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GFRP Misconceptions—Part 2

There are many design materials in a structural engineer's toolbox that should be evaluated for the structural and environmental conditions under consideration—concrete, mild reinforcement, prestressing, and even structural steel and wood. As engineers, we know that not even concrete is ideal for all structures. And so, glass fiber-reinforced polymer (GFRP) reinforcing bars cannot be used in all reinforced concrete applications. We should not be afraid of innovation as it will expand possibilities, and more research is being done to that aim. Many advances have been made in coated and uncoated specialty steels for reinforcing concrete as well.

In this series of Q&A articles, we will attempt to clarify some common questions and misconceptions about GFRP reinforcing bars. They are compared to steel reinforcing bars to reference something that the reader is likely more familiar with currently.

Support for the series is graciously recognized from the American Composites Manufacturers Association (ACMA) FRP Rebar Manufacturers Council, and NEX: An ACI Center of Excellence for Nonmetallic Building Materials.

Q1. *Traceability: Once the bars get to the project site, how will I be able to tell which products are which?*

A1. Purchasers of GFRP reinforcing bars can request in their purchase order or contract documents that the manufacturer provides a certificate of analysis (COA) for the bars, ensuring quality and compliance with ASTM International material specifications (ASTM D7957/D7957M¹ or D8505/D8505M²) at the time of purchase. The COA outlines both the testing results and the minimum standards for reference. Additionally, bar markings will be printed on each bar for cross-reference to these COAs. Each bar is clearly marked with the ASTM specification, bar size designation, manufacturer name, and lot number, allowing for easy identification and traceability to address any possible questions. This ensures that you know what products you have at any time during construction and is akin to a steel mill cert (or certificate) for steel reinforcing bars.

Q2. *Hybrid reinforced members with steel and GFRP: Am I allowed to use steel reinforcing bars and GFRP reinforcing bars together in the same structure or structural element?*

A2. Current provisions within ACI CODE-440.11-22³ would dictate that individual structural elements be designed using either GFRP reinforcing bars or steel reinforcing bars. Within a given structure, some structural elements may possibly be designed with GFRP reinforcing bars and other elements with steel reinforcing bars by following the respective provisions.

To highlight this distinction further, the design of members that use both GFRP reinforcing bars and steel reinforcing bars in the same element is not covered by ACI CODE-440.11-22 or ACI CODE-318-19.⁴ This may be allowed in future code provisions, however, given that research is currently being conducted for seismic-force-resisting elements that uses a combination of both GFRP and steel reinforcing bars. Additionally, it is important to note that there is no concern with mixing GFRP reinforcing bars and any coated or uncoated steel reinforcing bars from a dissimilar metal perspective (as there are with some steel reinforcing bar combinations) because GFRP is completely non-ferrous.

Q3. *Sustainability: Is there an embodied carbon benefit to using GFRP reinforcing bars? It seems like there must be some from what I know about production methods.*

A3. The product category rules (PCRs) for the development of Environmental Product Declarations (EPDs) for fiber-reinforced polymer (FRP) reinforcing bars have recently been published for North America, with other regions of the world offering alternative published PCRs.⁵ With that in mind, the American Composites Manufacturers Association (ACMA) has launched an EPD generator to facilitate development of EPDs in the composites industry. Several GFRP reinforcing bar manufacturers have published EPDs globally, and others are in process thanks to ACMA support. Purchasers or other interested parties can contact the manufacturer for their specific EPD.

Although comparisons are tempting and offer some indication of relative scale because the products were not prepared using the same PCRs (steel and GFRP, in this case), direct comparisons should not be made. That said, we can get an idea per linear foot. Given that the weight of GFRP reinforcing bars is approximately one-third to one-fourth of the weight for an equivalently sized steel reinforcing bar, and design for a given structural element or structure may not allow for a one-for-one replacement, comparison can be difficult. On a material-to-material basis, again based on a one-foot length of equivalently sized bars, further based on cradle-to-gate (modules A1-A3) and within the North American market, GFRP reinforcing bars would offer a 10 to 50% savings in greenhouse gas (GHG) emissions depending on the manufacturers used for comparison.

Comparisons at the element design level indicated that the difference between GFRP and steel is likely within ± 10 to 15% for common reinforced concrete structural designs, depending on specific structural considerations. Additional savings would be realized in transportation and construction (modules A4 and A5, where the weight savings really help with trucking/equipment needs) and the longevity of structures (for example, 100-year service life bridges with

lower maintenance costs). Inputs/data for the use stage (module B), end-of-life stage (module C), and beyond-the-system-boundary considerations like recycling and reuse (module D) are project-specific. This makes quantifying them more difficult, and to date, discussions have remained qualitative. Industry efforts to recycle both the resin and fiber from composites are currently underway, with the expectation that they will reach maturity prior to their need related to GFRP-reinforced concrete.

U.S.-based steel manufacturing uses high recycled content and electric arc furnace (EAF) production methods, making it some of the cleanest in the world.⁶ Globally, steel reinforcing bars are not all manufactured with these methods, and so comparisons may be quite different regionally around the world.

Q4. *Elevated temperatures and fire: What exactly are the limitations for GFRP-reinforced concrete structures when it comes to fire and elevated temperatures?*

A4. Per ACI CODE-440.11-22, Section 4.11, GFRP reinforcing bars cannot be used in any structures that require an elevated service temperature or a fire resistance rating unless the structural fire resistance has been shown to be adequate by calculations or tests and approved by the building official. Recall that a minimum glass-transition temperature T_g is specified in the material specification, and T_g is the temperature at which the composite goes from a hard solid consistency and begins to lose its rigidity, based on the modulus of the material. ACI CODE-440.11-22 limits the service temperature of members reinforced with GFRP reinforcing bars to 185°F (85°C).

ACI/NEEx MNL-6(23)⁷ outlines the limitations from the International Building Code (IBC) in Tables 2.4a and 2.4b (refer to Fig. 1 and 2, respectively) with the following guidance. Fire resistance ratings are generally required for reinforced concrete columns, elevated slabs, beams, and structural walls in building types that require structural fire ratings (for example, high-rise buildings, schools, and hospitals). Elements such as slabs-on-ground and footings generally do not require fire ratings.

Table 2.4a—Limits on permissible number of stories for sprinklered buildings with no fire resistance rating required by type

	II-B	III-B (except exterior walls)	V-B
Assembly	3	3	2
Business	4	4	3
Education	3	3	2
Mercantile	5	5	2
Residential R-1, R-2	5	5	3

Fig. 1: Table 2.4a from Reference 7

Table 2.4b—Limits on permissible area of sprinklered buildings with no fire resistance rating required by type

	II-B	III-B (except exterior walls)	V-B
Assembly	34,000 ft ² (3160 m ²)	34,000 ft ² (3160 m ²)	22,000 ft ² (2040 m ²)
Business	92,000 ft ² (8550 m ²)	76,000 ft ² (7060 m ²)	36,000 ft ² (3340 m ²)
Education	58,000 ft ² (5390 m ²)	58,000 ft ² (5390 m ²)	38,000 ft ² (3530 m ²)
Mercantile	50,000 ft ² (4640 m ²)	50,000 ft ² (4640 m ²)	36,000 ft ² (3340 m ²)
Residential R-1, R-2	64,000 ft ² (5950 m ²)	64,000 ft ² (5950 m ²)	28,000 ft ² (2600 m ²)

Fig. 2: Table 2.4b from Reference 7

Additionally, there are many common building types that do not require structural fire resistance ratings.

Significant research into fire performance of GFRP-reinforced concrete is underway (Fig. 3) for the next ACI CODE-440.11 cycle and has shown that the resin degrades within the concrete, but the fibers stay and, if there is sufficient anchorage in a cool zone (that is, an area where there is no fire), performance is sufficient for the required structural fire resistance ratings.



Fig. 3: Ongoing research led by Mark Green, Queen's University, and Hamzeh Hajloo, Carleton University, on GFRP-reinforced concrete under fire (Photos courtesy of MST Rebar Inc.)

Q5. *Seismic provisions: I understand that there are limitations to the use of GFRP reinforcing bars in higher seismic regions, is that true?*

A5. The Preface of ACI CODE-440.11-22 outlines that the design provisions cover the design of GFRP-reinforced concrete members in a structure assigned to Seismic Design Category (SDC) A and the design of GFRP-reinforced concrete members in SDC B and C if those members are not designated as part of the seismic-force-resisting system. Research is ongoing with the aim of expanding these provisions.⁸ ACI CODE-440.11-22 does not outline design provisions for structural concrete members in structures within SDC D, E, and F.

Q6. *Limitations: Should I be concerned about using GFRP reinforcing bars in light of the limitations that the Code is placing on their use?*

A6. The short answer is “no.” Nearly all “new” technologies have limits in the Code, especially as they are first included as acceptable materials, but even well beyond that. Although ACI CODE-318-19 does not specify a maximum strength for concrete, several design provisions do set a limit to $\sqrt{f'_c}$ of 100, effectively limiting the maximum concrete strength to 10,000 psi. Further, ACI CODE-318-19, Table 20.2.2.4(a), places maximum limits on the yield strength of mild steel reinforcement for various load conditions and structural applications. These limits are either 60, 80, or 100 ksi for various seismic, flexural, shear, and torsion applications.

Q7. *Currently, I am not seeing the option for GFRP mechanical splices or headed bars. Are future developments underway? And why are things like field bending not possible yet?*

A7. The industry has been working diligently over the past few decades to complete a bridge (through AASHTO) and building (through ACI) design code with accompanying materials specifications (through ASTM International). With those standards and specifications in place, research continues in several exciting areas, namely mechanical splices, headed bars, and the possibility to bend GFRP reinforcing bars post-production.

Several manufacturers and universities in the United States and Canada are working on research to develop a coupler/mechanical splice system for GFRP reinforcing bars. ICC-ES “AC552: Acceptance Criteria for Mechanical Splice Systems for Fiber Reinforced Polymer (FRP) Bars”⁹ was approved in 2023. Ideally, and to maintain the non-corrosive nature of GFRP reinforcing bars, these couplers will be nonmetallic. However, testing is underway to qualify GFRP reinforcing bars with commercially available metallic couplers and may be a nearer-term option.

Headed bars are also limited in their availability. CSA S807:19¹⁰ outlines some provisions for manufacturing headed bars, but there has not yet been broader consideration to create standards. This will be an area for future developments.

Additionally, related to the ability to bend GFRP reinforcing bars, the production of GFRP reinforcing bars using thermoplastic resins is under development. Compared to thermoset resins, which cure and will not soften in a manner that will allow for production-level manipulation of bar shape, thermoplastic resins have a more flexible polymer structure and could possibly allow for production-level manipulation of bar shape. This would allow GFRP

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reinforcing bars to be bent post-manufacturer at a fabricator facility or in the field. It is important to note that potentially bending bars post-production would require considerable quality control provisions. Yet, this is a possible development, like all those discussed herein that offer promise to the industry.

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Questions in this column were asked by users of ACI documents and have been answered by ACI staff or by a member or members of ACI technical committees. The answers do not represent the official position of an ACI committee. Comments should be sent to lacey.stachel@concrete.org.

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