The Implementation of Fire Resistance Recommendations in ACI Code-440.11

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Outline

- Research steps to identify the fire safety concerns
- Glass fiber reinforced polymer (GFRP) materials at high temperatures
- Design approaches to mitigate fire effects on FRP reinforced concrete

Fire resistance of GFRP reinforced concrete

- GFRP reinforcing bars are resistant to corrosion and have high strength-to-weight ratios
- Concerns about GFRP material performance at high temperature
- Extensive research has been conducted to understand the behavior of GFRP-reinforced concrete members under fire conditions
- Design standards (e.g., ACI Code-440.11) have been updated to include guidelines for achieving fire safety

Challenges in Establishing Fire Resistance

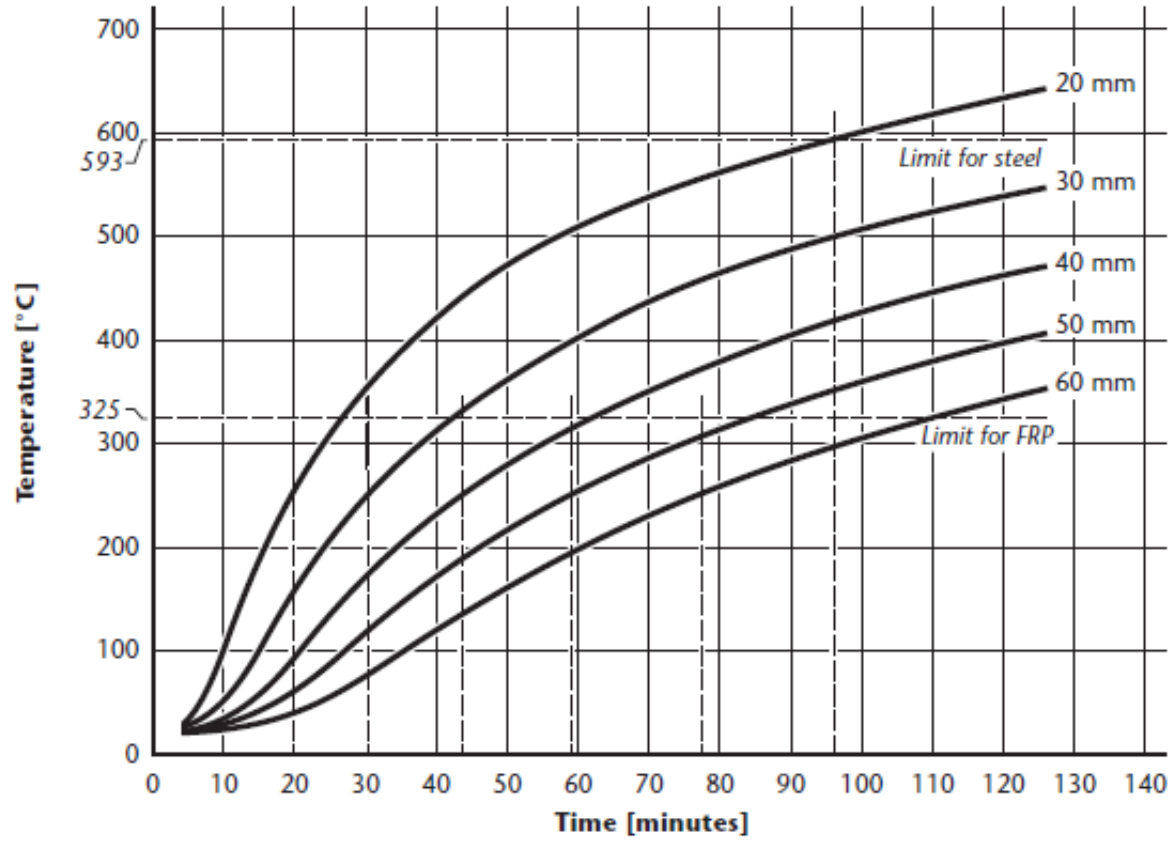
- ASTM E119 was developed on the notion that steel reinforced members are designed for full-strength, however, GFRP-reinforced concrete members are designed for service loads
- Deflection limits and crack width criteria generally govern design with GFRP reinforcement
- ASTM E119 requires application of a superimposed load, usually based on strength only

CSA S806-12: Building structures with FRPs

- Provides a semi-empirical approach for determining the fire resistance of FRP reinforced concrete
- Based on minimum concrete cover

- *Annex R – Procedure for the determination of a fire-resistance rating for concrete slabs reinforced with FRP and concrete members strengthened with FRP*
- Reliant on the notion of a critical temperature at which the reinforcing bar loses 50% of its strength – taken as 250 °C (480 °F) for CFRP and 325 °C (620 °F) for GFRP bars

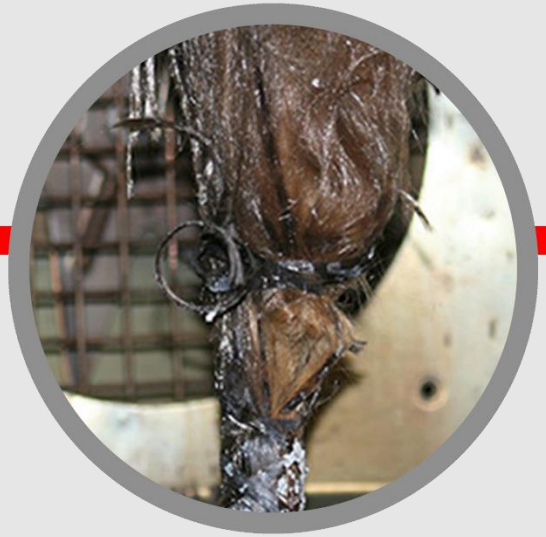
CSA S806-12 – Temperature of reinforcement



Note: *This figure is based on Kodur and Baingo* (1998).

Figure R.1
Fire resistance of 120 mm concrete slabs
(carbonate aggregate)
(See Clause R.1.)

Steps in studying GFRP in fire

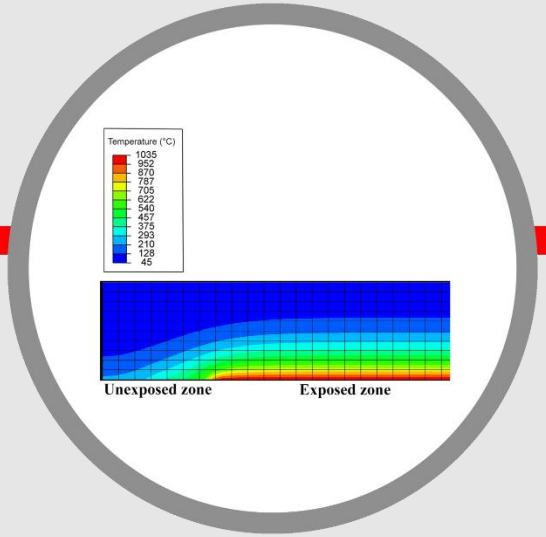


Material testing: GFRP
at high temperatures

(1)

Full-scale
fire test at NRC

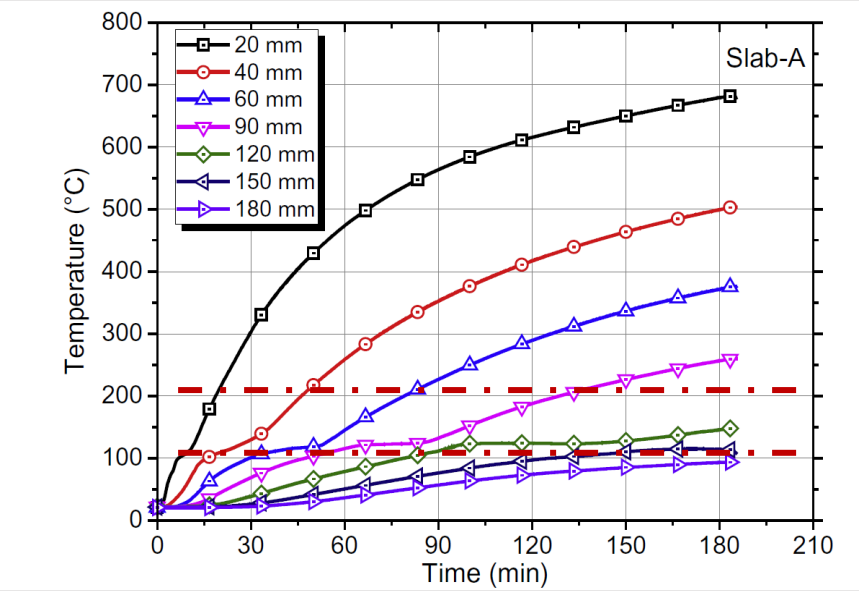
(2)



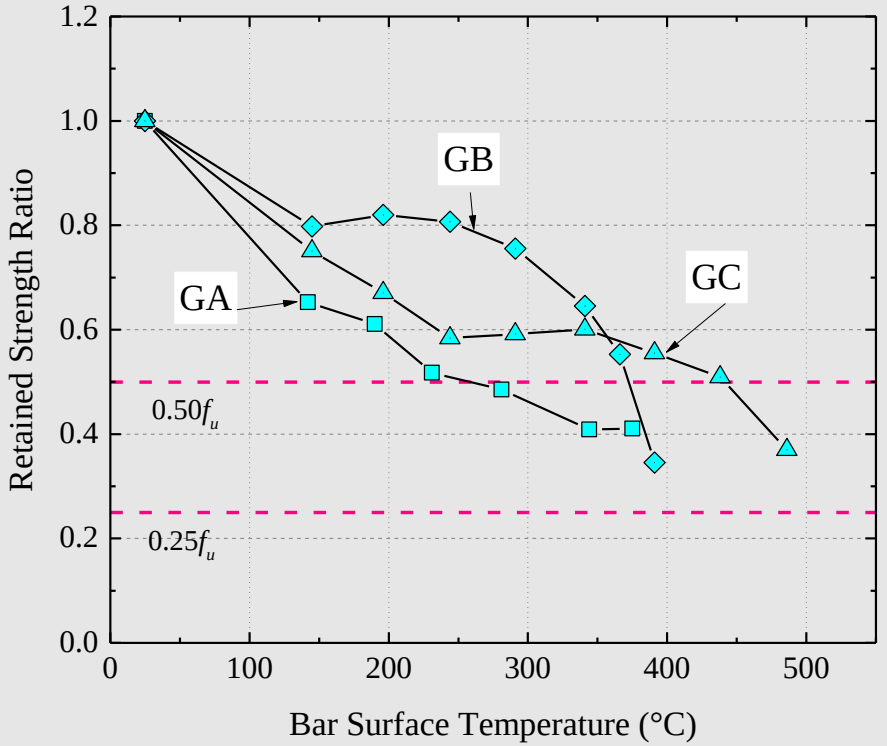
Finite element modelling

(3)

Tensile strength at high temperatures



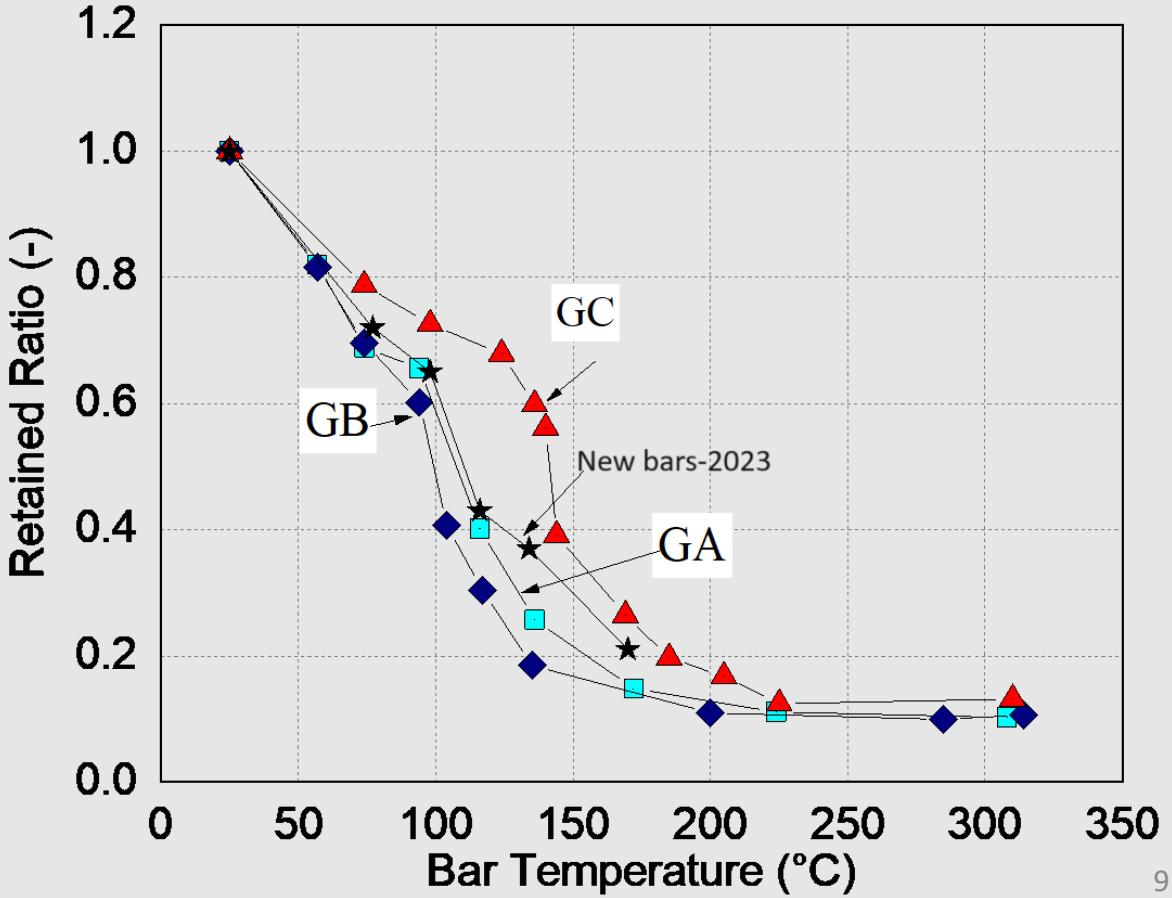
Temperatures within the thickness of the slabs.



Bond strength at high temperatures

Highlights:

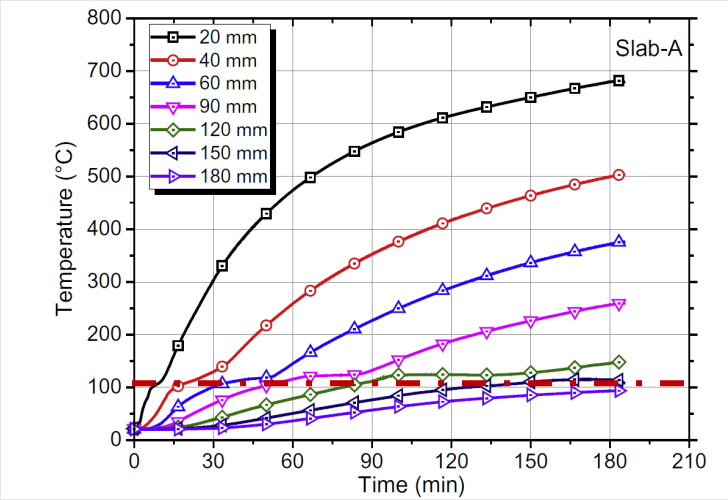
- New test series conducted in 2023

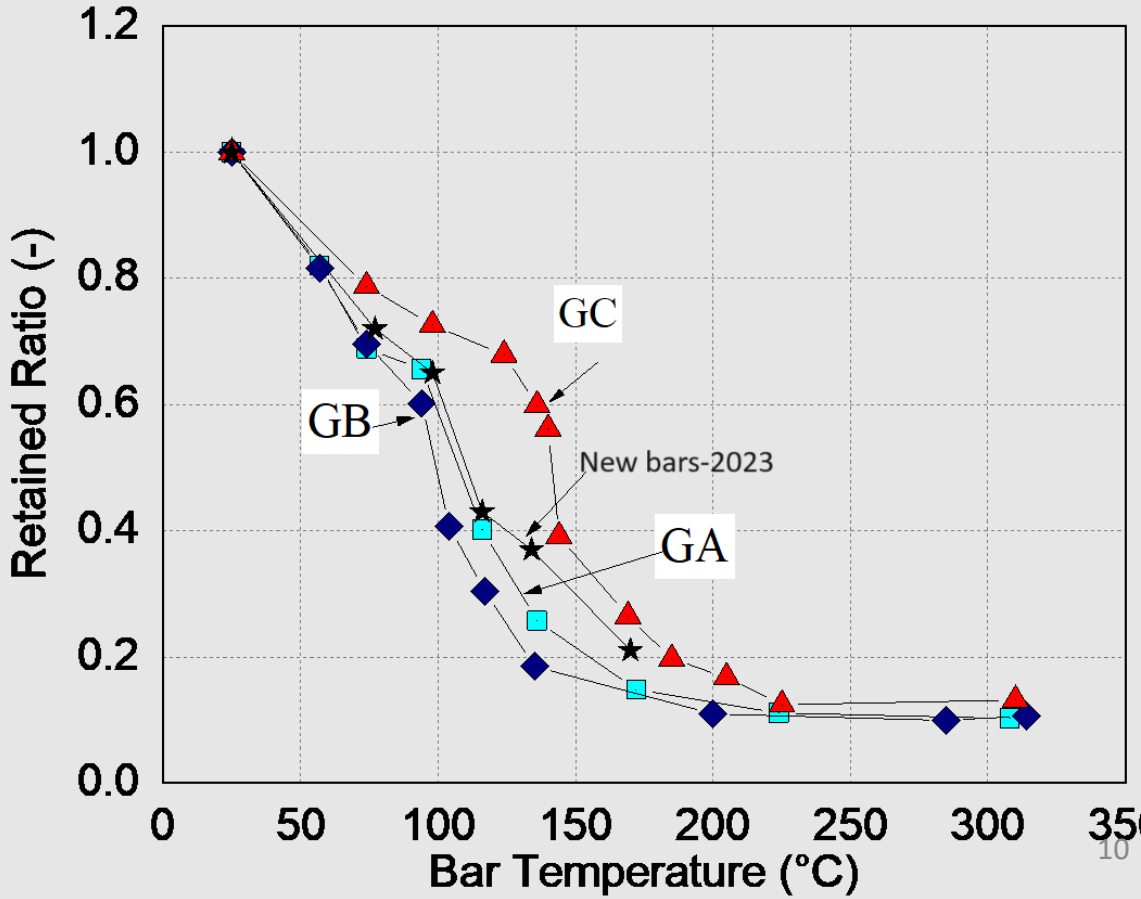


Bond strength at high temperatures

Highlights:

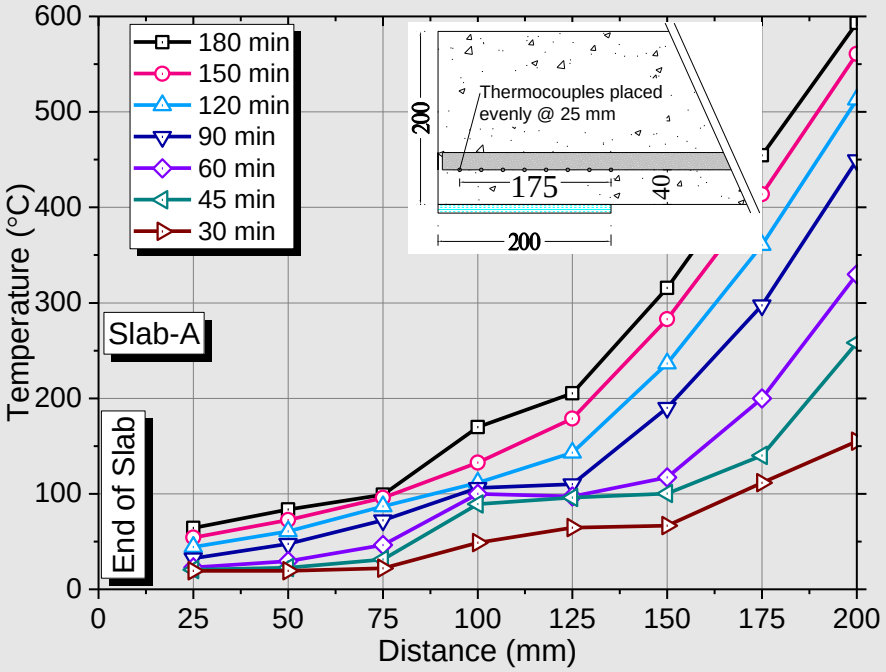
- Loss of bond strength (more than 80% loss at 170 °C (340 °F))
- Similar behaviour for GA and GB
- Slightly better bond strength of GC due to mainly higher glass transition temperature, T_g.





The conditions at end zones of GFRP concrete slabs
End zone length 200 mm (8 in.) & 40 mm cover (1.5 in.)

- Three hours of fire resistance
- 600 °C (1100 °F) at the bottom of the bars in the exposed zone
- 100 °C at 75 mm (3 in.) and 350 °C at 150 mm (6 in.) from the end of the slab



Temperature gradients in the unexposed zones

Condition of bars in the exposed and unexposed zones

ACI 440.11-22 guidelines for fire safety

1. Concrete cover
2. Unexposed length of FRP bars (embedment length)
3. FRP reinforcement layout (splices, cut-offs)
4. The tensile stress in FRP bars

Embedment into the support of at least 12 in. or 20d_b is conservative.

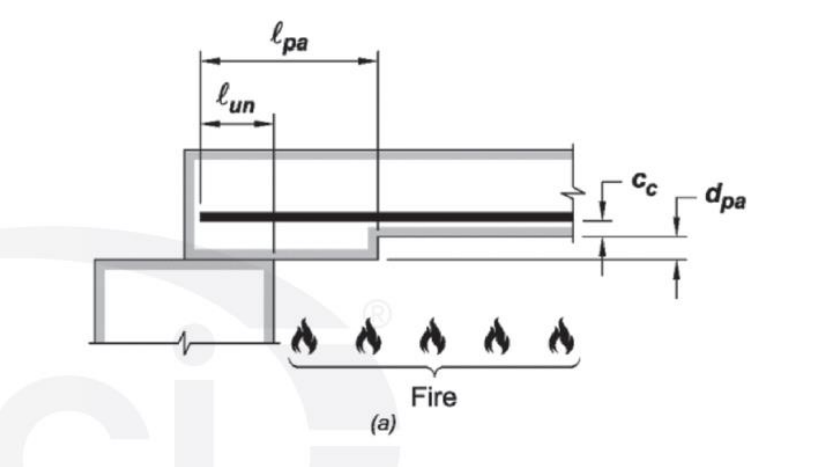
Table R20.5.1.3.1—Fire resistance rating provided by minimum cover for non-bond-critical GFRP reinforcement

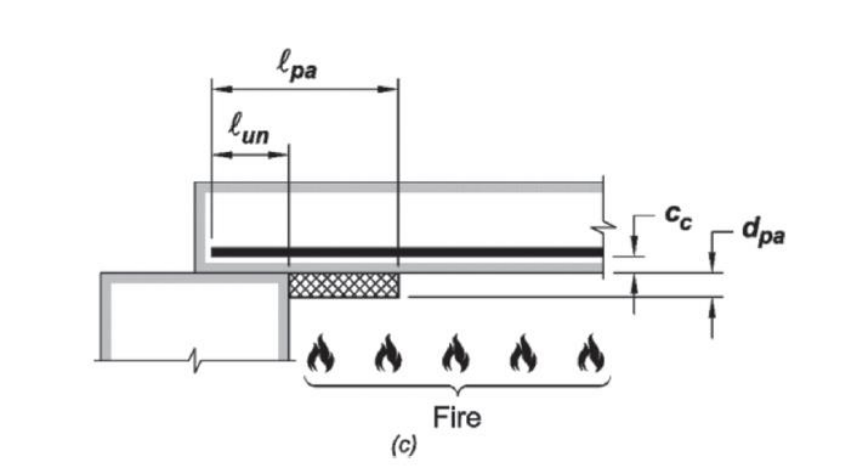
Specified cover, in.	Fire resistance, *h*		
	Slabs and non-load-bearing walls	Beams	Columns and load-bearing walls
2	1.5	1	0.5
1-1/2	1	0.5	0.5
3/4	0.5	NA	Less than 0.5

Table from ACI 440.11-22

ACI 440.11-22 guidelines for fire safety

If adequate embedment is not possible, additional protection can be provided by using a haunch or drop panel or insulating the concrete.



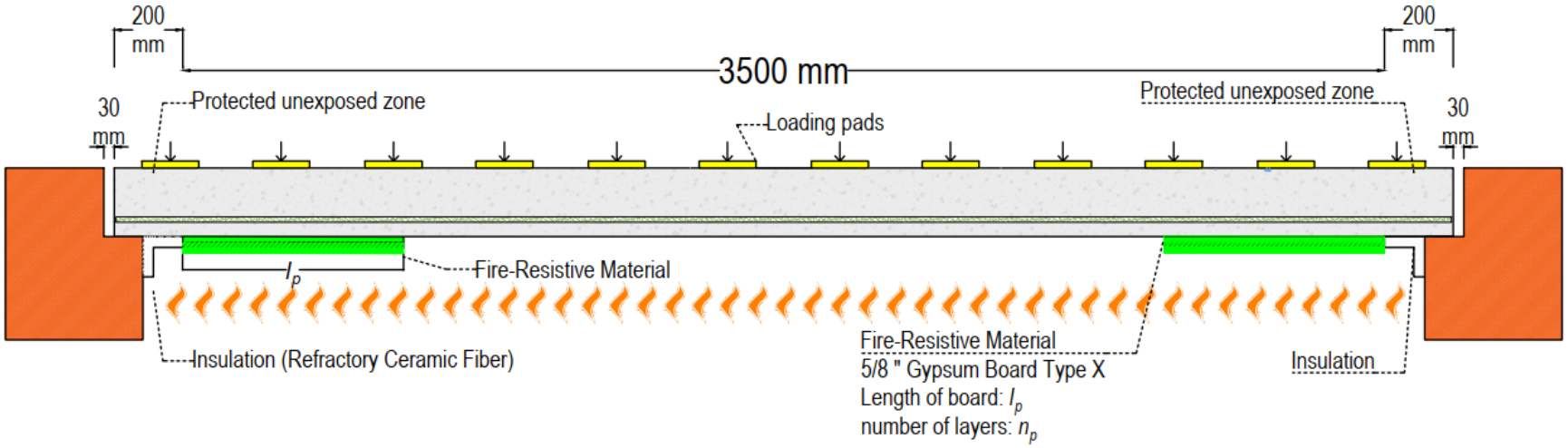


Protection of GFRP reinforcement near supports
(Figures from ACI 440.11-22)

Tentative test matrix

Several layers of fire protection to increase the cool embedment length of GFRP bar.

Insulation	l_p	Th_p
Gypsum Board	20 in (500 mm)	1 in (25 mm)
Gypsum Board	40 in (1000 mm)	½ in (12.5 mm)
SFRM	20 in (500 mm)	1.5 in (38/ mm)
Intumescent Paint	60 in (1000 mm)	1000 µm
Intumescent Paint	All substrate length	1000 µm



IBC, Chapter 7, Section 721

Tables: 721.1(3)- minimum protection for floor and roof systems

Item	Insulation Material	Thickness of floor or roof slab (inches)				Minimum thickness of ceiling (inches)			
		4 hours	3 hours	2 hours	1 hour	4 hours	3 hours	2 hours	1 hour
Reinforced Concrete Floor	Slab with suspended ceiling of vermiculite gypsum plaster over metal lath	3	2	-	-	1	3/4	-	-
	3/8" Type X gypsum wallboard	-	-	$2\frac{1}{2}$	-	-	-	5/8	-

Item	Insulation Material	Minimum Thickness for			
		4 hours	3 hours	2 hours	1 hour
Reinforcing steel in reinforced concrete columns, beams girders	Carbonate, lightweight and sand-lightweight aggregate concrete	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$
	Siliceous aggregate concrete	2	$1\frac{1}{2}$	$1\frac{1}{2}$	$1\frac{1}{2}$

Conclusions

Professional engineers who design GFRP-reinforced concrete must be aware of these guidelines and recommendations to achieve the desired fire ratings.

With proper design practices, GFRP-reinforced concrete members can be safely incorporated into reinforced concrete structures, ensuring both structural integrity and fire safety.

Acknowledgements

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Thank you. Questions?