

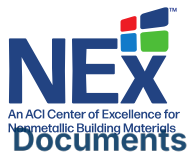


Recommended Practice Guidelines for FRP Bars in Pre-Engineered Projects

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Recommended Practice Guidelines for FRP Bars in Pre-Engineered Projects

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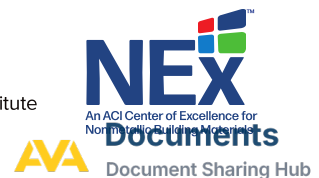
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**Recommended Practice Guidelines for FRP Bars in
Pre-Engineered Projects**

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PREFACE

The *ACI Recommended Practice Guidelines for FRP Bars in Pre-Engineered Projects* provide practical information on how to work with and install non-metallic glass fiber-reinforced polymer (GFRP) reinforcement. It details the key considerations for where to use GFRP reinforcement, the types of GFRP reinforcement available, and how to plan for installing this type of reinforcement. The key attributes of GFRP reinforcement and its proper use are also discussed.

In addition, the *ACI Recommended Practice Guidelines for FRP Bars in Pre-Engineered Projects* provides prescriptive design tables for common applications such as residential foundation walls and slabs-on-ground. The tables presented are similar to the prescriptive tables in “Code Requirements for Residential Construction and Commentary” (ACI 332). They are meant to allow contractors to understand how to select the appropriate size, location, and spacing of GFRP reinforcement for a project and to compare the layout of GFRP reinforcement to steel reinforcement.

The storage, handling, and installation of GFRP reinforcement is presented with focus on the requirements in “Construction with Glass Fiber-Reinforced Polymer Reinforcing Bars—Specification” (ACI SPEC-440.5).

The appendix to this guide provides additional detailed information from FRP bar manufacturers on commercially available products and solutions.

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CHAPTER 1—INTRODUCTION

This manual aims to provide guidance for the use of glass fiber-reinforced polymer (GFRP) reinforcing bars in common concrete construction applications, including basement foundation walls and flatwork. The guidance is based on the code requirements provided in ACI CODE-440.11-22, “Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary.” It uses the requirements in this document to modify the tables provided for steel-reinforced concrete in ACI 332-20, “Code Requirements for Residential Concrete and Commentary.” Combining the requirements of these two documents provides a set of pre-engineered design tables for GFRP bars in a range of common residential and light commercial applications. Note that these tables only apply to buildings assigned to Seismic Design Categories A, B, or C as defined in ACI 332 Section 1.1.7.

Additionally, this manual aims to provide an overview of GFRP bars and fiber-reinforced polymer (FRP) materials broadly. A basic understanding of the material properties, strengths, and limitations of these materials, their history of use and research, and typical applications can help guide decisions on where and how to use these bars.

Lastly, construction with GFRP bars differs from the use of traditional steel reinforcement. Application guidance and examples are provided in this manual to facilitate the safe and proper use of GFRP bars in reinforced concrete construction.

1.1—Application and research history

The use of GFRP reinforcement began in the late 1970s as a nonmetallic alternative to steel reinforcement. Much of the initial interest in GFRP reinforcement was due to applications that demanded nonmetallic reinforcement. These include reinforcement of structures around magnetic resonance imaging (MRI) units in hospitals and in magnetic levitating (maglev) trains, as shown in Fig. 1.1a. In both of these applications, ferrous materials can interfere with the operation of the equipment, and GFRP reinforcement—as a nonmetallic, non-ferrous alternative—has become a standard construction practice for these applications. Some of the largest early applications of GFRP reinforcing bars were in the Gonda Building at the Mayo Clinic in Rochester, MN, built in 2001, and at the National Institutes of Health in Bethesda, MD, built in 1984, both involving reinforcing concrete elements in close proximity to MRI units.

During this time, there was also interest in the noncorrosive nature of GFRP reinforcement and an increasing aware-



ness of the deterioration of steel-reinforced concrete due to corrosion of the embedded steel. By the mid-1990s, several bridge structures were constructed using GFRP reinforcement as a way of reducing maintenance costs associated with corrosion issues. There are several early examples of bridge decks exposed to deicing salts being reinforced with GFRP bars to reduce corrosion and spalling of the concrete surface. One example is shown in Fig. 1.1b.

Early applications of GFRP reinforcement were coupled with and supported by research into the structural capacity of GFRP-reinforced concrete members. Early studies of FRP-reinforced concrete focused on beams and slabs reinforced with GFRP (Faza and GangaRao 1993; Nanni 1993; Benmokrane 1996). These early studies verified that many of the same principles of steel-reinforced concrete also apply to GFRP-reinforced concrete.

Later studies focused on specific aspects of GFRP reinforcement such as durability (Benmokrane and Rahman 1998; Porter et al. 1997). Much of the durability research was concerned with the ability of GFRP bars to sustain loads in the alkaline environment of cast concrete. These studies indicated that proper resin systems in these bars



Fig. 1.1a—GFRP reinforcement used around MRI units in hospitals and in maglev train applications. The photo on the left is of the AirportLink maglev railway that connects to the Miami Intermodal Center (MIC), built in 2011. The photo on the right is a cage of reinforcement being transported to a concrete placement in a room that will eventually house an MRI unit (photos courtesy of Doug Gremel).

would provide protection to the glass fiber reinforcement and allow for long-term performance. This has been further substantiated through long-term studies of bars in service (Gooranorimi et al. 2019). More discussion of durability is in Chapter 2.

Research on bond characteristics of GFRP reinforcement to concrete (Bakis et al. 1998; Bank et al. 1998), the shear strength of concrete elements reinforced with FRP (Tureyen and Frosch 2003), and reinforcing other concrete elements such as square and circular columns (De Luca et al. 2010; Afif 2013) have all helped serve as the basis for the development of ACI CODE-440.11. Additional information on the research and initial applications of GFRP reinforcement can be found in ACI 440.1R-15, “Guide for the Design and Construction of Structural Concrete Reinforced with Fiber-Reinforced Polymer (FRP) Bars.”

1.2—Application examples

Today, GFRP reinforcing bars are used extensively in coastal construction, bridge construction, and general construction where lightweight, easy-to-place reinforcement is advantageous. A few recent examples are highlighted in Fig. 1.2a to 1.2e.



Fig. 1.1b—Bridge decks reinforced with GFRP bars as a way of mitigating corrosion issues when exposed to deicing salts. The photo on the left is of the Sierrita de la Cruz Creek Bridge in Amarillo, TX, which was constructed in 2000. The photo on the right is of the Red River Floodway bridge in Winnipeg, MB, Canada, which consumed over 310,000 lb (140,000 kg) of GFRP reinforcing bars and was constructed in 2006.



Fig. 1.2a—The use of GFRP reinforcing bars on Brays Bayou Hike & Bike Trail in Houston, TX, allowed the contractor to work efficiently using lighter equipment. This was in areas where heavier equipment was not always possible to use. The contractor was able to pre-tie grids of reinforcement that were easily moved into position.

- Project size: 10 ft (3 m) wide x 9 miles (14 km) long, or 475,000 ft² (44,000 m²)
- GFRP bar: GatorBar GFRP No. 3 (M10)
- Construction time frame: Summer/Fall 2022



Fig. 1.2b—The foundations and shear walls of this eight-story building were reinforced with GFRP reinforcing bars. Sizes ranging from No. 3 to No. 11 bars were used and required complicated bend geometries for anchorages and ties. This illustrates the utility of GFRP bars in complex and demanding structural applications.

- Project size: 1,400,000 linear ft (426,000 linear m) of GFRP bar
- GFRP bar: MST-BAR Sizes No. 3 (10M), No. 5 (M16), No. 8 (M25), and No. 11 (M35)
- Construction time frame: 2020



Fig. 1.2c—The Low Battery Seawall and seaside promenade is a historic landmark in Charleston, SC. The seawall was raised 1.8 ft (0.5 m) to match the High Battery Seawall. GFRP reinforcement was used due to its ability to resist corrosion in this severe coastal environment and for aesthetic concerns with steel corrosion products leaching onto the surface of the concrete (Steputat et al. 2022).

- Project size: 3.9 miles (6.3 km) of seawall
- GFRP bar: *Fiberglas™ Rebar by Owens Corning Infrastructure Solutions*
- Construction time frame: 2021 to 2022



Fig. 1.2d—Currently the largest single project to use GFRP reinforcement, the Jizan Flood Mitigation Channel is a megaproject to protect the refining facilities of Saudi Aramco on the banks of the Red Sea in Saudi Arabia. The GFRP bar provides corrosion resistance in this coastal region and its light weight allowed for faster installation than traditional methods. There was a reported 21% cost savings in initial construction using GFRP bars versus epoxy-coated steel bars (Villen Salan et al. 2021).

- Project size: Total length of 13 miles (21 km); the channel reaches a maximum width of 236 ft (72 m)
- GFRP bar: *Dextra ASTEC Glass Rebar Galen-Panamerica/Binevir Fiberglass Rebar and IKK Mateenbar™*
- Construction time frame: 2019 to 2020



Fig. 1.2e—The Harker Island Bridge in Carteret County, NC, is a 3.2 mile (5 km) long vehicular bridge near the Outer Banks that includes 28 spans. The bridge deck is reinforced with GFRP bars, and the bridge girders are both prestressed with carbon FRP (CFRP) tendons and reinforced with GFRP bars. The entire bridge structure uses almost no steel reinforcement. FRP solutions were used on this bridge to combat the corrosive, brackish coastal environment of the Outer Banks.

- Project size: 1,575,000 linear ft (480,000 linear m) of GFRP reinforcement
- GFRP bar: Fiberglas™ Rebar by Owens Corning Infrastructure Solutions No. 4 (M13), No. 5 (M16), No. 6 (M19), and No. 8 (M25)
- Construction time frame: 2022 to 2023

CHAPTER 2—MATERIALS AND DURABILITY**2.1—Introduction**

It is important to understand that simply replacing steel reinforcement with the same size and spacing of fiber-reinforced polymer (FRP) reinforcement is not appropriate. FRP reinforcement must be specifically designed based on the unique properties of FRP. This chapter is meant to provide a synopsis of the key properties of FRP as it relates to its use in reinforced concrete structures.

FRP reinforcement behaves in a much different way than steel reinforcement. It is not ductile like steel, meaning that it does not reach a yield point and permanently bend. Rather, it is fully elastic and will snap back to its original shape once loads are removed. This also means that when it does fail or break, it does so suddenly and without warning. It is the very definition of a brittle material. Although these materials are brittle, most FRP materials have very high tensile strength (much higher than steel in many cases), and they are very lightweight (weighing only a fraction of what steel or aluminum weighs on a weight per volume basis).

These unique properties have led to the widespread use of this material in aircraft (the wings and fuselage of modern commercial aircraft such as the Boeing 787 are constructed almost entirely of FRP materials), sporting goods (golf clubs, bicycles, skis, surf boards, fishing rods, and many other sporting goods rely heavily on the use of FRP materials), and automotive applications.

FRP material is a composite material consisting of a dense network of high-strength, continuous fibers that are bound together by a polymer material. The fibers provide the strength and stiffness properties to the composite and the polymer binds the fibers together and give the material its shape. It is important to recognize that FRP materials have different properties in different directions. Similar to wood, which is strong along its grain and weak perpendicular to its grain, FRP materials are strongest and stiffest in the direction of the fibers, but significantly weaker in directions off-axis to the fiber direction. The FRP material shown in Fig. 2.1, for example, would have high strength only in the direction along the fibers. In the directions perpendicular to the fibers, the material would be significantly lower in strength (just the strength of the polymer alone). In addition to mechanical properties, other properties such as the coefficient of thermal expansion, electrical conductivity, and thermal conductivity can also vary depending on direction.

FRP reinforcing bars typically have fibers running only along the length of the bar. This allows the bars to have high



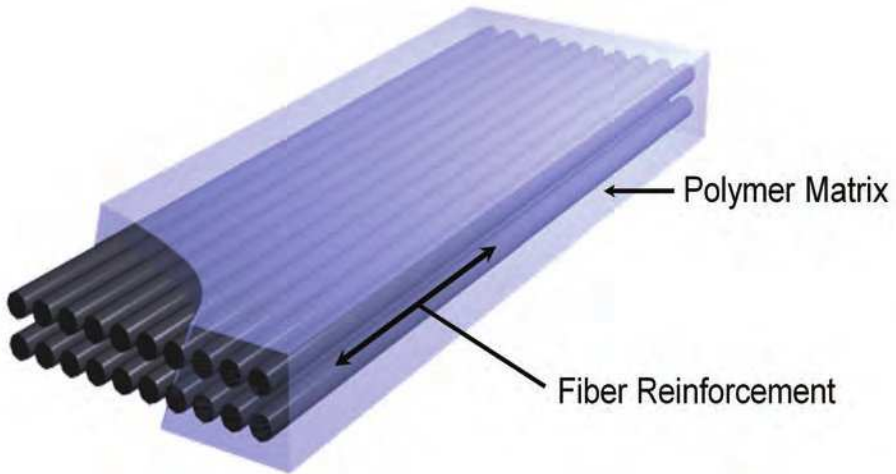


Fig. 2.1—FRP composite material showing the two materials forming it. The fibers used in high-strength FRP composites are continuous (they are not chopped fibers or discrete fibers like may be found in fiber-reinforced concrete). The fibers themselves are very small diameter (less than the diameter of a human hair). A dense network of these small-diameter, continuous fibers reinforce the FRP material. An FRP composite material will generally have several million fibers per square inch of cross section.

strength and stiffness along the length of the bar, but the bars have relatively lower strength and stiffness perpendicular to the bar. As such, FRP bars have lower shear strength and may have lower bond strength than comparable steel bars.

2.2—FRP types

The FRP materials most commonly found for construction applications are constructed of glass fiber (GFRP), basalt fiber (BFRP), or carbon fiber (CFRP). Aramid fibers (AFRP) may also be used but are less common. The polymers used to construct FRP bars are typically vinyl ester or epoxy thermosetting polymers. Other thermoset polymers such as polyesters may also be found but are not as common.

The types of FRP systems, materials, and other structures in construction are quite vast and are increasing. They range from the very exotic, such as the circular CFRP roof of the Apple Theater at Apple Computer's headquarters in Cupertino, CA, to more common applications such as moisture-resistant GFRP wall panels used in garages and laundry spaces. Figure 2.2a shows an array of various FRP materials used in construction applications.

Specifically for concrete construction, FRP materials are used for structural applications, including FRP bars and

grids for concrete reinforcement, stay-in-place FRP forms, and as externally bonded reinforcement for strengthening and retrofit of existing concrete elements.

GFRP, BFRP, and CFRP reinforcing bars are commonly available. GFRP and BFRP bars are generally the most economical and have similar properties. CFRP bars have much higher strength and stiffness than GFRP or BFRP but are generally more costly. CFRP reinforcing bars are less



Fig. 2.2a—FRP materials are used in a wide variety of construction applications. The images above show GFRP window frames used by many window and door manufacturers, composite gratings and railing systems used in industrial and pedestrian bridge applications, FRP utility and light poles, and FRP stakes used in gardens and for snowplow markers (photos courtesy of Galen-Panamerica/Binevir).

common for new construction. They are more commonly used in strengthening or reinforcing existing structures. CFRP wraps and laminates, as shown in Fig. 2.2b, are also commonly used for strengthening existing structures.

FRP bars can also be assembled into manufactured grids or manufactured as grids similar to welded wire fabric reinforcement, as shown in Fig. 2.2c.

Figure 2.2d shows several types of FRP bars. ASTM D7957/D7957M sets standard requirements for FRP reinforcing bars. This standard applies only to **solid, round, GFRP bars** made with vinyl ester resin. ACI CODE-

440.11 provides building code requirements only for bars that conform to ASTM D7957/D7957M and the prescriptive design tables and recommendations in this manual applies only to bars that conform to ASTM D7957/D7957M. New standards from ASTM are under development that will allow for broader fiber and resin types (such as basalt fiber and epoxy resins) in future code requirements.



Fig. 2.2b—Externally bonded FRP reinforcement is often used to strengthen existing concrete elements. This photo shows a carbon fabric or wrap FRP system being applied with structural resins and adhesives to add external reinforcement to a concrete beam.

2.3—Mechanical properties

2.3.1 Tensile properties—The most significant difference between the tensile



Fig. 2.2c—FRP grids used similarly to welded wire fabric for reinforcement of concrete slabs, walls, and other elements (photos courtesy Galen-Panamerica/Binevi)

properties of FRP materials and steel is the brittle nature of FRP materials. The lack of ductility or yielding in FRP bars requires that they have higher safety factors in design. In reinforced concrete applications, this might result in more FRP reinforcement being required versus steel reinforcement even though FRP materials typically have higher tensile strength than steel. GFRP and BFRP bars also have lower stiffness than steel reinforcement, which results in more GFRP or BFRP bars being needed to control cracking and deflections in concrete elements compared to elements with steel reinforcement. CFRP bars generally have much higher strength and similar stiffness to steel bars. A comparison of how these various materials behave under tensile stress is shown in Fig. 2.3.1.

It is also important to note that the tensile strength of FRP bars changes with the bar size. Larger bar diameters generally have lower net tensile strength because the outer fibers of the bar are more highly stressed than the inner fibers of the bar when loaded in tension (and bonded to concrete). ASTM D7957/D7957M provides a table of the minimum tensile force for GFRP bars with a range of values, depending on the bar size. For example, the minimum tensile force for a 1/4 in. (6.3 mm) diameter, No. 2 (No. M6) bar is 6100 lb



Fig. 2.2d—Solid, round, FRP bars for concrete reinforcement. The photo on the left shows GFRP (lighter-colored bars) and BFRP (darker-colored bars) (photo courtesy of Galen Composites). The photo on the right is a bundle of GFRP bars (photo courtesy of Gator Bars).

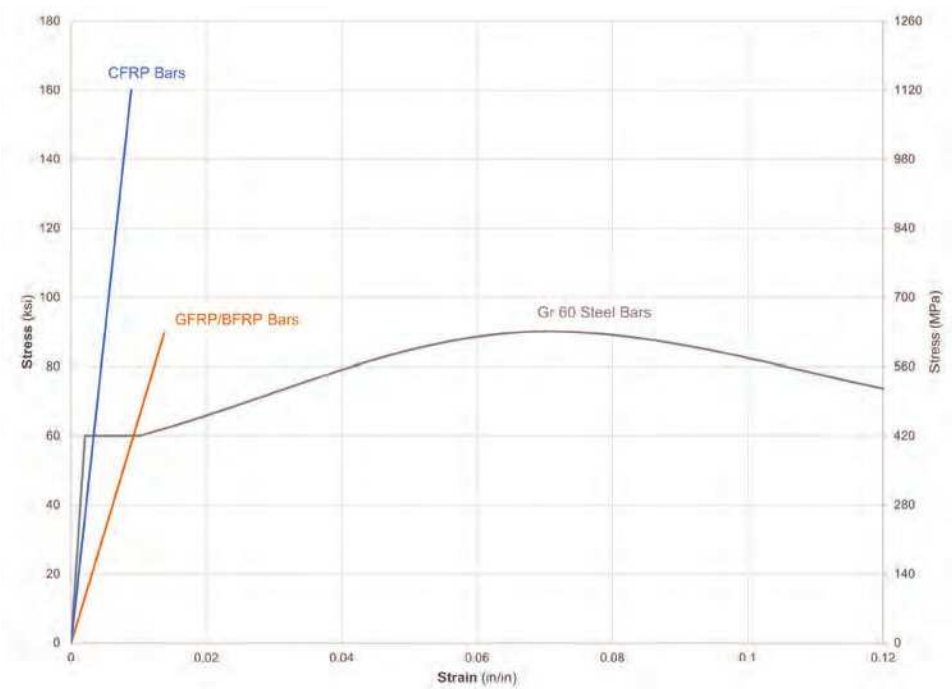


Fig. 2.3.1—Tensile stress-strain curves for various FRP reinforcing bars versus Grade 60 steel reinforcing bars. FRP is, in general, a brittle material. GFRP and BFRP bars have high strength but lower stiffness than steel. CFRP bars have very high strength and similar, but slightly less, stiffness than steel reinforcement.

(27 kN), which translates to 125 ksi (844 MPa), whereas the minimum strength of a 1-1/4 in. (32.3 mm) diameter, No. 10 (No. M32) bar is 98,200 lb (437 kN), which translates to 77 ksi (534 MPa).

2.3.2 Compressive properties—FRP bars do have significant compressive strength. However, their compressive strength and stiffness is lower than their tensile strength. FRP bars are typically used for tensile reinforcement without much reliance on them for compressive strength.

2.3.3 Shear strength—The shear strength of FRP bars is generally lower than comparably sized steel bars. ASTM D7957/D7957M does require that bars have a minimum shear strength of 19,000 psi (131 MPa) when tested per ASTM D7617/D7617M.

2.3.4 Bond strength—FRP bars intended to be used for concrete reinforcement generally have surface treatments that allow for bond to concrete. These can be sand coatings, deformations such as helically wound fibers that indent the surface of the bar, or protrusions or lugs machined into the surface of the bar. (There are other FRP bars used with

concrete that do not use surface treatments, such as FRP dowel bars and FRP bars embedded in epoxy used for strengthening existing structures.) GFRP bars conforming to ASTM D7957/D7957M are required to have a bond strength of at least 1100 psi (7.6 MPa) to concrete when tested per ASTM D7913/D7913M.

2.3.5 *Strength at bends*—FRP bars cannot be field bent due to their lack of ductility. However, it is common for bars to be produced with 90-degree bends by bar manufacturers. The bend radius that the fibers must follow to allow such bends do result in a lower tensile strength at bend locations. ASTM D7957/D7957M requires the tensile strength of the bent portion of a bar to be at least 60% of the strength of the straight bar.

2.3.6 *Durability*—FRP bars are often selected for their long-term durability, particularly in corrosive environments. However, durability of FRP bars has been the subject of much research. In particular, the durability of GFRP bars in alkaline environments, as exist in new concrete, has been of interest. It is known that alkaline environments can degrade some commonly used types of bare glass fibers, especially when coupled with moisture and heat. Research has indicated that the resin component of the GFRP material is critical in offering protection to GFRP bars. ASTM D7957/D7957M specifies only vinyl ester resin because research has shown good performance of GFRP bars in alkaline environments for this resin type and the bulk of the research and long-term durability studies are on bars made with vinyl ester resins. Figure 2.3.6 shows a microscopic view of a GFRP-to-concrete interface. Between the concrete and the GFRP bar is a white band with darker ovals. This is the resin-rich sand coating on a typical GFRP bar. It has been proposed that this band provides protection for the glass fibers from the alkaline environment of the surrounding concrete. Even without this layer, the glass fibers along the outside of the bar may deteriorate due to alkalinity but only outer fibers would be affected. Long-term durability studies have shown that bars in service for nearly 20 years have shown only a 2% reduction in tensile strength. Furthermore, design procedures in ACI CODE-440.11 account for potential reductions in strength over time to help ensure adequate long-term structural capacity of GFRP-reinforced concrete elements.

2.3.7 *ASTM minimum properties*—ASTM D7957/D7957M sets minimum properties for GFRP bars. However, many manufacturers produce bars that have much higher properties, especially higher stiffness. Higher-stiffness bars

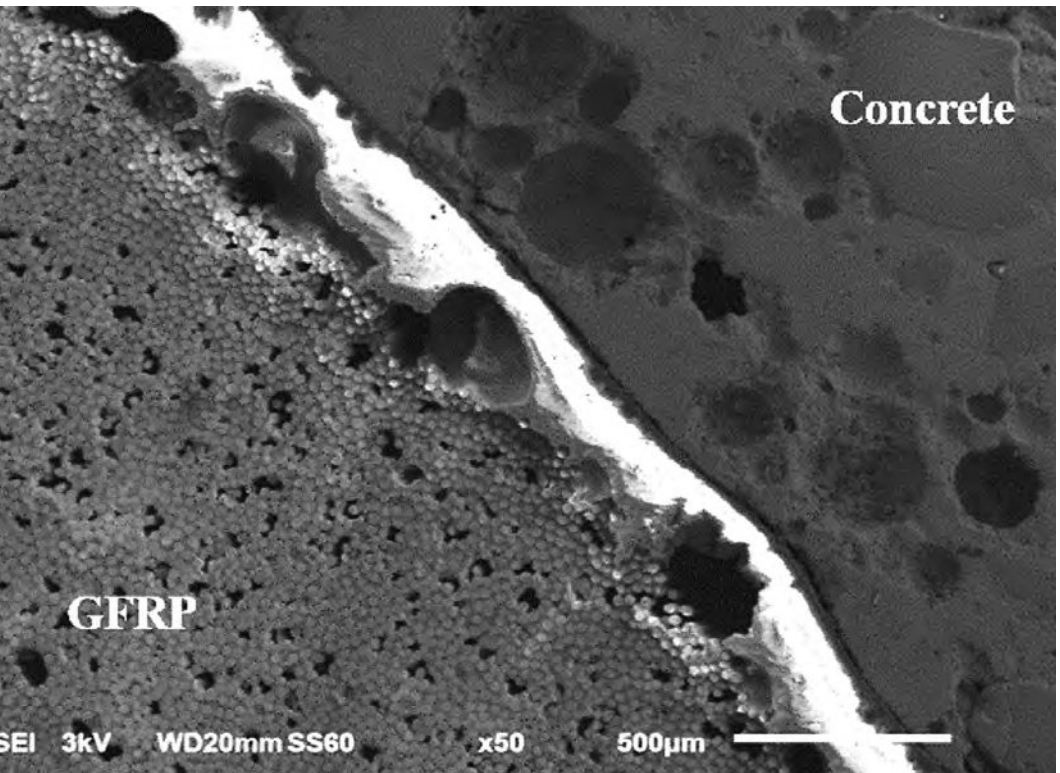


Fig. 2.3.6—Microscopic image of the interface between a GFRP bar and concrete. The white band with dark ovals is the resin-rich sand coating on the outside of the bar (sand particles are the dark ovals, the resin is the white band), showing the protection the resin offers to the GFRP bar (Gooranorimi et al. 2019).

would result in better structural performance. The design tables provided in this manual are all based on ASTM minimums. ACI CODE-440.11 does allow for designing using a specific bar manufacturer’s properties. Thus, bar spacings may be able to be reduced if higher-stiffness bars are used. The table values in this manual should be considered conservative for bars that conform to ASTM D7957/D7957M.

Table 2.3.7 (Table M2.3.7 for SI units) gives the minimum properties for bars from ASTM D7957/D7957M. Note that bar sizes and cross-sectional areas are the same as steel bars. Also note that bar strength does vary with bar size. As stated previously, larger bars have lower strength than smaller bars due to stresses in the inner portion of the bar being lower than on the outer surface of the bar. ASTM D7957/D7957M only covers bars ranging from No. 2 (No. M6) to No. 10 (No. M32). GFRP bars larger than No. 10 (No. M32) are not common but are becoming available. **The appendix to this manual provides properties for specific FRP bar manufacturers.**

Table 2.3.7—ASTM D7957/D7957M minimum properties for GFRP bars

Bar no.	Diameter, in.	Area, in. ²	Guaranteed ultimate tensile force, kip	Guaranteed ultimate tensile strength, psi	Guaranteed tensile strength at bends, psi	Elastic modulus, psi	Shear strength, psi	Bond strength, psi
2	0.25	0.049	6.1	124,000	74,400	6,500,000	19,000	1100
3	0.375	0.11	13.2	120,000	72,000			
4	0.5	0.2	21.6	108,000	64,800			
5	0.625	0.31	29.1	94,000	56,400			
6	0.75	0.44	40.9	93,000	55,800			
7	0.875	0.6	54.1	90,000	54,000			
8	1.0	0.79	66.8	85,000	51,000			
9	1.125	1.0	82.0	82,000	49,200			
10	1.25	1.27	98.2	77,000	46,200			

Table M2.3.7—ASTM D7957/D7957M minimum properties for GFRP bars

Bar no.	Diameter, mm	Area, mm ²	Guaranteed ultimate tensile force, kN	Guaranteed ultimate tensile strength, MPa	Guaranteed tensile strength at bends, MPa	Elastic modulus, MPa	Shear strength, MPa	Bond strength, MPa
M6	6.3	32	27	844	506	44,800	131	7.6
M10	9.5	71	59	831	499			
M13	12.7	129	96	744	447			
M16	15.9	199	130	653	392			
M19	19.1	284	182	641	385			
M22	22.2	387	241	623	374			
M25	25.4	510	297	582	349			
M29	28.7	645	365	566	339			
M32	32.3	819	437	534	320			

2.4—Fire resistance considerations

The polymer component of FRP materials will soften under moderately high heat. At elevated temperatures, the polymer rapidly transitions from a glassy material to a rubbery material and the FRP material rapidly loses strength and stiffness. The glass transition temperature T_g of FRP materials is the average temperature over which it transitions from a rigid, glassy material to a rubbery material. The transition occurs rapidly over a small temperature change as shown in Fig. 2.4. The transition to a rubbery material is a permanent change for thermosetting polymers such as the vinyl esters used in FRP reinforcing bars.

Most commercially available FRP bars constructed using vinyl ester polymers have a glass transition temperature near 250°F (120°C). ASTM D7957/D7957M requires a minimum glass transition temperature of 212°F (100°C) tested per ASTM E1356. In the commentary, ACI CODE-440.11 Section R20.2.2.3 recommends that GFRP reinforcement

should not be used in structures that are in environments with service temperatures that rise to within 27°F (15°C) of the glass transition temperature. That is, service temperature should not exceed $T_g - 27^\circ\text{F}$ ($T_g - 15^\circ\text{C}$) to avoid softening of the FRP and loss of properties.

Under more severe elevated temperature conditions, such as fire, the strength of the FRP bars may be compromised. ACI CODE-440.11 does not allow the use of GFRP bars in fire-rated construction unless the fire resistance is demonstrated by calculations or tests and the building official allows it. The commentary to ACI CODE-440.11 provides guidance for methods to protect GFRP bars in a fire using additional cover or insulation near the ends of bars and at bar splices. The use of these methods would require additional scrutiny by the building official.

Fire resistance ratings are generally required for reinforced concrete columns, elevated slabs, beams, and structural walls in building types that require structural fire ratings (such as high-rise buildings, schools, and hospitals).

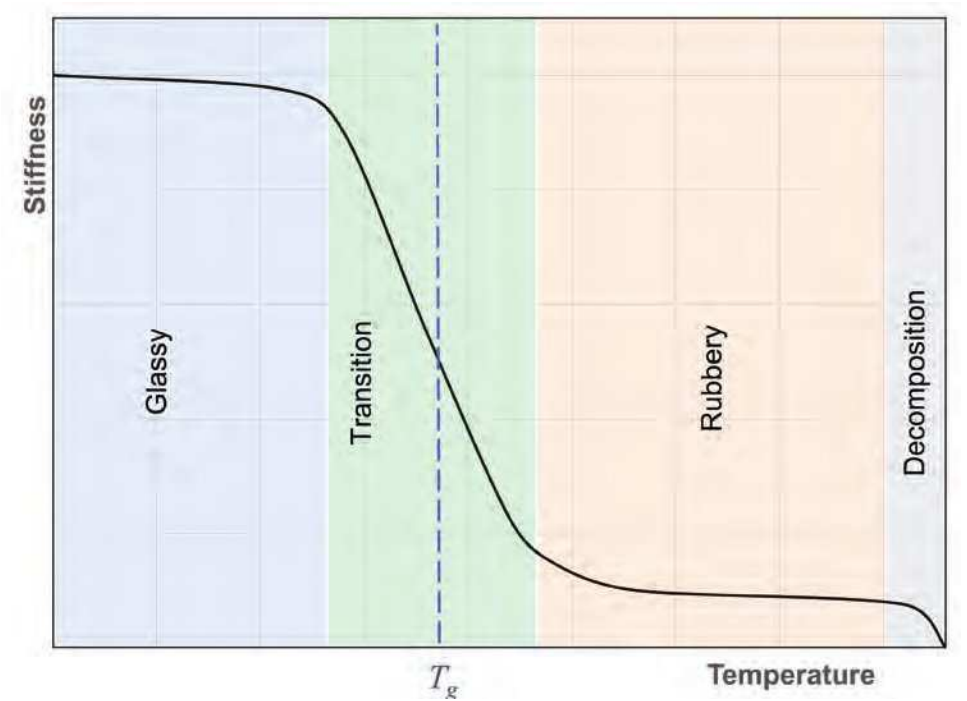


Fig. 2.4—Idealized stiffness-versus-temperature curve for FRP materials showing the transition from a glassy, rigid material to a rubbery, flexible material. The temperature at the midpoint of this rapid transition is the glass transition temperature T_g .

Elements such as slabs-on-ground and footings generally do not require fire ratings. Additionally, there are many common building types that do not require structural fire resistance ratings especially when other fire protection methods (such as the use of sprinkler systems) are in place. Tables 2.4a and 2.4b give limitations on building story height and building area (square footage) where no fire resistance requirement is required, provided sprinkler systems are in place. Type II-B, Type III-B, and Type-VB construction do not require structural fire ratings. Type II-B buildings are constructed from unprotected non-combustible materials but do not have fire resistance rating requirements. Concrete buildings with FRP reinforcement would fall into this category because the construction is noncombustible, but does not possess/require a fire resistance rating. Type III-B buildings are typically a combination of masonry or concrete walls with a fire rating and roof and floor assemblies constructed of wood with no fire ratings required. Usually these comprise historic buildings. Type VB construction is unprotected wood construction common in residential construction. FRP reinforcement may be used in concrete components of such buildings. IBC Section 504 provides additional information.

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

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)

CHAPTER 3—APPLICATIONS

Fiber-reinforced polymer (FRP) reinforcing bars have many unique properties compared to traditional steel reinforcement. They are non-corrosive, non-magnetic, and are lighter weight and easier to cut than steel reinforcement. All these properties make them an attractive alternative to steel reinforcement in certain applications. Many of the applications where glass FRP (GFRP) reinforcement has specific benefits are described in this chapter.

3.1—Benefits of FRP bars

3.1.1 Non-corrosive—One of the main benefits of FRP reinforcing bars is that they do not corrode. This has led to the use of FRP reinforcing bars as an alternative to steel reinforcing bars in several applications where corrosion of reinforcing steel is a significant concern. Examples include parking garages subject to deicing salts, as shown in Fig. 3.1.1a, and coastal infrastructure exposed to marine chlorides, such as the seawall shown in Fig. 3.1.1b.

Corrosion of reinforcing steel in concrete and its effects are well known. In new steel-reinforced concrete construction, the high alkalinity of the fresh concrete generates a passivating layer around internal steel reinforcement that protects it from corrosion. However, over time, the alkalinity of concrete can be reduced by carbonation and/or the introduction of chlorides into the concrete can provide an environment suitable for corrosion of steel to occur. As internal steel reinforcement corrodes, expansive forces from the oxidation of the steel lead to cracks and spalls of the concrete surrounding the reinforcing steel. Such cracks and spalls of concrete can be unsightly and hazardous. Ultimately, the corrosion of the reinforcing steel leads to a reduction in structural capacity because corrosion reduces both the cross-sectional area of steel able to carry tensile stresses and the bond between the steel and concrete.

Improved knowledge of the steel-reinforced concrete corrosion process in turn improves design and construction practices to mitigate corrosion of reinforcing steel. These are well discussed in ACI 222.3R. However, many highly corrosive environments still present long-term durability challenges for steel-reinforced concrete. FRP bars offer a completely non-corrosive alternative in these environments.

3.1.2 Lightweight—FRP is a high-strength, lightweight material. Its unit density is one-third to one-fourth that of mild steel. As an example, a No. 5 (No. M16) GFRP bar weighs approximately 0.30 lb/linear ft (0.45 kg/linear m),





Fig. 3.1.1a—This parking garage uses GFRP reinforcement as the top mat of reinforcement to minimize corrosion issues. Vehicles carrying deicing salts into parking garages can create corrosion issues on the top of parking decks, leading to shortened lifespans of these structures (photo courtesy of Owens Corning Infrastructure Solutions).



Fig 3.1.1b—GFRP reinforcement for a concrete seawall. Coastal structures such as this are highly susceptible to chloride-induced corrosion from seawater exposure. GFRP reinforcement provides a lasting solution for these applications (photo courtesy of Doug Green).