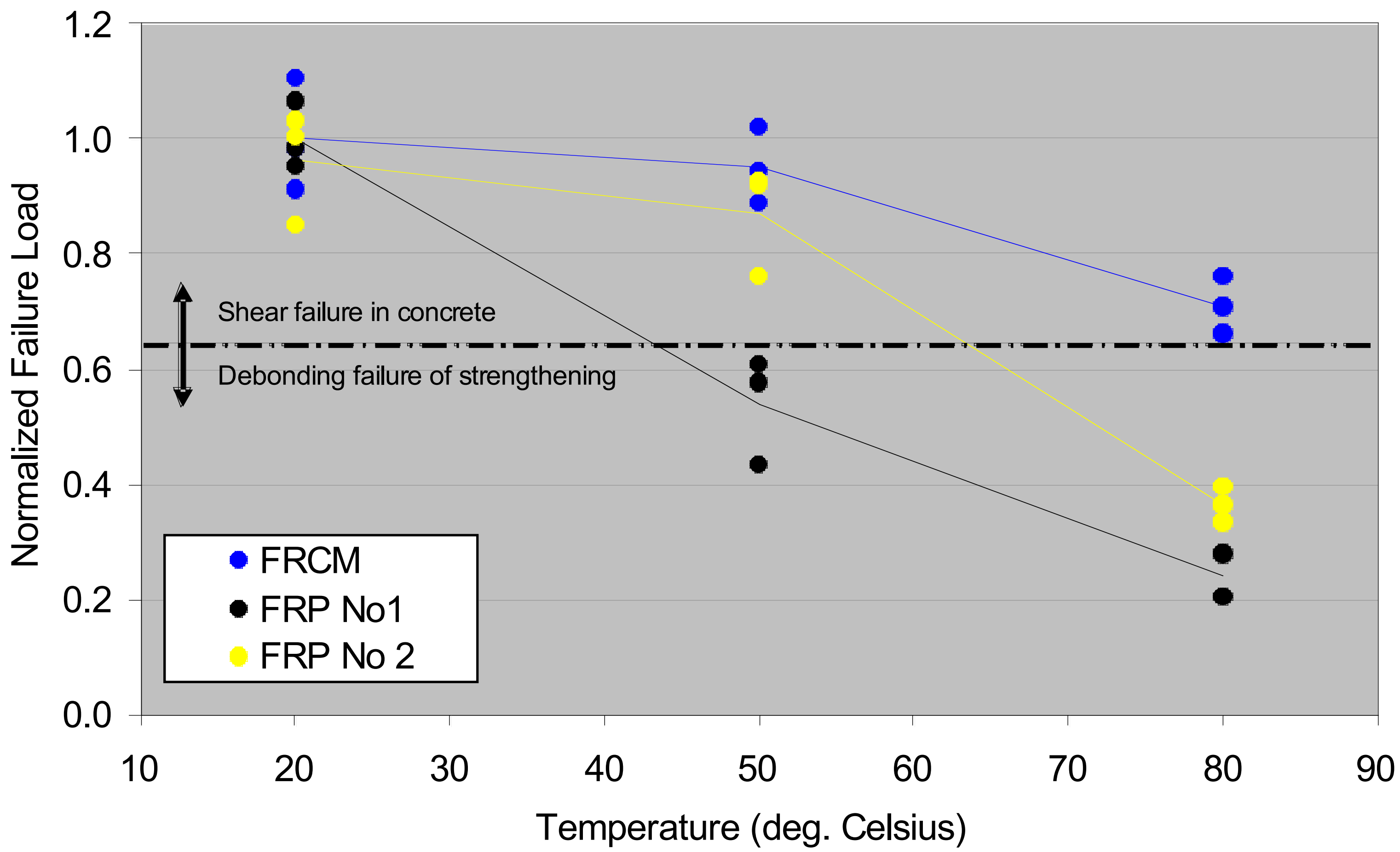
Load vs. Displacement: Tests @ 80°C



Failure Modes: 80°C



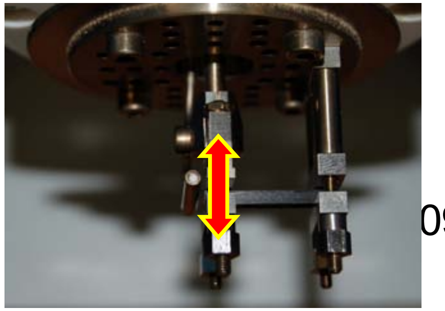
Effect of Temperature

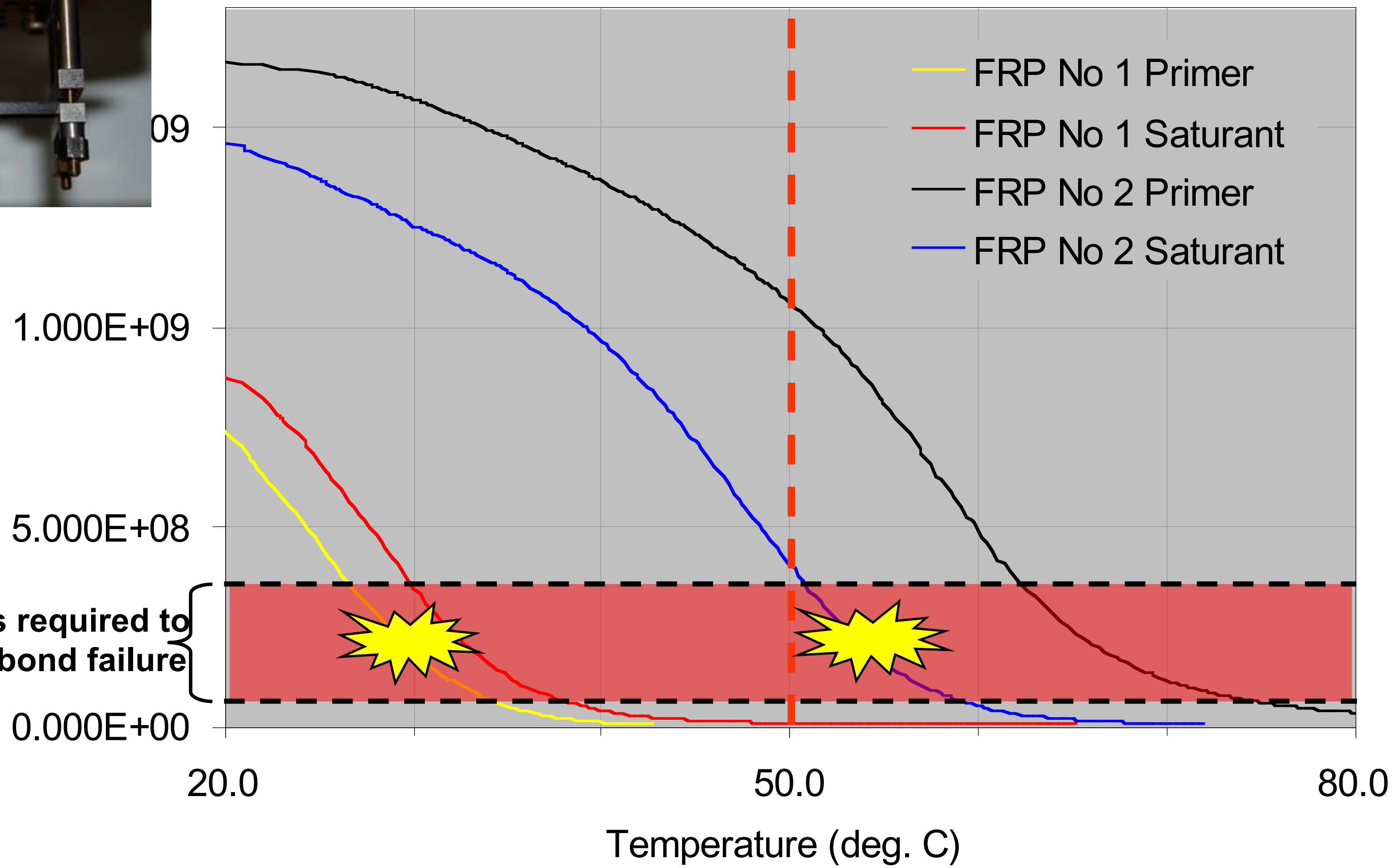


Strength reduction of FRCM beams may be due to reductions in shear strength of concrete at 80°C, rather than indicating damage to the FRCM

Aside: Characterization of Epoxy Resins

- DMTA testing on polymer primer & saturants





Conclusions

1. The **FRCM system can be effectively used, without supplemental anchorage, to strengthen RC beams** in bending

2. Effects of Temperature:
   - FRP Nº1 experienced reductions of 52% at 50°C and 74% at 80°C
   - FRP Nº2 experienced reductions of 10% at 50°C and 64% at 80°C
   - **FRCM experienced reductions of only 6% at 50°C and 28% at 80°C**
     - **May represent a reduction in the strength of the concrete rather than damage to the FRCM system**

3. FRCM appears to be **a superior candidate for use in strengthening applications** at temperatures of 25°C to 80°C

Acknowledgements

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Thank you for your attention

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Aside: Flame Spread & Combustibility

- **FRP systems:**
  - Loss of the strengthening systems' mechanical performance during fire may not be critical if reasonable strengthening limits are imposed
- **Structural performance is only one of many concerns in fire:**
  - Fire severity and fuel load
  - Flame spread
  - Smoke generation and toxicity
- **FRP strengthening systems often require flame spread coatings in interior applications to meet life-safety objectives in fire**
- **FRCM systems bonded with inorganic mortars:**
  - **Inherently non-combustible**
  - **Can be used unprotected**
  - **Reductions in material and installation costs**
  - **Improved aesthetics**

Aside: Aging of Polymer Resins?

- DMTA testing **after 3 hrs at high temperature**