The Performance of CFRP Strengthening During a Real Fire

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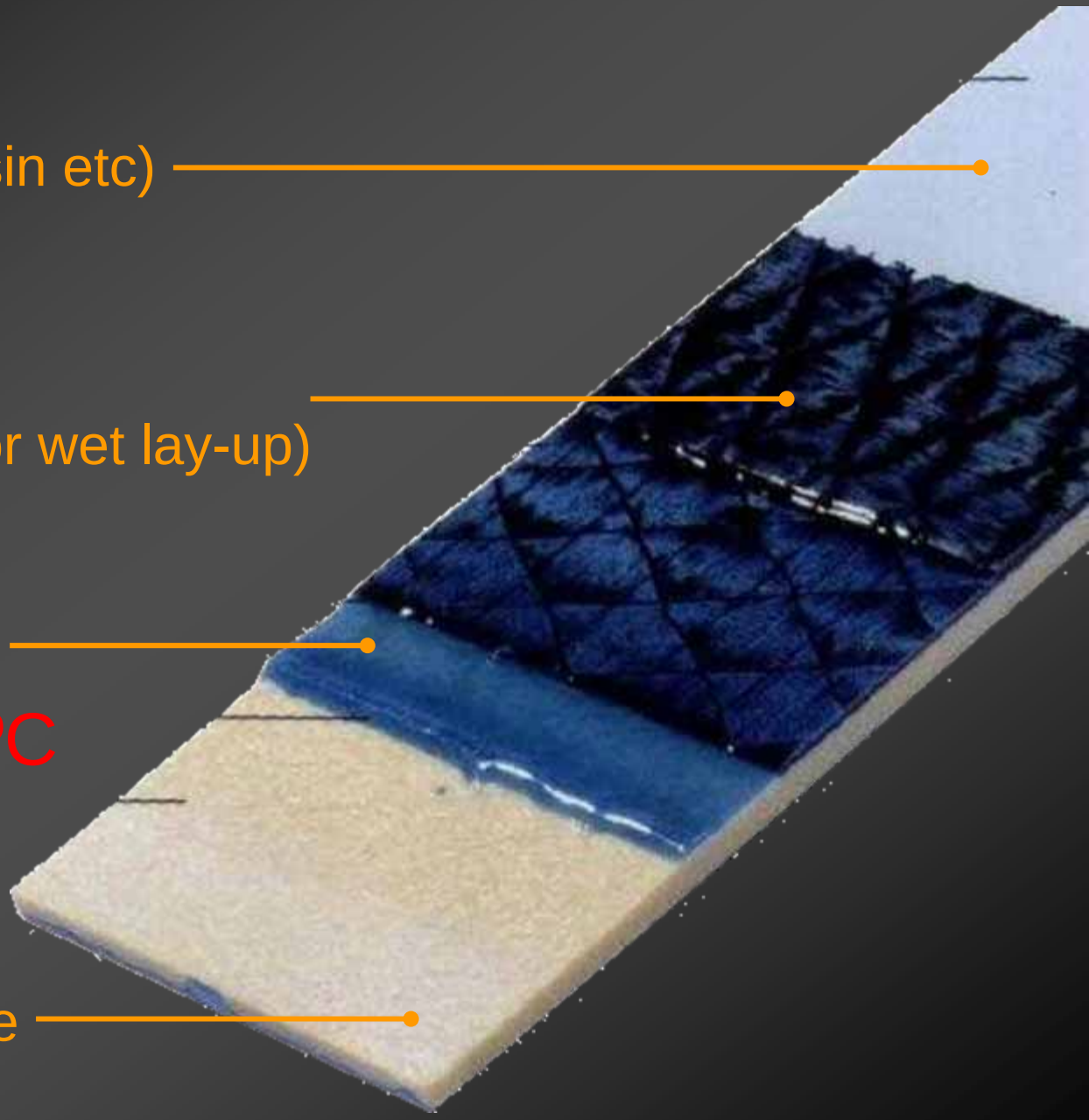
Background

Carbon fibre reinforced polymer (CFRP) strengthening

Example applications of Carbon Fibre Reinforced Polymer (CFRP) strengthening systems


Finish (coating resin etc)
Carbon fibre
(preformed plate or wet lay-up)
Bonding adhesive
T_g = 65 - 100ºC
Concrete substrate

Background

Bonding adhesive
$T_g \approx 65$ to 100ºC (?)

Preformed CFRP plate
T_g of resin $\approx$ 250ºC (?)

Concrete Society Technical Report 55:

"Unless a rigorous analysis is undertaken it is sensible to neglect the strengthening from FRP in fire situations."

"***Fire protection.***
Regulations may require the application of an over-coat layer, which has been tested on the fully-cured composite system"

Background

Structural alterations ⇒
FRP carrying permanent load, and must carry load during fire

Fire protection?

Background

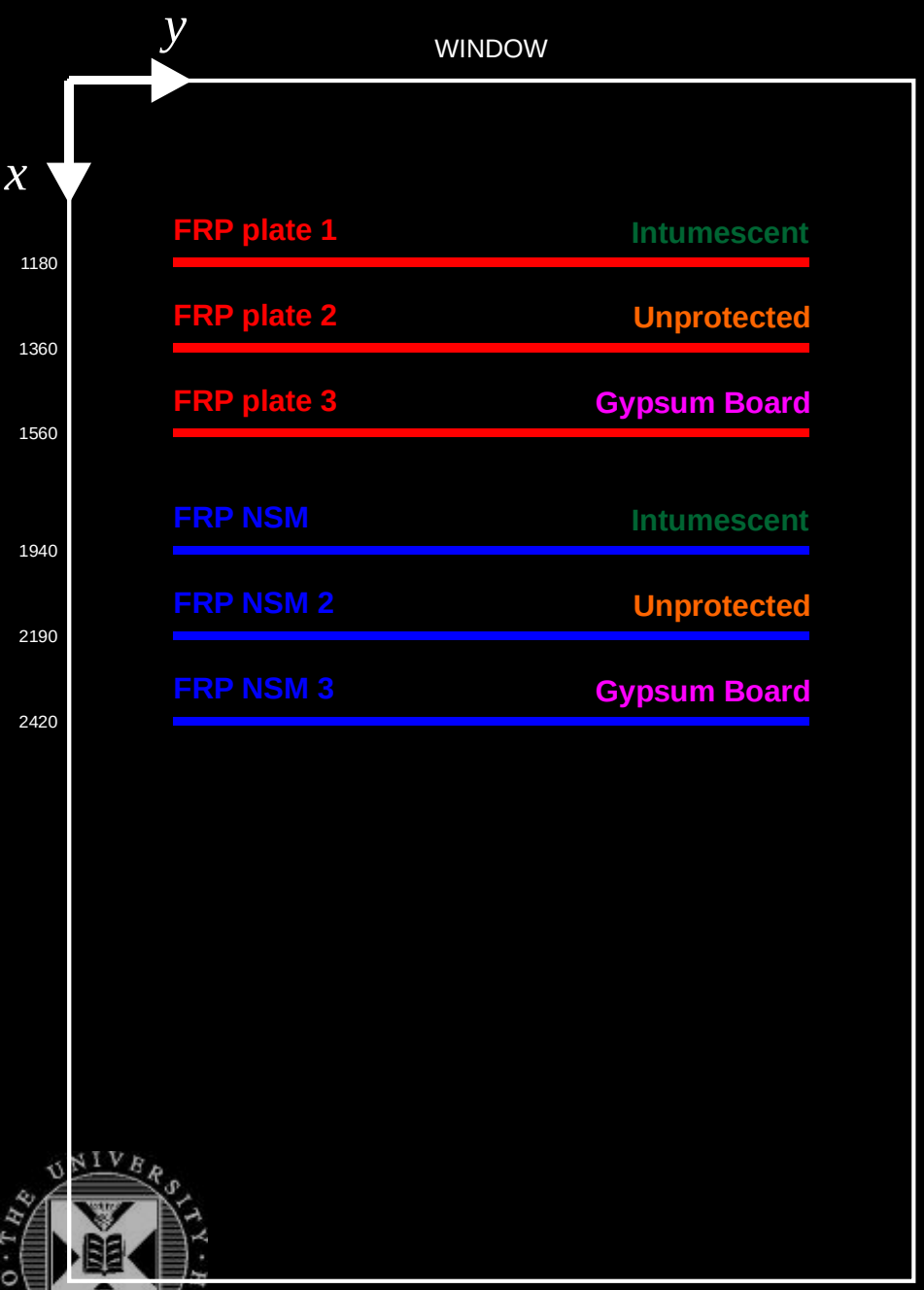
Dalmarnock compartment fire tests

⇓

Unique opportunity to assess CFRP Strengthening in a Real Fire

Installation of Strengthening

Installation

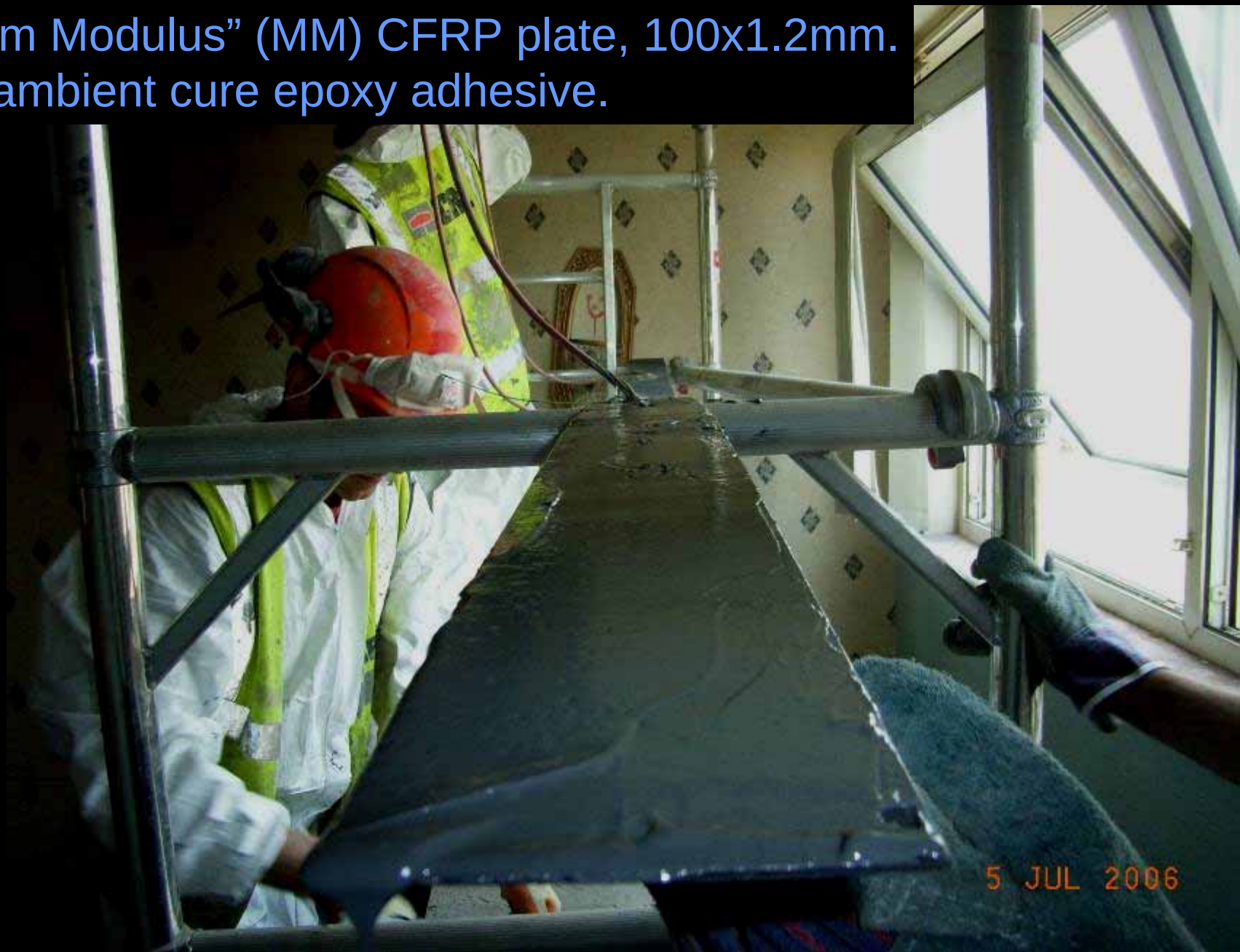


Installation

Installation – FRP Plates

Installation – FRP Plates

"Medium Modulus" (MM) CFRP plate, 100x1.2mm.
2-part ambient cure epoxy adhesive.



Installation – FRP Plates

Installation – FRP Plates

Installation – NSM FRP

Near-surface mounted FRP strengthening:
bonded into a groove cut into the concrete soffit

Industry perception: better fire performance.

Installation – NSM FRP

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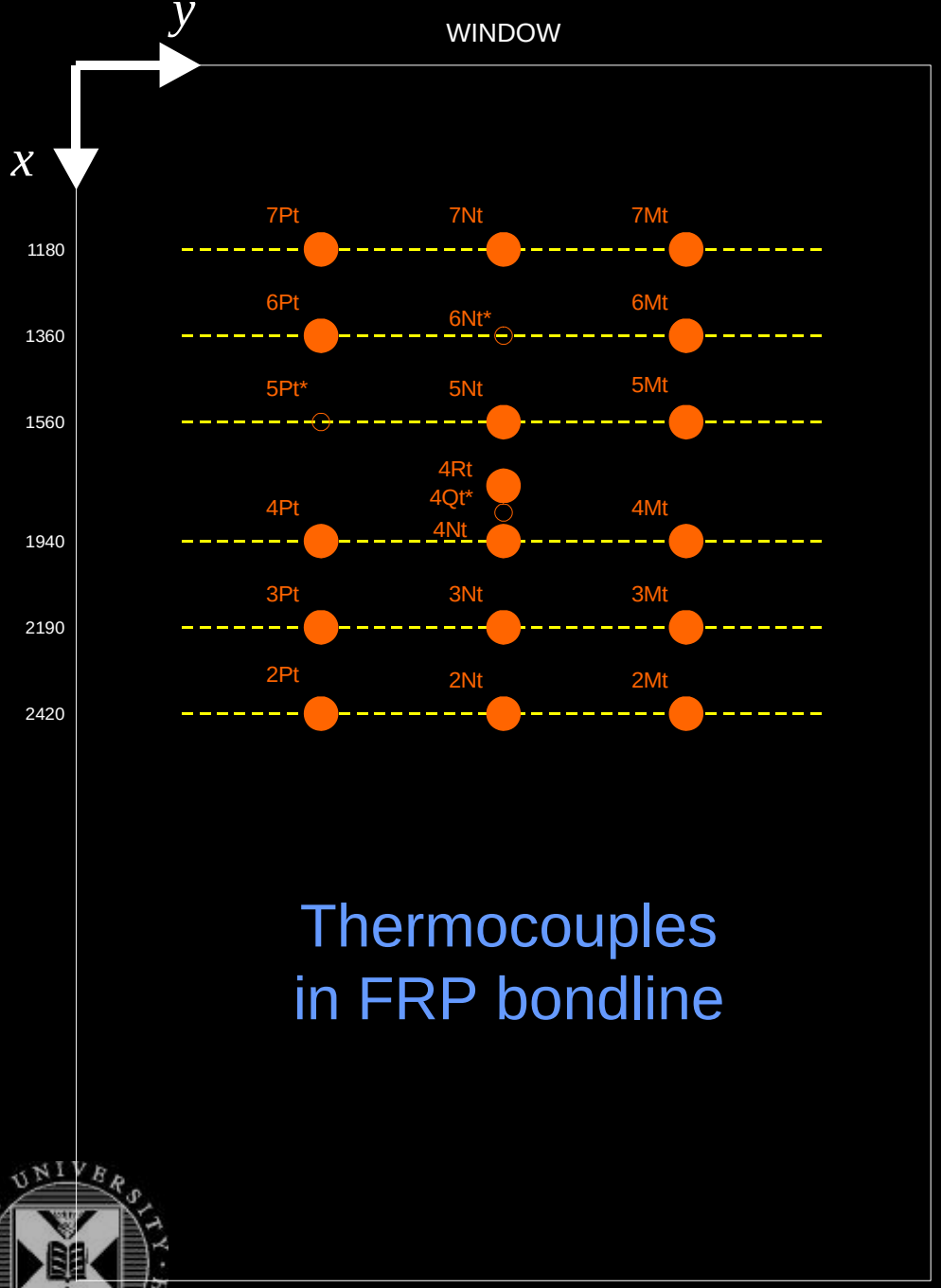
Gypsum board
2 layers of 12mm board
+ intumescent sealer
(“Designed system”)

Experimental Setup

Strain gauges, Thermocouples

Experimental Setup



FRP plate 1

FRP plate 2

FRP plate 3

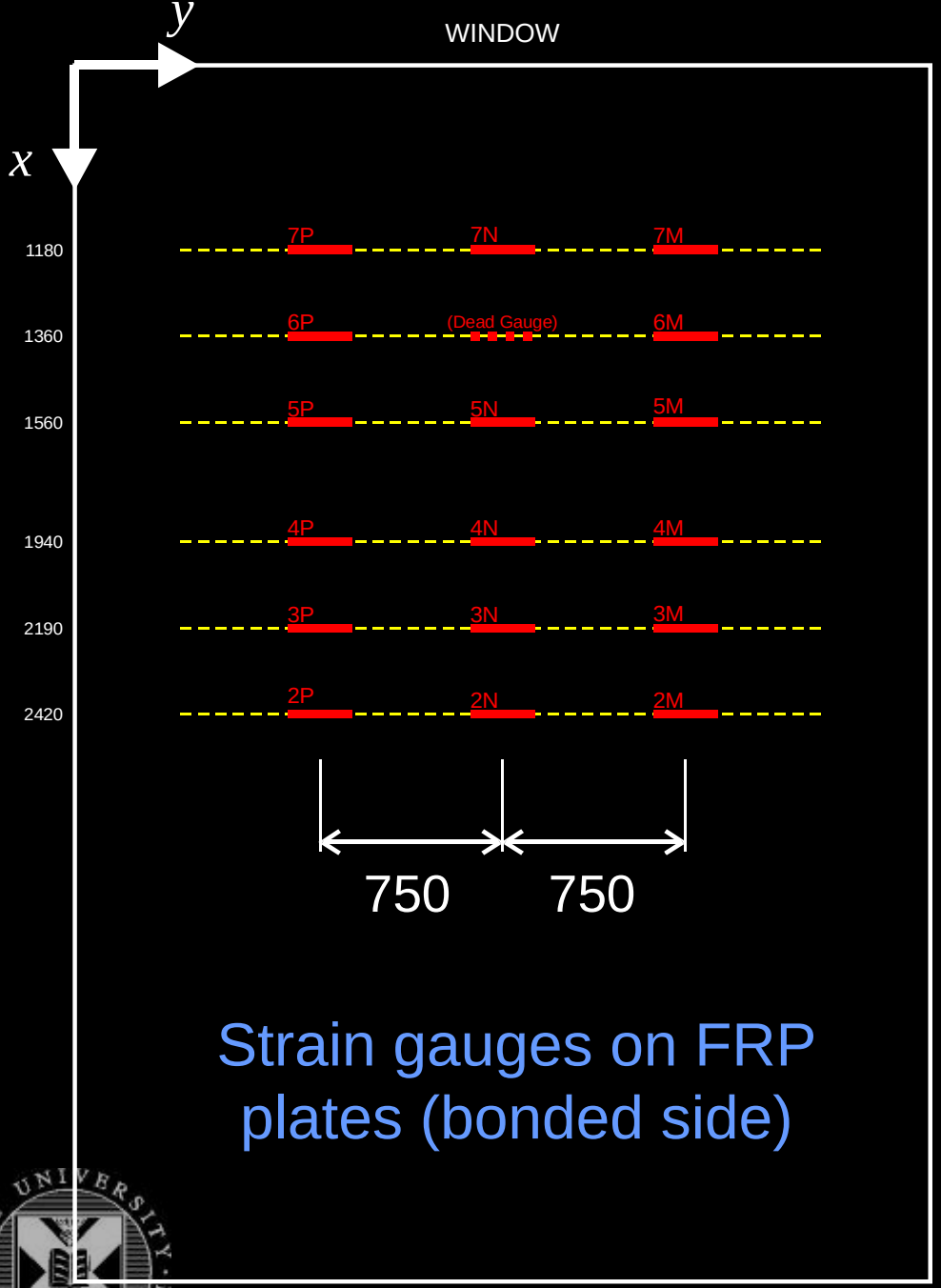
FRP NSM 1

FRP NSM 2

FRP NSM 3

Thermocouples in FRP bondline

Experimental Setup



FRP plate 1

FRP plate 2

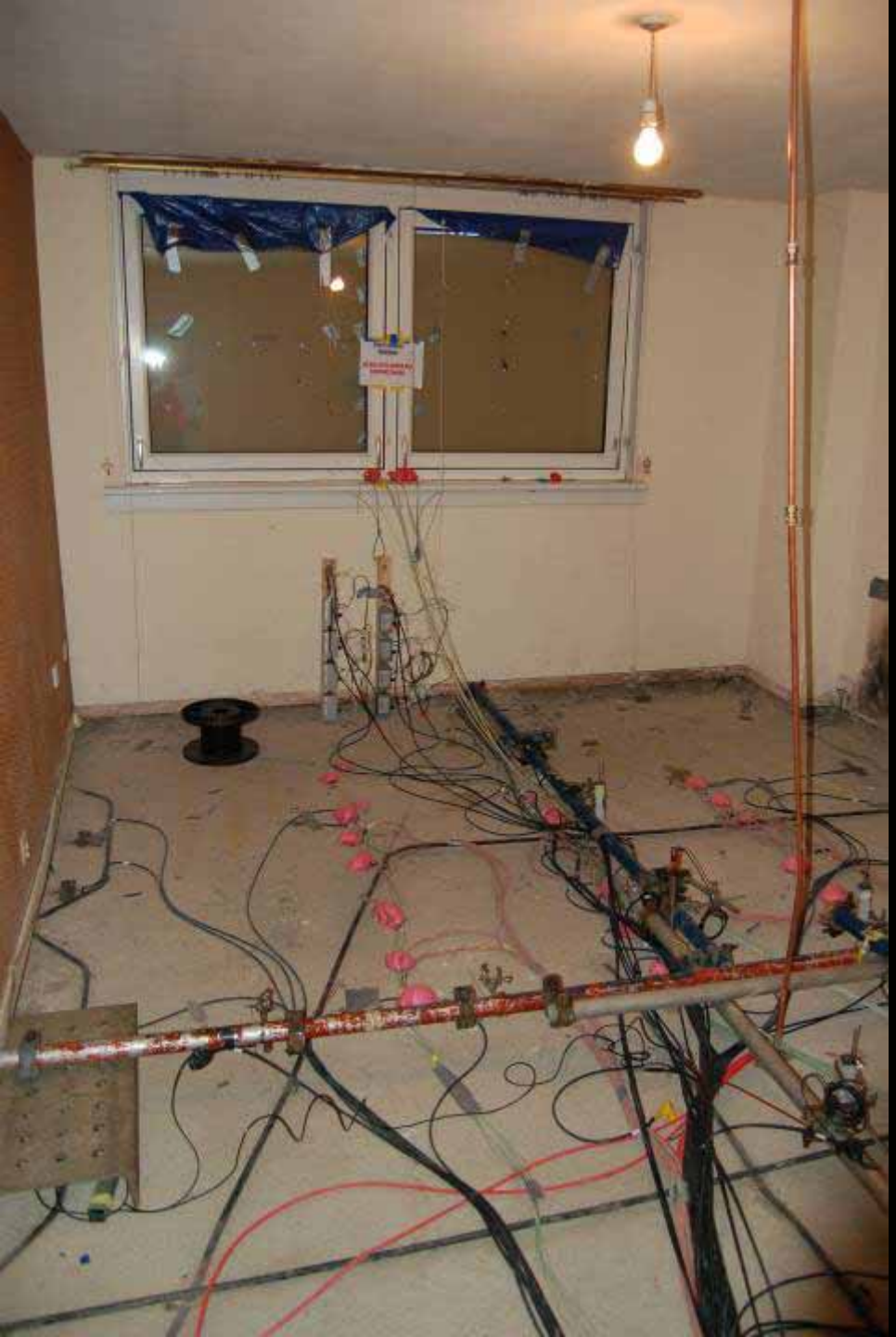
FRP plate 3

FRP NSM 1

FRP NSM 2

FRP NSM 3

Strain gauges on FRP plates (bonded side)



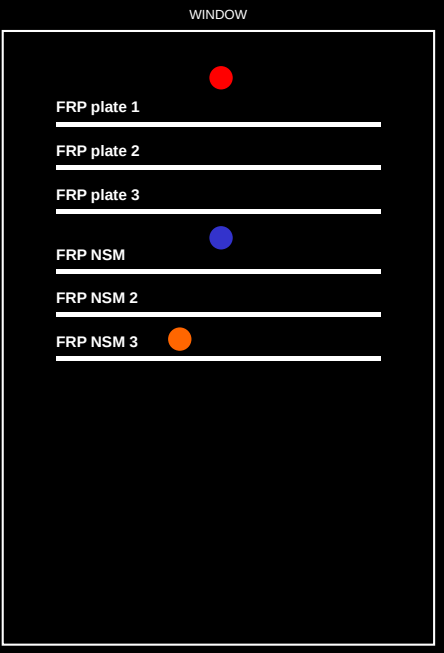
Other instrumentation:

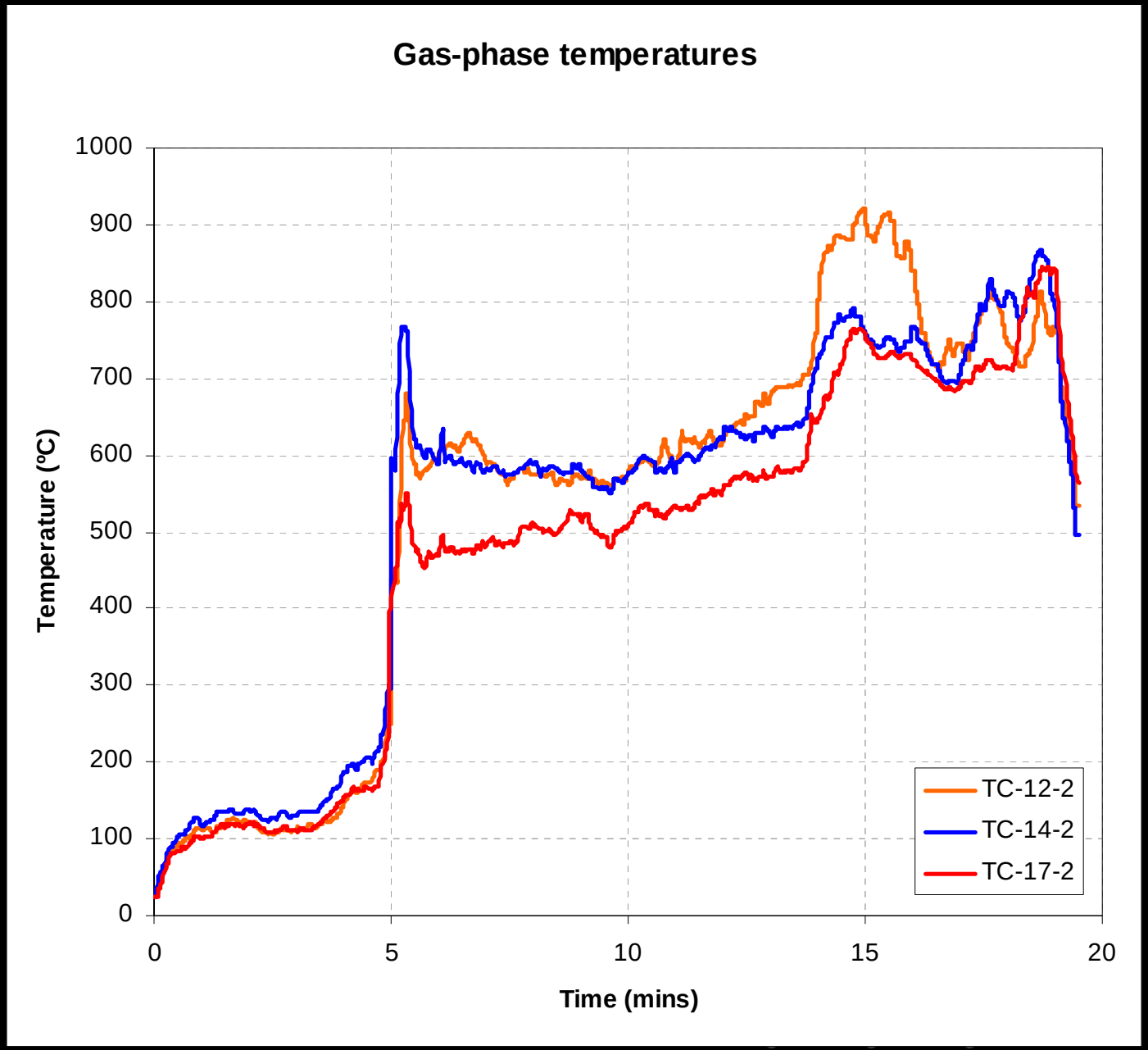
- δ-gauges on top of slab
- ε-gauges on top of slab
- δ-gauges against adjoining wall
- Thermocouples through slab depth
- Thermocouples within compartment (gas phase)

Results

Results

Results


WINDOW
FRP plate 1
FRP plate 2
FRP plate 3
FRP NSM
FRP NSM 2
FRP NSM 3


Gas-phase temperatures
Temperature (ºC)
1000
900
800
700
600
500
400
300
200
100
0
0
5
10
15
20
Time (mins)
TC-12-2
TC-14-2
TC-17-2

Results

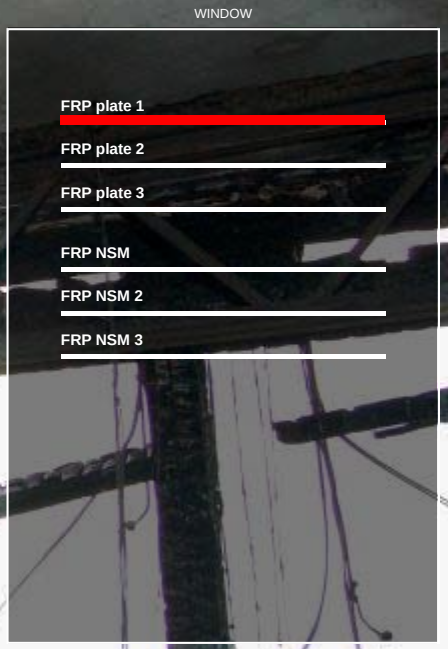
Unprotected FRP Plate

Results

Intumescent + FRP Plate

Results

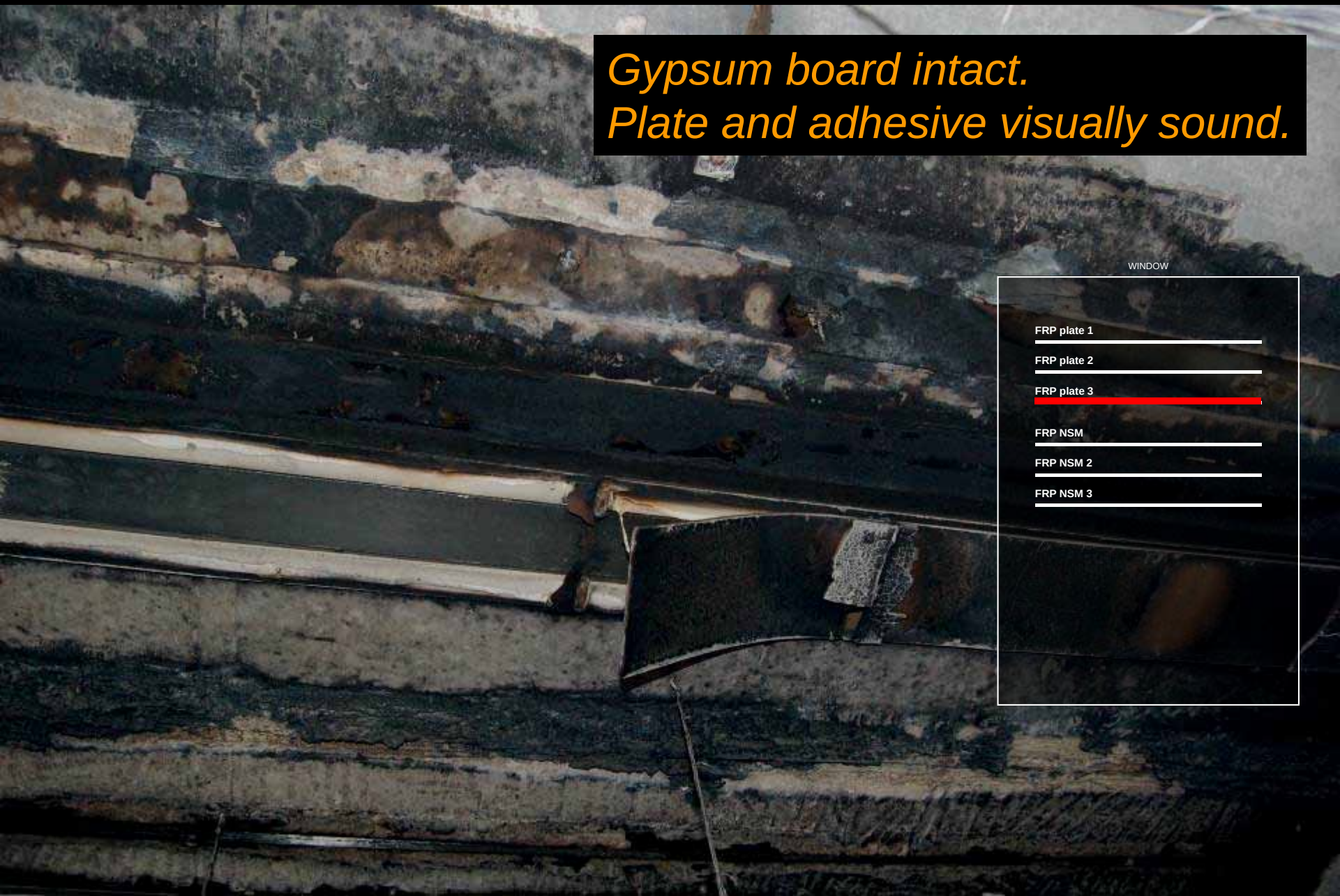
Mostly debonded.
Resin mostly burnt off.



Gypsum board + FRP Plate

Results

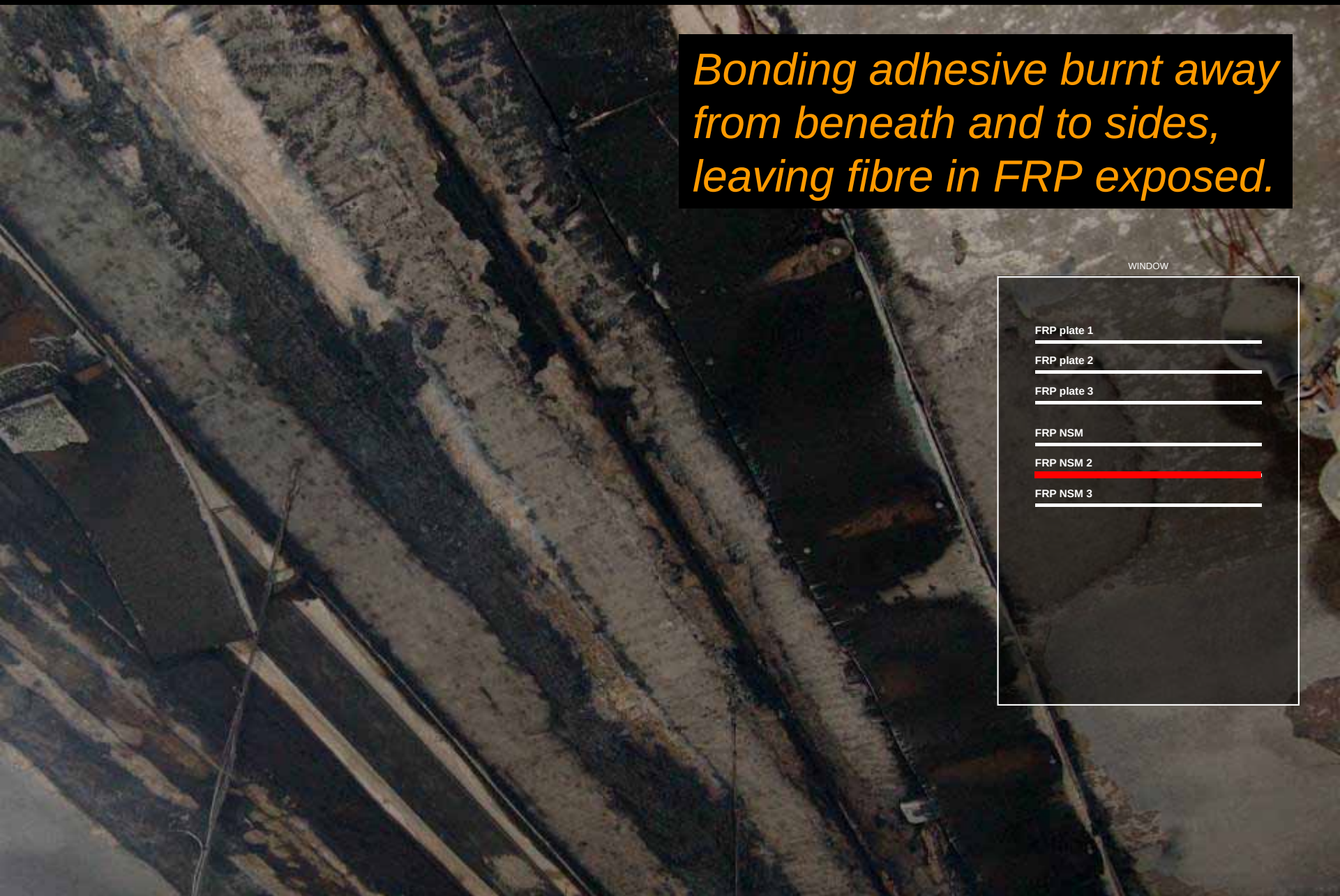
Gypsum board intact.
Plate and adhesive visually sound.



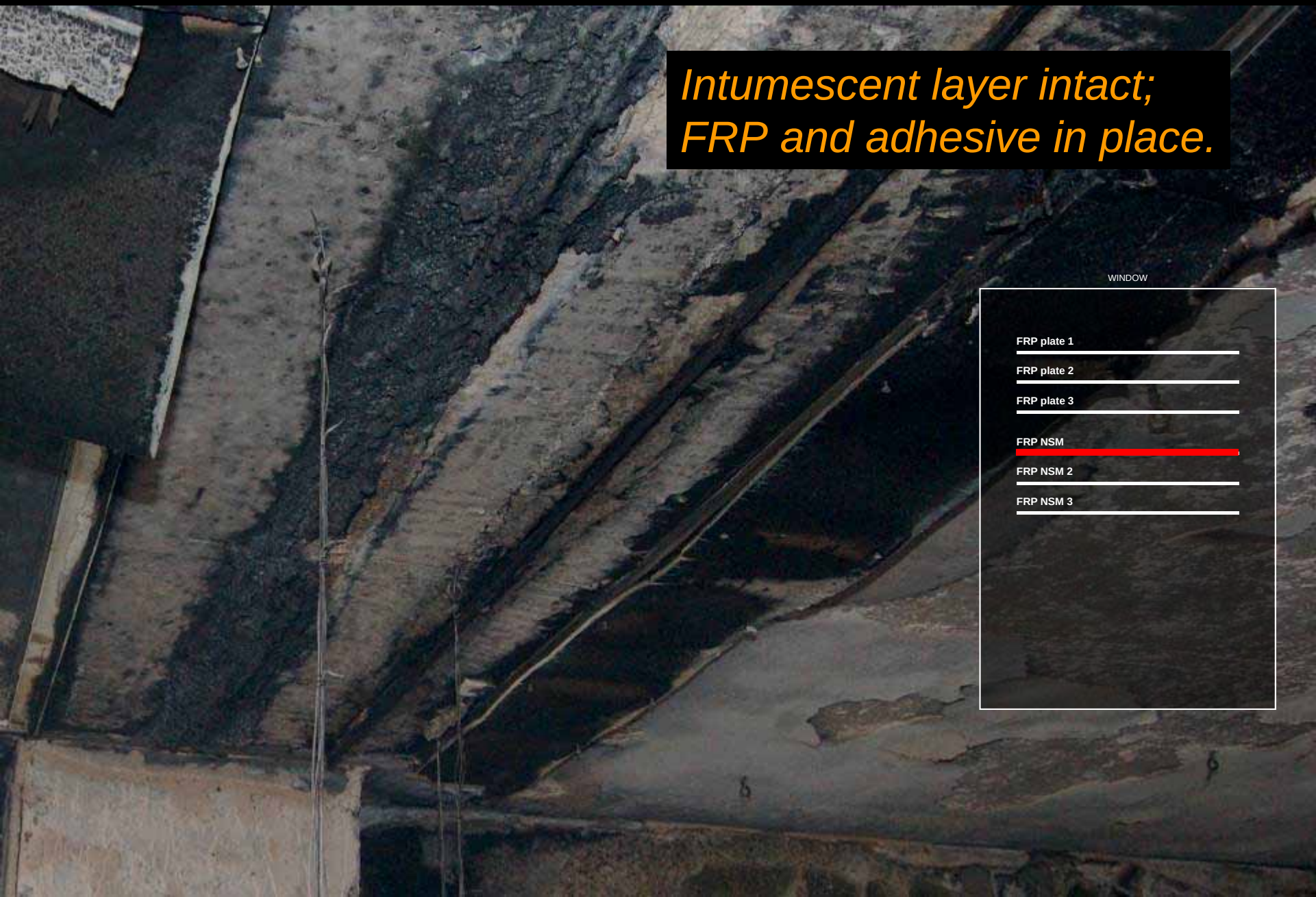
Unprotected NSM FRP

Results

Bonding adhesive burnt away from beneath and to sides, leaving fibre in FRP exposed.



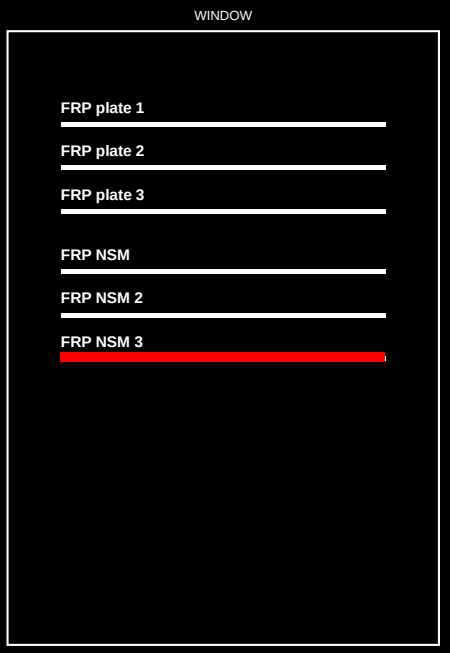
Intumescent layer intact;
FRP and adhesive in place.



Gypsum board + NSM FRP

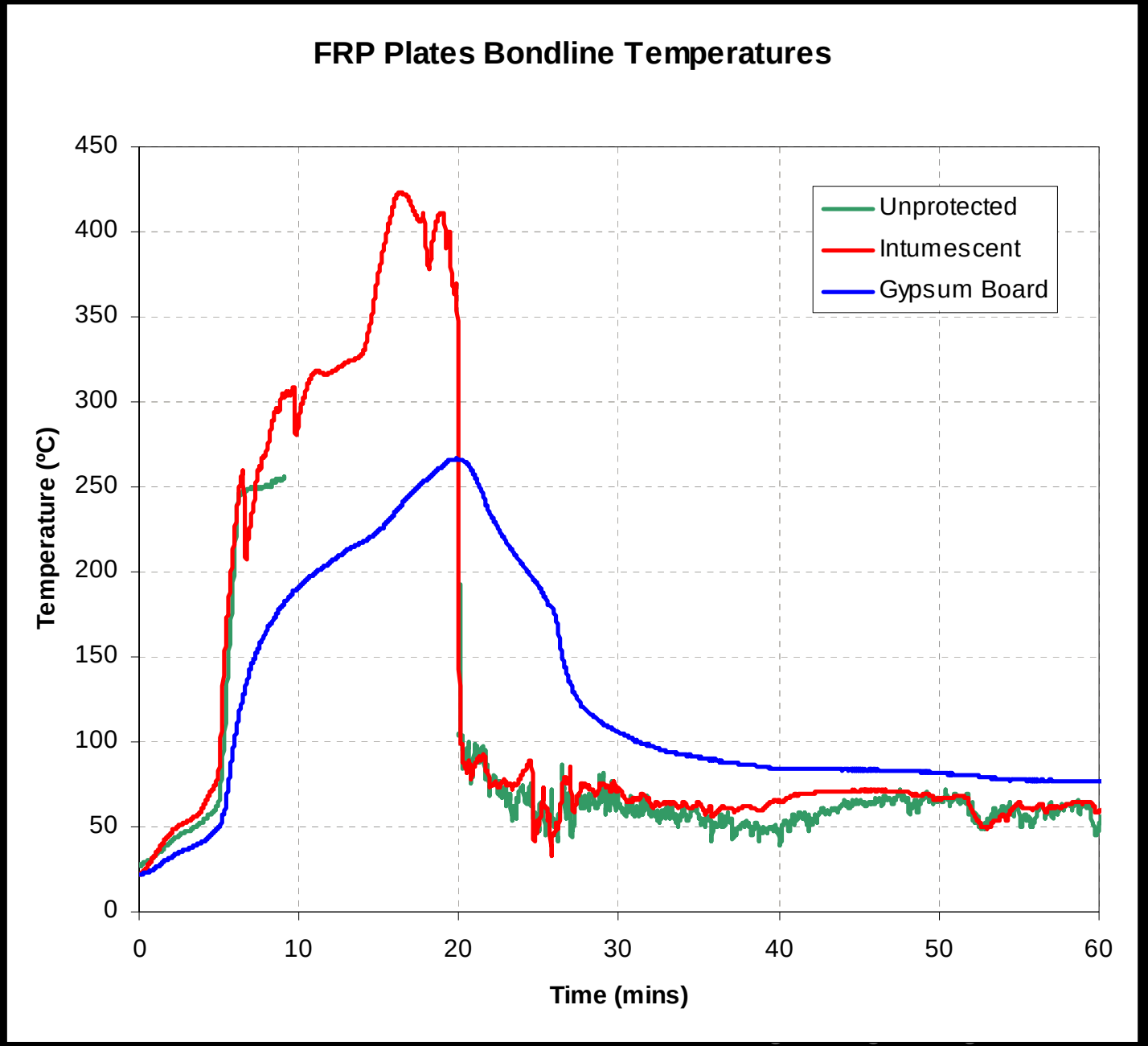
Results

Gypsum board sound.
FRP and adhesive visually sound.

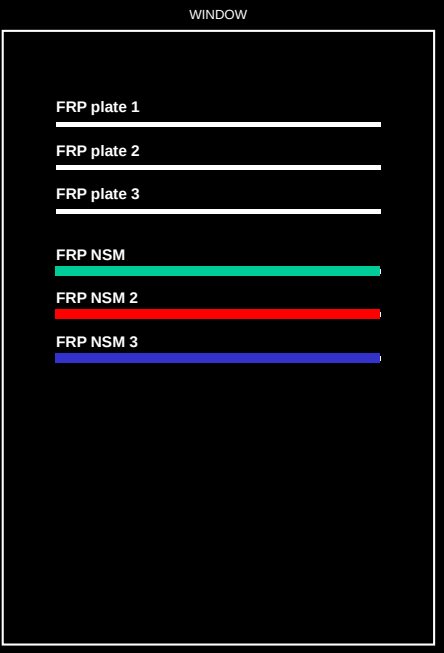


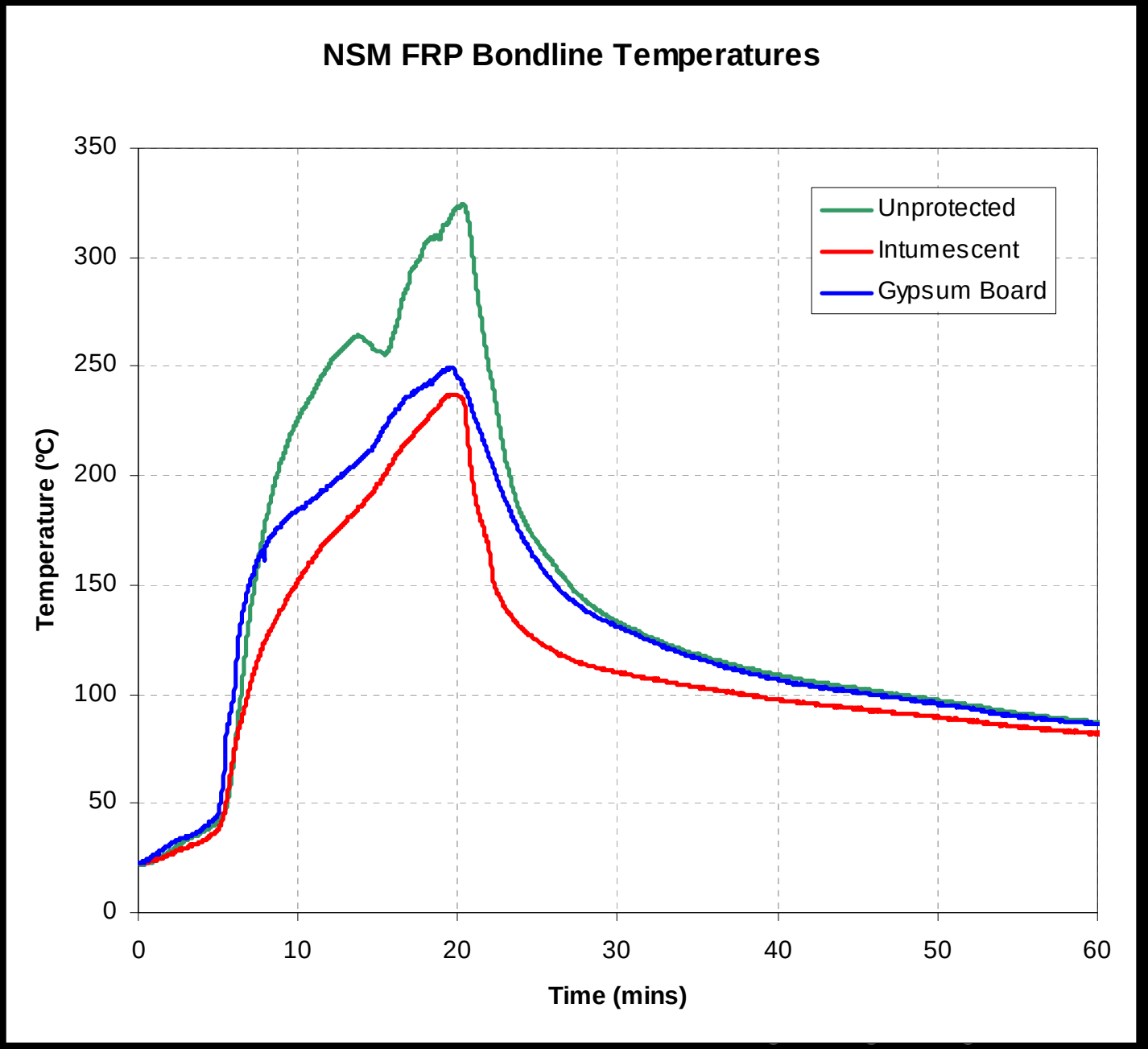
Results


WINDOW
FRP plate 1
FRP plate 2
FRP plate 3
FRP NSM
FRP NSM 2
FRP NSM 3

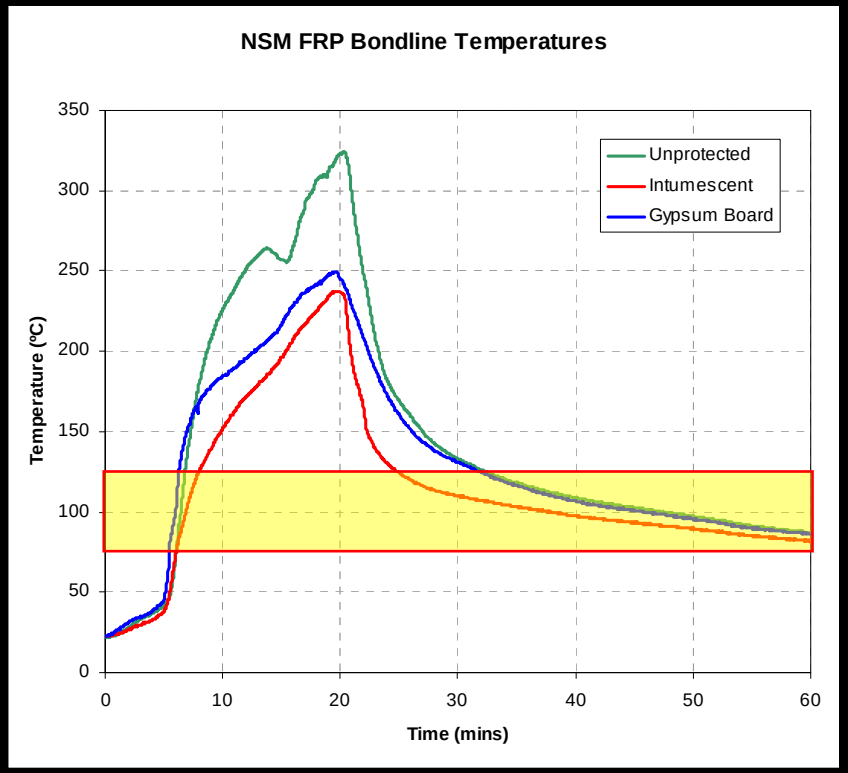

FRP Plates Bondline Temperatures
Temperature (ºC)
Time (mins)
Unprotected
Intumescent
Gypsum Board
0
50
100
150
200
250
300
350
400
450
0
10
20
30
40
50
60

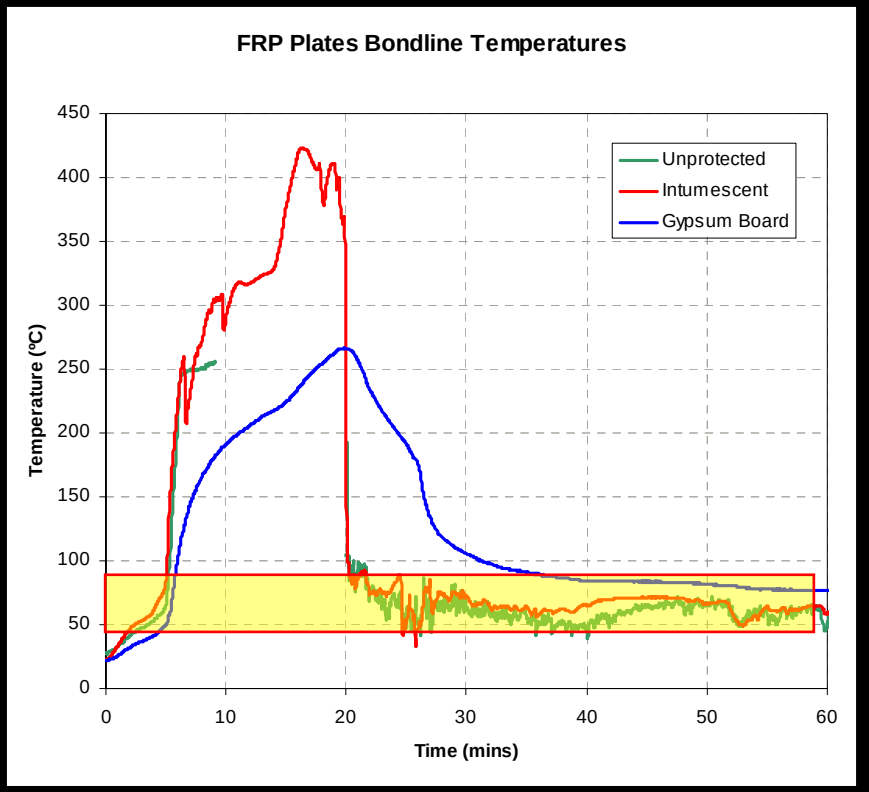
Results


WINDOW
FRP plate 1
FRP plate 2
FRP plate 3
FRP NSM
FRP NSM 2
FRP NSM 3


NSM FRP Bondline Temperatures
Temperature (ºC)
Time (mins)
Unprotected
Intumescent
Gypsum Board
0
50
100
150
200
250
300
350
0
10
20
30
40
50
60

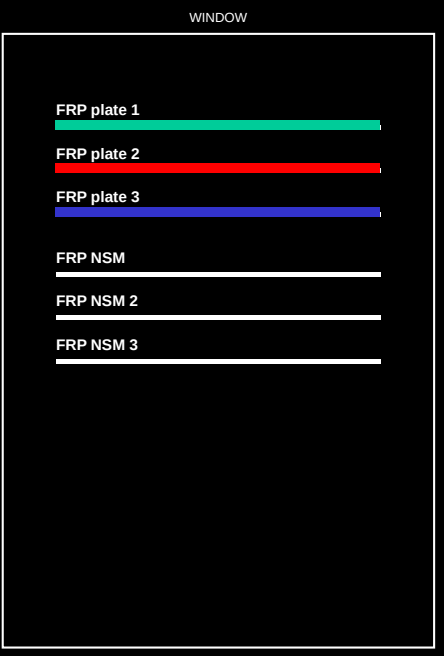
Results

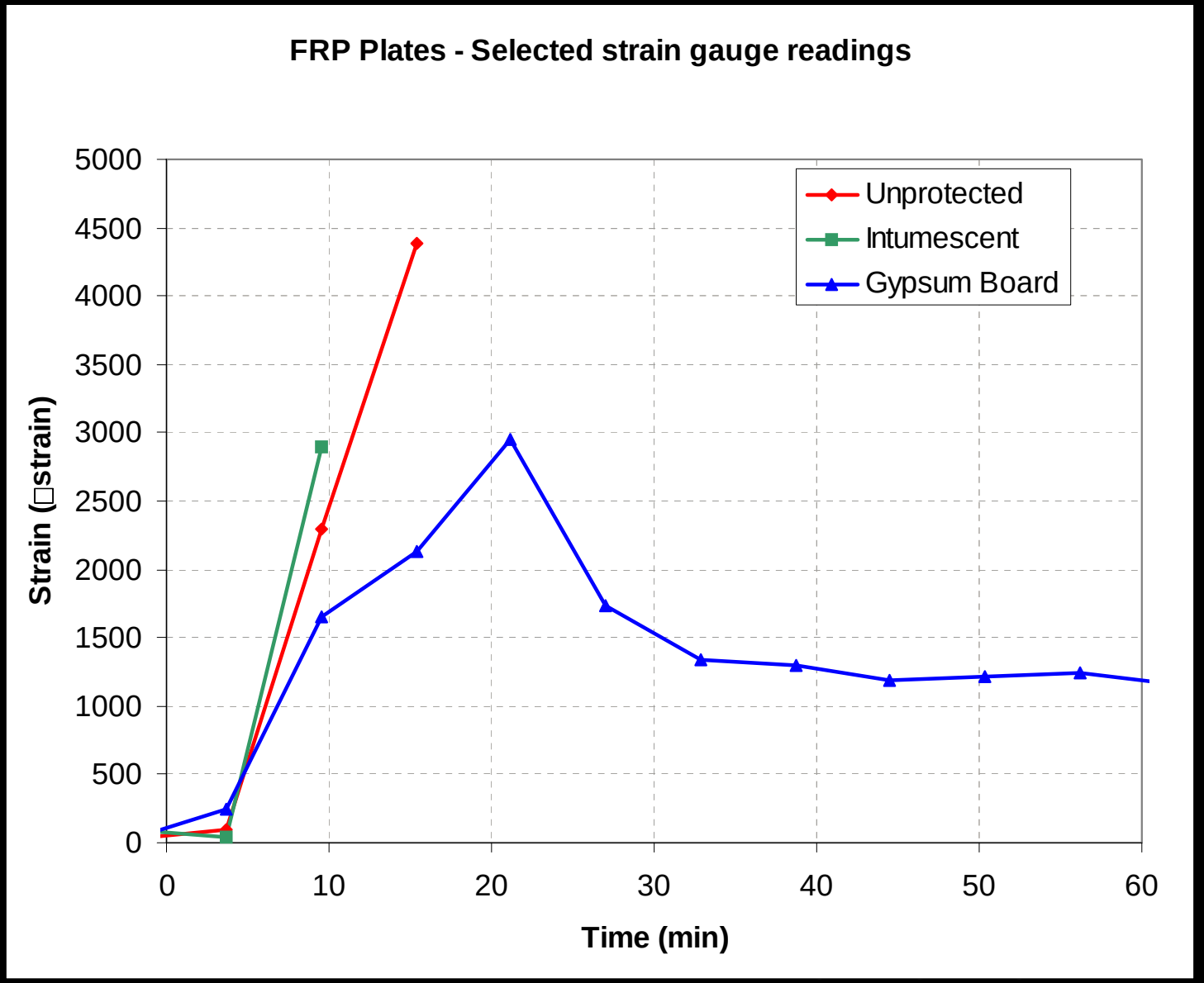




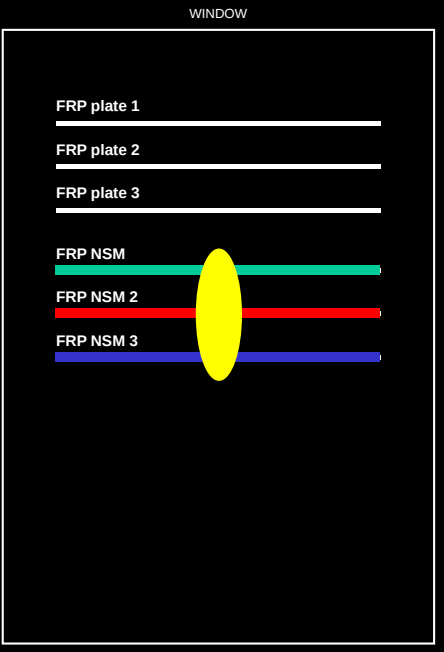
Temperatures >> T_g in <u>all</u> tests.

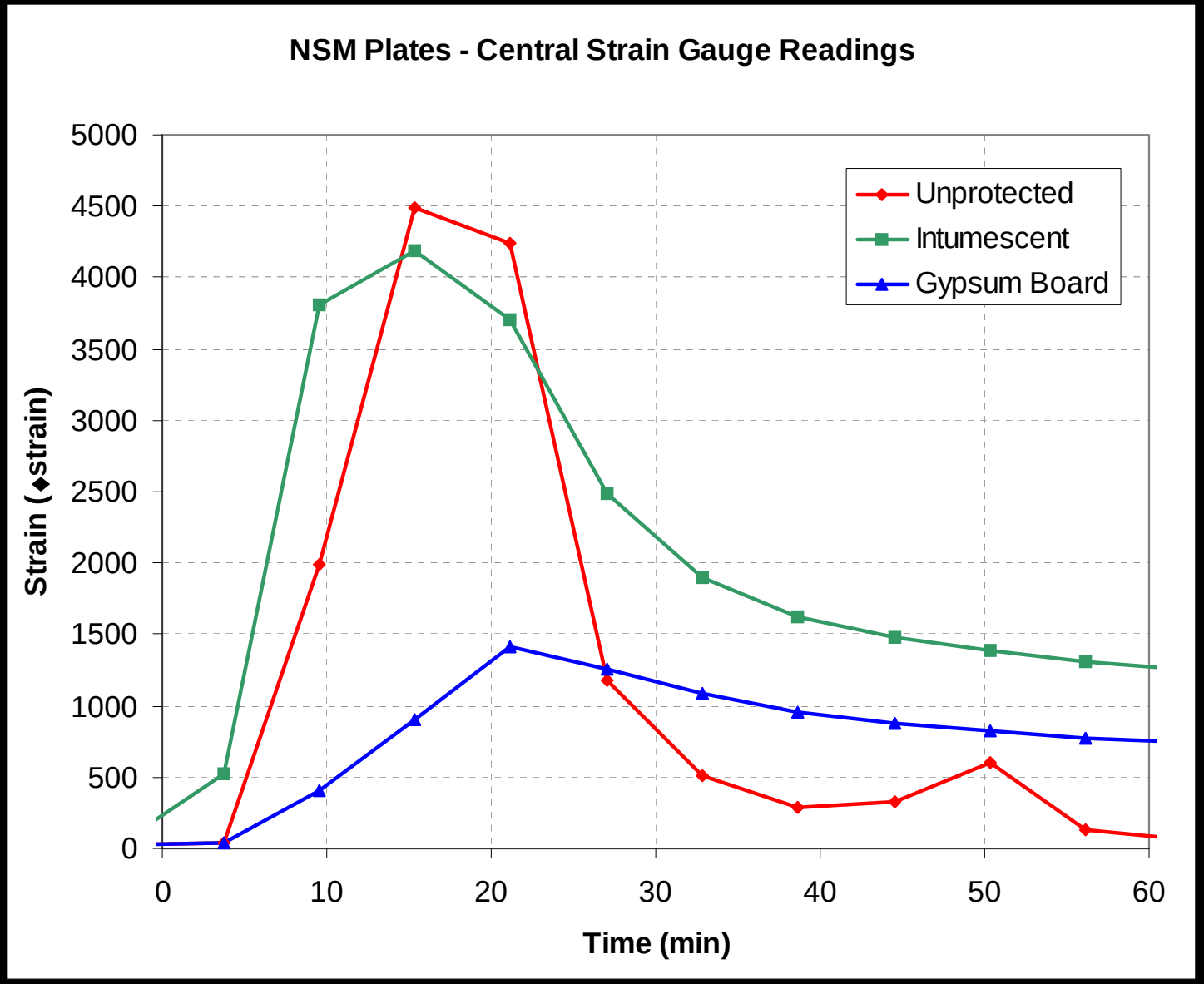
Results


WINDOW
FRP plate 1
FRP plate 2
FRP plate 3
FRP NSM
FRP NSM 2
FRP NSM 3

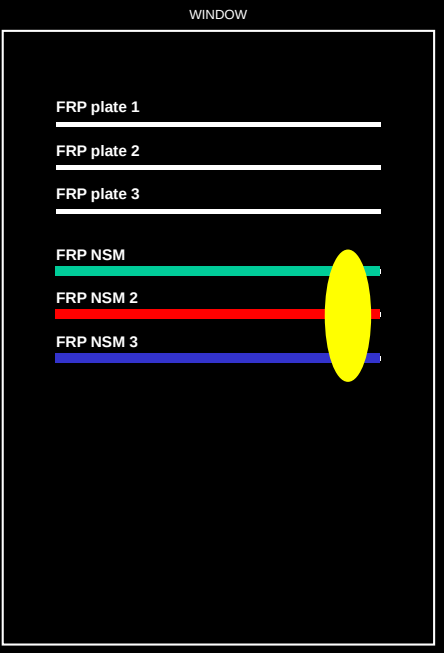

FRP Plates - Selected strain gauge readings
Strain (□strain)
Time (min)
Unprotected
Intumescent
Gypsum Board
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0
10
20
30
40
50
60

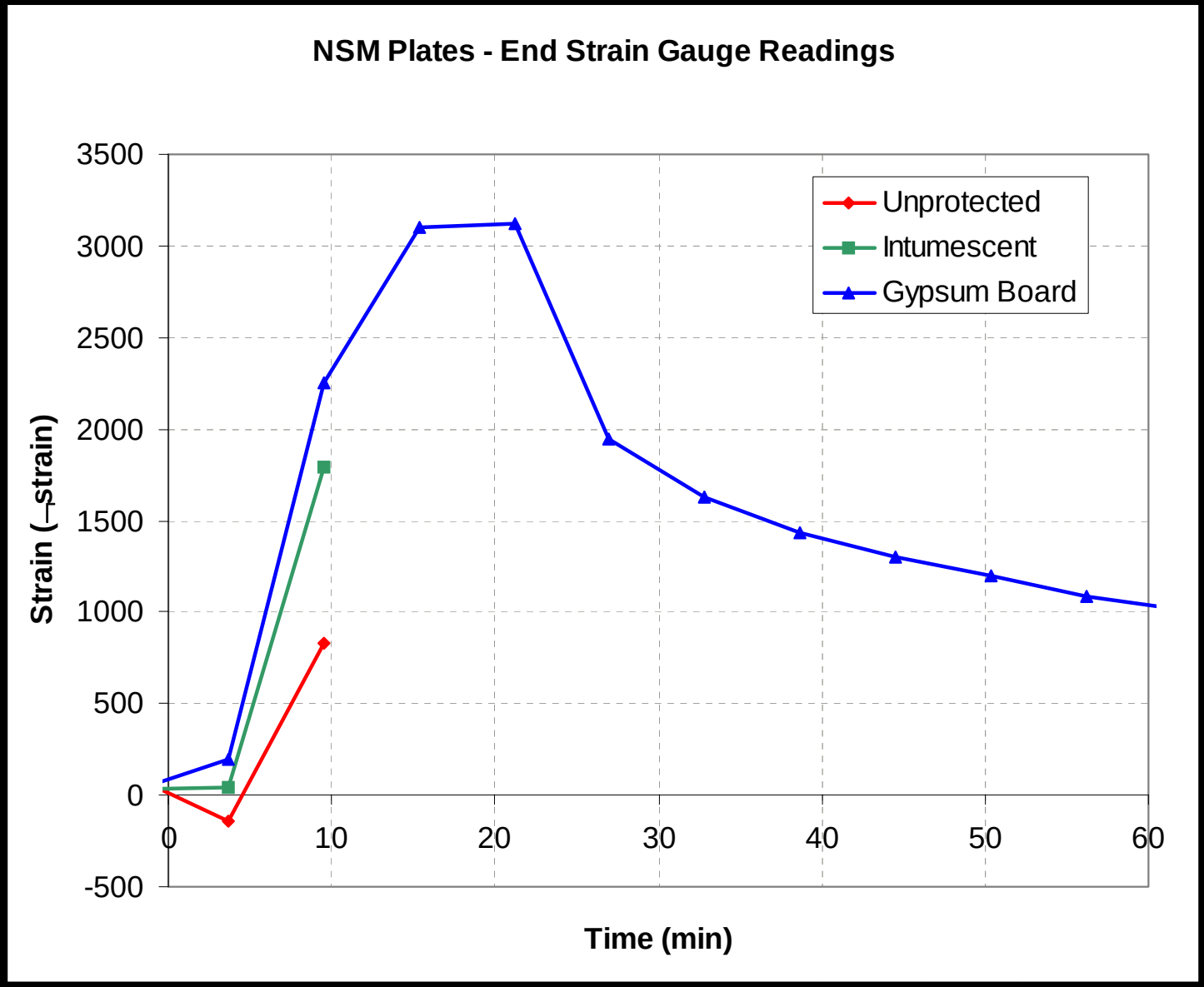
Results


WINDOW
FRP plate 1
FRP plate 2
FRP plate 3
FRP NSM
FRP NSM 2
FRP NSM 3

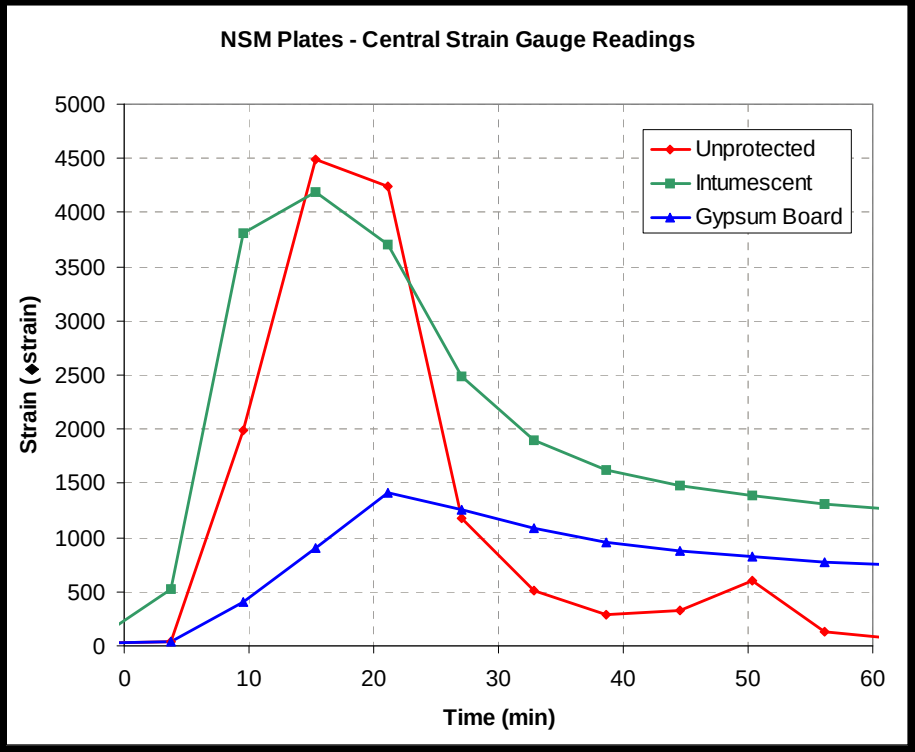

NSM Plates - Central Strain Gauge Readings
Strain (♦strain)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
Time (min)
Unprotected
Intumescent
Gypsum Board

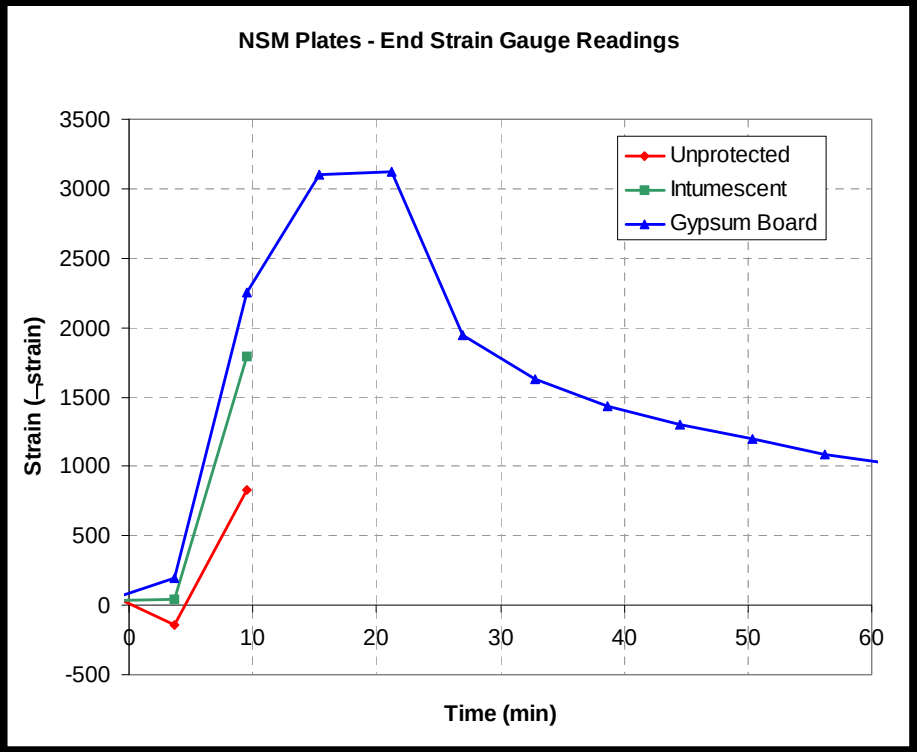
Results


WINDOW
FRP plate 1
FRP plate 2
FRP plate 3
FRP NSM
FRP NSM 2
FRP NSM 3


NSM Plates - End Strain Gauge Readings
Strain (–strain)
Time (min)
Unprotected
Intumescent
Gypsum Board
3500
3000
2500
2000
1500
1000
500
0
-500
0
10
20
30
40
50
60

Results





Strains ⇒ indication of catastrophic failure

NB: - Corrected for temperature effects using T.C. data.
- All strains are the result of thermal effects: no applied load.

Ongoing work and Conclusions

Ongoing Work

- Further analysis of complete strain and thermal dataset
- Characterisation of properties of materials used
- Modelling of composite strengthened slab (thermal strains in concrete)
- Thermal analysis

Conclusions

- During a real fire, the glass transition temperature of the adhesive is exceeded.
- Gypsum board can be used to insulate the FRP, but further research is required before it can be reliably designed
- The integrity of NSM strengthening is superior to plate FRP strengthening during a fire.

Acknowledgements

Concrete Repairs Ltd

BASF Construction