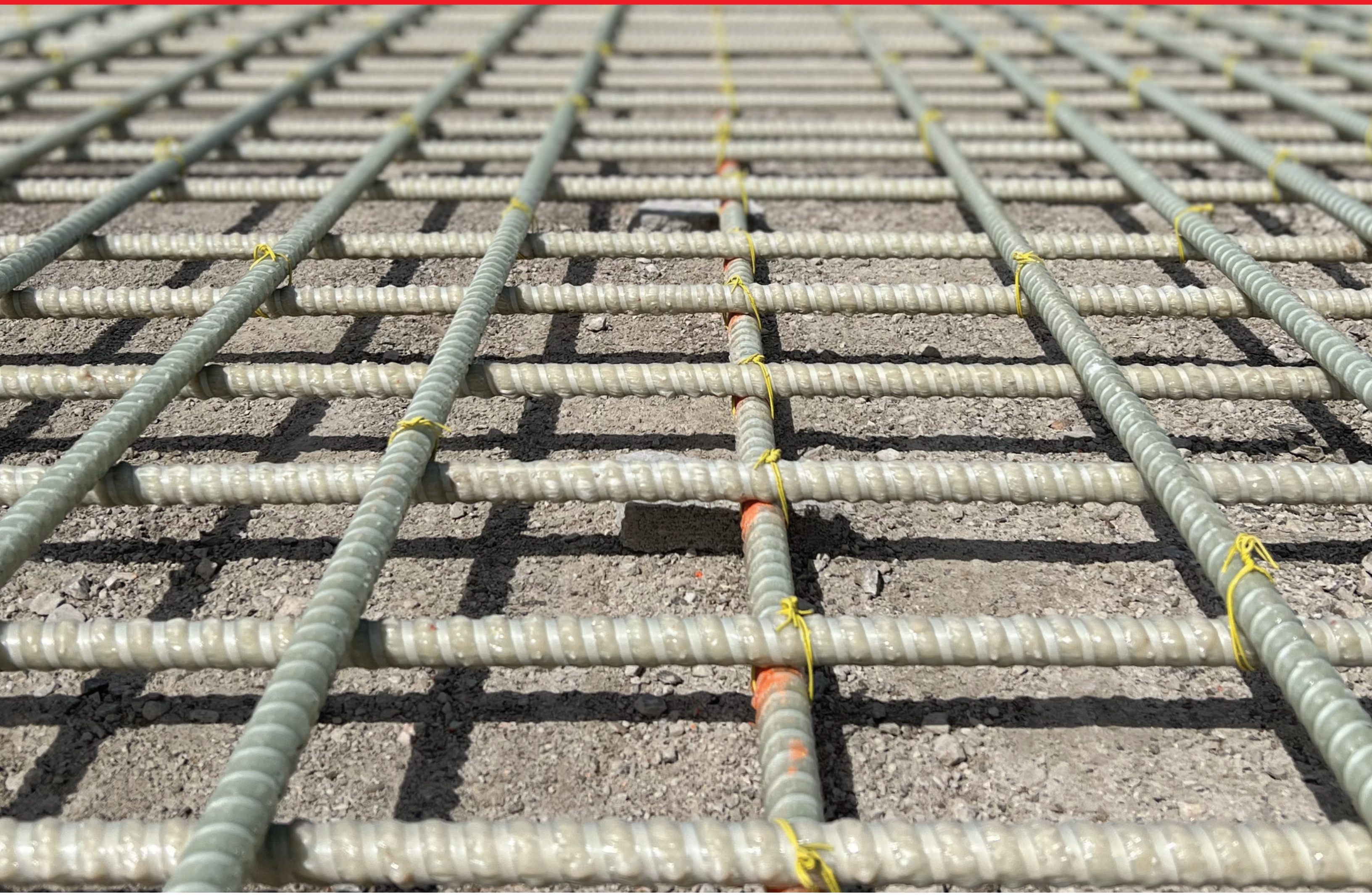
An ACI / NEx Manual

GFRP-Reinforced Concrete Design Handbook

A Companion to ACI CODE 440.11-22



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MNL-7(23)

GFRP-Reinforced Concrete Design Handbook

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*NEx member companies:
Sustaining: Aramco
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Bronze: MST Bar, Owens Corning, GatorBar, Dextra, Creative Composites Group, Galen Panamerica, IKK Mateenbar, Comp-King, Strongwell, Rochling

Front cover photo: Port Clinton Walkway, Port Clinton, Ohio, USA (photo courtesy MST Bar, Inc.)

Back cover photo: GFRP Bars (photo courtesy Galen-Panamerica/Binevir)

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CONTENTS

PREFACE

The *GFRP Reinforced Concrete Design Handbook* is a vital reference for professionals interested in the use of non-metallic GFRP reinforcement for concrete structures. It is meant to provide valuable insight to structural engineers on understanding and utilizing the provisions of "Building Code Requirements for Structural Concrete Reinforced with Glass Fiber Reinforced Polymer (GFRP) Bars" (ACI CODE 440.11).

The *GFRP Reinforced Concrete Design Handbook* provides several engineering design examples for various concrete members reinforced with GFRP bars including beams, one-way slabs, two-way slabs, and slender columns. The examples help illustrate the provisions of ACI CODE 440.11 as they pertain to serviceability, flexural strength, shear strength, torsional strength, axial strength, stability, and structural analysis. Many of the examples are based on a fictious four-story GFRP reinforced concrete building to illustrate how the design provisions work together in a full building design. These examples are also closely related to the example problems presented in the *ACI Reinforced Concrete Design Handbook* (ACI MNL-17) to allow for comparison to the steel reinforced concrete members presented in MNL-17. Each example starts with a brief problem statement and then presents a full set of design calculations that reference the appropriate provisions in ACI CODE 440.11 (red highlighted text next to equations) to arrive at a solution. Detailed explanations of the design calculations are provided throughout.
In addition to the example problems, this handbook provides general information and guidance about the appropriate use of GFRP reinforcement, its material and durability characteristics, typical applications, and considerations for fire resistance. It also highlights key differences between designing GFRP reinforced concrete versus traditional steel reinforced concrete.

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

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Managing Editor

CHAPTER 1—INTRODUCTION

The use of fiber-reinforced polymer (FRP) composite materials in structural applications has transformed many industries over the past several decades. The aerospace industry has used these materials due to their very high strength-to-weight ratio and excellent fatigue resistance; the naval and ship building industry has used these materials for their durability because these materials do not corrode, rot, or decay; and the sporting goods industry has used these materials for their stiffness, which can be tailored in various directions, and for their ability to be molded into a variety of structural shapes. Their use in the construction industry has not been as widespread as other industries, but it has had a significant impact. Structures such as the carbon fiber-reinforced polymer (CFRP) roof of the auditorium on Apple Computer's campus have reimagined what is possible in architecture; and concrete bridges that use no steel reinforcement, such as the 28-span Harker Island bridge in North Carolina, have reimagined how civil structures can resist deterioration due to corrosion.

The use of non-metallic, FRP reinforcement for concrete structures has, in fact, started to gain widespread use. Not only is this reinforcement non-corrosive, it is also lightweight and easy to handle, allowing increases in productivity as well as the health and safety of workers. These and other advantages, as discussed in more detail in Chapter 3 of this manual, are resulting in increased use of FRP reinforcement for concrete structures.

However, as the use of this type of reinforcement increases, it is important to implement its use in a safe and effective manner. FRP reinforcement behaves differently than steel. (These differences and the unique properties of FRP reinforcement are discussed in Chapter 2 of this manual.) As such, the engineering design of FRP-reinforced concrete structures must take into account the way in which the material behaves and how that is different than steel reinforcement. Some of the most important design differences are due to the lack of ductility of FRP reinforcement, which results in the need for higher reserves of strength, and the lower modulus of elasticity of some FRP reinforcements, which results in most FRP-reinforced concrete structures being controlled by serviceability (deflection, crack width, or sustained stress limits). Most importantly, it is not appropriate to simply replace steel reinforcement with an equal amount of FRP reinforcement. The design of FRP reinforcement must be carried out with specific engineering principals that take into account its material characteristics.

The American Concrete Institute (ACI) and other institutions globally have recognized the need for specific engineering guidance on the use of FRP reinforcement for concrete. ACI published the first state-of-the-art report on FRP reinforcement of concrete in 1996 (ACI 440R-96, which has been subsequently updated to ACI PRC-440-07) and has since published numerous guidelines and specifications for the design, construction, testing, and material requirements for FRP reinforcement. This includes ACI PRC-440.1-15, "Guide for the Design and Construction of Structural Concrete Reinforced with Fiber-Reinforced Polymer Bars," which was first published in 2001. These documents all establish methods for properly using FRP reinforcement and have been used to design and construct FRP-reinforced concrete elements for decades. As this industry and technology has matured, building officials, designers, contractors, and manufacturers have all seen an increased need to codify requirements for FRP-reinforced concrete. As such, in 2022, ACI published the first building code requirements for FRP-reinforced concrete: ACI CODE-440.11-22, "Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars—Code and Commentary." This manual serves as a companion to ACI CODE-440.11, which provides additional insights on the background of the code, engineering design approaches using the code, and detailed example problems that illustrate how to apply the code.

1.1—ACI CODE-440.11 format and scope

Relative to the type of FRP reinforcement, ACI CODE-440.11-22 limits the scope of the code to solid, round glass fiber-reinforced polymer (GFRP) reinforcing bars constructed using vinyl ester resins and that conform to ASTM D7957/7957M-22. Although there are other shapes of FRP reinforcing bars (square and rectangular cross sections and hollow bars or tube sections), other resin types that may be used (vinyl esters, polyesters, epoxies, and other polymers have all been used to produce FRP bars), and other types of fiber comprising the FRP material (basalt and carbon fiber being the most notable), the scope of ACI CODE-440.11 is limited to solid, round, GFRP bars made with vinyl ester polymers. This scope limitation is based on the preponderance of research data and field experience using this type of FRP reinforcement as well as the acceptance and availability of the ASTM D7957/7957M material standard for this type of reinforcement. As of the publication of this manual, there is now an ASTM standard that includes basalt fiber-reinforced polymer bars (BFRP): ASTM D8505/D8505M. This may allow for inclusion of BFRP bars in future editions of ACI CODE-440.11; however, the current code limits the use to bars conforming to ASTM D7957/7957M. (Indications are that future editions of the code will include reference to both material standards to allow bars conformance to either standard. Additional discussion of these standards is in Chapter 4 of this manual.) The ACI PRC-440.1 design guide also serves as a resource for using FRP reinforcing bars of many various types.

ACI CODE-440.11-22 follows the same structure and format as ACI CODE-318-19(22), "Building Code Requirements for Structural Concrete—Code and Commentary." The intent of ACI CODE-440.11 is to maintain all the requirements of ACI CODE-318 and only replace requirements that would change when using GFRP reinforcement instead of steel reinforcement. Some chapters of ACI CODE-318 are omitted in ACI CODE-440.11 where there is not sufficient research into the use of GFRP reinforcement (such as Chapter 12 on Diaphragms); these chapters are marked "Not Addressed". Other chapters where GFRP reinforcement would not be used (such as Chapter 14 on Plain Concrete) are marked "Not Applicable". However, most topics pertaining to regularly reinforced concrete structures are covered in ACI CODE-440.11. Table 1.1 provides a comparison of the chapters that ACI CODE-440.11 covers versus the chapters that ACI CODE-318-19(22) covers.

In addition to the chapters indicated in Table 1.1 that ACI CODE-440.11 excludes, there are other topics that the code does not cover. These include provisions for the use of lightweight concrete, the use of shotcrete, and the design of deep beams. Additionally, the code does not cover prestressed concrete; however, FRP prestressing systems (using prestressed FRP bars or tendons) do exist and there is a guideline available from ACI on this topic: ACI PRC 440.4-04(11), "Prestressing Concrete Structures with FRP Tendons." Neither ACI CODE-318 or ACI CODE-440.11 cover topics such as slabs-on-ground, residential construction, or environmental structures. FRP bars are, however, common in many of these applications. ACI PRC-440.1-15 and the *ACI Recommended Practice Guidelines for FRP Bars in Pre-Engineered Projects* (MNL-6) provide recommendations on slabs-on-ground, and MNL-6 provides recommendations on residential foundation walls.

All the chapter and section numbers in ACI CODE-440.11 mirror the chapter and section numbers in ACI CODE-318-19(22). This has been done to allow the user familiar with ACI CODE-318 to easily navigate the requirements in ACI CODE-440.11 and to allow for direct comparisons between the requirements of each code. Code provisions in ACI CODE 440.11 that are direct copies of code provisions in ACI CODE-318 are marked with a superscript equal sign ($^{=}$) before the provision to further assist the user in comparing requirements in the two codes (refer to Fig. 1.1 for an example). Some provisions of ACI CODE-440.11 are marked "Not Applicable" where the corresponding code requirement in ACI CODE-318 would not apply to GFRP reinforcement (such as provisions for plain concrete or epoxy-coated steel reinforcement). Other provisions of ACI CODE-440.11 are marked "Out of Scope" where there is not sufficient data, research, or experience to include provisions for the corresponding requirement in ACI CODE-318 (such

APPENDIX

The appendix to this manual provides properties of bars supplied by several manufacturers. The properties listed are current as of the publication of this manual and are subject to change. It is recommended to consult with specific manufacturers for the most up-to-date product information.

It is important to reiterate that the prescriptive tables in this manual are all based on using ASTM D7957/D7957M minimum material properties. ACI CODE-440.11 does allow engineers to design using either ASTM D7957/D7957M minimum properties or the properties reported by manufacturers (properties must be reported according to ASTM D7957/D7957M standards). Because manufacturer's properties often exceed the minimum values required by ASTM D7957/D7957M, the use of a specific manufacturer's properties may result in less reinforcement being required than values in the prescriptive tables in this manual. Consideration of specific material properties of a given manufacturer (such as those reported in this appendix) would require additional engineering design by a licensed design professional.

The values reported in this appendix were obtained directly from the manufacturers listed. The contribution of material characteristics from the following manufacturers is acknowledged and thanked:

CompKing, Inc. – GBar®
Dextra Group – Durabar™ and ASTEC™
Galen-Panamerica/Binevir Composites
Isam Kabbani Plastic & Insulation Factory – IKK Mateenbar™
MST Rebar, Inc. – MST-BAR®
Neuvokas Corporation – GatorBar®
Owens Corning Infrastructure Solutions – PINKBAR®+ Fiberglas™ Rebar
Röchling Industrial – Durostone® FRP Rebar

CompKing, Inc.
850 Euclid Avenue, Suite #819 Cleveland, OH 44112 USA www.compking.com, +1 843 906-8049, email: ccr@compking.com

Design Values – GBar

Property	Test Method	Bar Size											
		No. 2 [M6]	No. 3 [M10]	No. 4 [M13]	No. 5 [M16]	No. 6 [M19]	No. 7 [M22]	No. 8 [M25]	No. 9 [M29]	No. 10 [M32]	No. 11 [M38]	No. 12 [M40]	No. 13 [M50]
Cross Sectional Area, in.^{2} [mm^2]	ASTM D7205 11.2.5.1		0.13 [84]	0.24 [155]	0.36 [232]	0.48 [310]		0.87 [561]					
Guaranteed Ultimate Tensile Force, kip [kN]	ASTM D7205		16.1 [71.6]	29.2 [130]	39.9 [177]	46.5 [207]		105.0 [467]					
Mean Tensile Modulus of Elasticity, ksi [GPa]	ASTM D7205		10800 [74]	10300 [71]	10300 [71]	9700 [67]		10300 [71]					
Guaranteed Ultimate Tensile Force of Bent Portion of Bar, kip [kN]	ASTM D7914		N/A	N/A	N/A	N/A		N/A					
Guaranteed Transverse Shear Strength, ksi [MPa]	ASTM D7617		27.8 [191]	20.7 [143]	26.4 [182]	25.5 [176]		25.7 [177]					
Guaranteed Bond Strength, psi [MPa]	ASTM D7913		1,110 [7.7]	2,080 [14.3]	1,870 [12.9]	1,600 [11.0]		1,110 [7.7]					

Guaranteed and mean values are as defined in ASTM D7957.

Property	Test Method	Value
Glass Transition Temperature	ASTM E1356	213 to 255°F [100 to 124°C]
Alkali Resistance	ASTM D7705 Procedure A	82 to 94%
Degree of Cure	ASTM E2160	99.41 to 100%
Moisture Absorption to Saturation	ASTM D570, subsection 7.4	8-week range 0.42 to 0.89%

Dextra Group
Head Office = 5th Floor, Lumpini II Bldg., 247 Sarasin Road, Lumpini, Pathumwan, Bangkok, 10330, Thailand www.dextragroup.com, +66 2 021 3800, email: marketing@dextragroup.com

Design Values – Durabar DIY

Property	Test Method	Bar Size											
		No. 2 [M6]	No. 3 [M10]	No. 4 [M13]	No. 5 [M16]	No. 6 [M19]	No. 7 [M22]	No. 8 [M25]	No. 9 [M29]	No. 10 [M32]	No. 11 [M38]	No. 12 [M40]	No. 13 [M50]
Cross Sectional Area, in.^{2} [mm^2]	ASTM D7205 11.2.5.1	0.049 [32]	0.11 [71]	0.20 [129]	0.31 [199]								
Guaranteed Ultimate Tensile Force, kip [kN]	ASTM D7205	5.85 [26.0]	11.9 [53.0]	19.6 [87.0]	29.2 [130]								
Mean Tensile Modulus of Elasticity, ksi [GPa]	ASTM D7205	6530 [45]	6530 [45]	6530 [45]	6530 [45]								
Guaranteed Ultimate Tensile Force of Bent Portion of Bar, kip [kN]	ASTM D7914	N/A	N/A	N/A	N/A								
Guaranteed Transverse Shear Strength, ksi [MPa]	ASTM D7617	N/A	N/A	N/A	N/A								
Guaranteed Bond Strength, psi [MPa]	ASTM D7913	N/A	N/A	N/A	N/A								

Guaranteed and mean values are as defined in ASTM D7957.

Property	Test Method	Value
Glass Transition Temperature	ASTM E1356	N/A
Alkali Resistance	ASTM D7705 Procedure A	N/A
Degree of Cure	ASTM E2160	N/A
Moisture Absorption to Saturation	ASTM D570, subsection 7.4	N/A

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Design Values – Durabar SLIM

Property	Test Method	Bar Size											
		No. 2 [M6]	No. 3 [M10]	No. 4 [M13]	No. 5 [M16]	No. 6 [M19]	No. 7 [M22]	No. 8 [M25]	No. 9 [M29]	No. 10 [M32]	No. 11 [M38]	No. 12 [M40]	No. 13 [M50]
Cross Sectional Area, in.^{2} [mm^2]	ASTM D7205 11.2.5.1	0.049 [32]	0.11 [71]	0.20 [129]	0.31 [199]								
Guaranteed Ultimate Tensile Force, kip [kN]	ASTM D7205	6.52 [29.0]	13.3 [59.0]	21.6 [96.0]	32.0 [143]								
Mean Tensile Modulus of Elasticity, ksi [GPa]	ASTM D7205	6820 [47]	6820 [47]	6820 [47]	6820 [47]								
Guaranteed Ultimate Tensile Force of Bent Portion of Bar, kip [kN]	ASTM D7914	N/A	N/A	N/A	N/A								
Guaranteed Transverse Shear Strength, ksi [MPa]	ASTM D7617	N/A	N/A	N/A	N/A								
Guaranteed Bond Strength, psi [MPa]	ASTM D7913	N/A	N/A	N/A	N/A								

Guaranteed and mean values are as defined in ASTM D7957.

Property	Test Method	Value
Glass Transition Temperature	ASTM E1356	N/A
Alkali Resistance	ASTM D7705 Procedure A	N/A
Degree of Cure	ASTM E2160	N/A
Moisture Absorption to Saturation	ASTM D570, subsection 7.4	N/A

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Design Values – ASTEC GR45P Rebar

Property	Test Method	Bar Size											
		No. 2 [M6]	No. 3 [M10]	No. 4 [M13]	No. 5 [M16]	No. 6 [M19]	No. 7 [M22]	No. 8 [M25]	No. 9 [M29]	No. 10 [M32]	No. 11 [M38]	No. 12 [M40]	No. 13 [M50]
Cross Sectional Area, in^2 [mm^2]	ASTM D7205 11.2.5.1	0.049 [32]	0.11 [71]	0.20 [129]	0.31 [199]	0.44 [284]	0.60 [387]	0.79 [510]	1.00 [645]	1.27 [819]	2.07 [1335]		
Guaranteed Ultimate Tensile Force, kips [kN]	ASTM D7205	6.52 [29]	14.39 [64]	25.85 [115]	39.57 [176]	54.40 [242]	71.49 [318]	90.60 [403]	107.4 [478]	132.6 [590]	192.7 [857]		
Mean Tensile Modulus of Elasticity, ksi [GPa]	ASTM D7205	6,527 [45]	6,527 [45]	6,527 [45]	6,527 [45]	6,527 [45]	6,527 [45]	6,527 [45]	6,527 [45]	6,527 [45]	6,527 [45]		
Guaranteed Ultimate Tensile Force of Bent Portion of Bar, kips [kN]	ASTM D7914	3.66 [16.3]	7.92 [35.2]	12.96 [57.6]	17.46 [77.7]	24.54 [109]	32.46 [144]	40.08 [178]	N/A	N/A	N/A		
Guaranteed Transverse Shear Strength, ksi [MPa]	ASTM D7617	19.0 [131]	19.0 [131]	19.0 [131]	19.0 [131]	19.0 [131]	19.0 [131]	19.0 [131]	19.0 [131]	19.0 [131]	19.0 [131]		
Guaranteed Bond Strength, psi [MPa]	ASTM D7913	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]		

Guaranteed and mean values are as defined in ASTM D7957.

Property	Test Method	Value
Glass Transition Temperature	ASTM E1356	>212°F [>100°C]
Alkali Resistance	ASTM D7705 Procedure A	>80%
Degree of Cure	ASTM E2160	>95%
Moisture Absorption to Saturation	ASTM D570, subsection 7.4	<1.0%

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Design Values – ASTEC GR50P Rebar

Property	Test Method	Bar Size											
		No. 2 [M6]	No. 3 [M10]	No. 4 [M13]	No. 5 [M16]	No. 6 [M19]	No. 7 [M22]	No. 8 [M25]	No. 9 [M29]	No. 10 [M32]	No. 11 [M38]	No. 12 [M40]	No. 13 [M50]
Cross Sectional Area, in^2 [mm^2]	ASTM D7205 11.2.5.1	0.049 [32]	0.11 [71]	0.20 [129]	0.31 [199]	0.44 [284]	0.60 [387]	0.79 [510]	1.00 [645]	1.27 [819]	2.07 [1335]		
Guaranteed Ultimate Tensile Force, kips [kN]	ASTM D7205	6.52 [29]	14.61 [65]	25.63 [114]	39.79 [177]	56.20 [250]	74.86 [333]	96.22 [428]	118.9 [529]	141.9 [631]	222.6 [990]		
Mean Tensile Modulus of Elasticity, ksi [GPa]	ASTM D7205	7,252 [50]	7,252 [50]	7,252 [50]	7,252 [50]	7,252 [50]	7,252 [50]	7,252 [50]	7,252 [50]	7,252 [50]	7,252 [50]		
Guaranteed Ultimate Tensile Force of Bent Portion of Bar, kips [kN]	ASTM D7914	3.66 [16.3]	7.92 [35.2]	12.96 [57.6]	17.46 [77.7]	24.54 [109]	32.46 [144]	40.08 [178]	N/A	N/A	N/A		
Guaranteed Transverse Shear Strength, ksi [MPa]	ASTM D7617	19.0 [131]	19.0 [131]	19.0 [131]	19.0 [131]	19.0 [131]	19.0 [131]	19.0 [131]	19.0 [131]	19.0 [131]	19.0 [131]		
Guaranteed Bond Strength, psi [MPa]	ASTM D7913	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]	1,100 [7.6]		

Guaranteed and mean values are as defined in ASTM D7957.

Property	Test Method	Value
Glass Transition Temperature	ASTM E1356	>212°F [>100°C]
Alkali Resistance	ASTM D7705 Procedure A	>80%
Degree of Cure	ASTM E2160	>95%
Moisture Absorption to Saturation	ASTM D570, subsection 7.4	<1.0%

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Design Values – Fiberglass Rebar

Property	Test Method	Bar Size											
		No. 2 [M6]	No. 3 [M10]	No. 4 [M13]	No. 5 [M16]	No. 6 [M19]	No. 7 [M22]	No. 8 [M25]	No. 9 [M29]	No. 10 [M32]	No. 11 [M38]	No. 12 [M40]	No. 13 [M50]
Cross Sectional Area, in.^{2} [mm^2]	ASTM D7205 11.2.5.1		0.146 [94]	0.247 [159]	0.386 [249]	0.536 [346]							
Guaranteed Ultimate Tensile Force, kip [kN]	ASTM D7205		17.9 [79.6]	26.8 [120]	44.1 [196]	49.3 [219]							
Mean Tensile Modulus of Elasticity, ksi [GPa]	ASTM D7205		8,290 [57]	8,170 [56]	8,520 [59]	8,050 [56]							
Guaranteed Ultimate Tensile Force of Bent Portion of Bar, kip [kN]	ASTM D7914		N/A	16.4 [73]	N/A	N/A							
Guaranteed Transverse Shear Strength, ksi [MPa]	ASTM D7617		29.3 [202]	27.3 [189]	25.8 [178]	23.9 [165]							
Guaranteed Bond Strength, psi [MPa]	ASTM D7913		1,400 [10.0]	2,000 [14.0]	1,400 [10.0]	1,100 [8.0]							

Guaranteed and mean values are as defined in ASTM D7957.

Property	Test Method	Value
Glass Transition Temperature	ASTM E1356	223°F (106°C)
Alkali Resistance	ASTM D7705 Procedure A	>80% retention
Degree of Cure	ASTM E2160	98%
Moisture Absorption to Saturation	ASTM D570, subsection 7.4	0.54%

Isam Kabbani Plastic & Insulation Factory (IKK Mateenbar)
Isam Kabbani Plastic & Insulation Factory (IKK Mateenbar), Dammam 3rd Industrial City, Saudi Arabia, www.ikkmateenbar.com, +966 138923537, email: mateenbar@ikkgroup.com

Design Values – Mateenbar™ 52 GPa

Property	Test Method	Bar Size											
		No. 2 [M6]	No. 3 [M10]	No. 4 [M13]	No. 5 [M16]	No. 6 [M19]	No. 7 [M22]	No. 8 [M25]	No. 9 [M29]	No. 10 [M32]	No. 11 [M38]	No. 12 [M40]	No. 13 [M50]
Cross Sectional Area, in.^{2} [mm^2]	ASTM D7205 11.2.5.1	0.049 [32]	0.11 [71]	0.20 [129]	0.31 [199]	0.44 [284]	0.60 [387]	0.79 [510]	1.0 [645]	1.27 [819]	1.66 [1071]	1.88 [1213]	3.01 [1942]
Guaranteed Ultimate Tensile Force, kip [kN]	ASTM D7205	10.4 [46.3]	16.4 [72.9]	28.6 [127]	39.3 [175]	55.1 [245]	69.7 [310]	92.1 [410]	116 [516]	148 [659]	193 [859]	204 [907]	328 [1460]
Mean Tensile Modulus of Elasticity, ksi [GPa]	ASTM D7205	7,500 [52]	7,500 [52]	7,500 [52]	7,500 [52]	7,500 [52]	7,500 [52]	7,500 [52]	7,500 [52]	7,500 [52]	7,500 [52]	7,500 [52]	7,500 [52]
Guaranteed Ultimate Tensile Force of Bent Portion of Bar, kip [kN]	ASTM D7914	5.0 [22.2]	8.2 [36.5]	14 [62.3]	19 [84.5]	27 [120]	34 [151]	45 [200]	N/A	N/A	N/A	N/A	N/A
Guaranteed Transverse Shear Strength, ksi [MPa]	ASTM D7617	22 [152]	22 [152]	22 [152]	22 [152]	22 [152]	22 [152]	22 [152]	22 [152]	22 [152]	19 [131]	19 [131]	19 [131]
Guaranteed Bond Strength, psi [MPa]	ASTM D7913	1,160 [8.0]	1,160 [8.0]	1,160 [8.0]	1,160 [8.0]	1,160 [8.0]	1,160 [8.0]	1,160 [8.0]	1,160 [8.0]	1,160 [8.0]	1,160 [8.0]	1,160 [8.0]	1,160 [8.0]

Guaranteed and mean values are as defined in ASTM D7957.

Property	Test Method	Value
Glass Transition Temperature	ASTM E1356	>212°F [>100°C]
Alkali Resistance	ASTM D7705 Procedure A	>80%
Degree of Cure	ASTM E2160	>97%
Moisture Absorption to Saturation	ASTM D570, subsection 7.4	<0.1%

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Design Values – Mateenbar™ 60 GPa

Property	Test Method	Bar Size											
		No. 2 [M6]	No. 3 [M10]	No. 4 [M13]	No. 5 [M16]	No. 6 [M19]	No. 7 [M22]	No. 8 [M25]	No. 9 [M29]	No. 10 [M32]	No. 11 [M38]	No. 12 [M40]	No. 13 [M50]
Cross Sectional Area, in.^{2} [mm^2]	ASTM D7205 11.2.5.1	0.049 [32]	0.11 [71]	0.20 [129]	0.31 [199]	0.44 [284]	0.60 [387]	0.79 [510]					
Guaranteed Ultimate Tensile Force, kip [kN]	ASTM D7205	10.4 [46.3]	19.8 [88.2]	29.1 [129]	41.8 [186]	57.5 [256]	78.4 [349]	103 [459]					
Mean Tensile Modulus of Elasticity, ksi [GPa]	ASTM D7205	8,700 [60]	8,700 [60]	8,700 [60]	8,700 [60]	8,700 [60]	8,700 [60]	8,700 [60]					
Guaranteed Ultimate Tensile Force of Bent Portion of Bar, kip [kN]	ASTM D7914	5.0 [22.2]	9.8 [43.6]	14 [62.3]	20 [89.0]	28 [125]	39 [174]	50 [222]					
Guaranteed Transverse Shear Strength, ksi [MPa]	ASTM D7617	22 [152]	22 [152]	22 [152]	22 [152]	22 [152]	22 [152]	22 [152]					
Guaranteed Bond Strength, psi [MPa]	ASTM D7913	1160 [8.0]	1160 [8.0]	1160 [8.0]	1160 [8.0]	1160 [8.0]	1160 [8.0]	1160 [8.0]					

Guaranteed and mean values are as defined in ASTM D7957.

Property	Test Method	Value
Glass Transition Temperature	ASTM E1356	>212°F [>100°C]
Alkali Resistance	ASTM D7705 Procedure A	>80%
Degree of Cure	ASTM E2160	>97%
Moisture Absorption to Saturation	ASTM D570, subsection 7.4	<0.1%

MST Rebar, Inc.
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Design Values – MST-BAR® Grade III GFRP

Property	Test Method	Bar Size											
		No. 2 [M6]	No. 3 [M10]	No. 4 [M13]	No. 5 [M16]	No. 6 [M19]	No. 7 [M22]	No. 8 [M25]	No. 9 [M29]	No. 10 [M32]	No. 11 [M38]	No. 12 [M40]	No. 13 [M50]
Cross Sectional Area, in.^{2} [mm^2]	ASTM D7205 11.2.5.1		0.11 [71]	0.20 [129]	0.31 [199]	0.44 [284]	0.60 [387]	0.79 [510]	1.0 [645]	1.27 [819]	1.66 [1071]		
Guaranteed Ultimate Tensile Force, kip [kN]	ASTM D7205		16.0 [71.2]	30.4 [135]	45.0 [200]	65.0 [289]	87.7 [390]	114 [507]	145 [645]	184 [818]	226 [1005]		
Mean Tensile Modulus of Elasticity, ksi [GPa]	ASTM D7205		8700 [60]	8700 [60]	8700 [60]	8700 [60]	8700 [60]	8700 [60]	8700 [60]	8700 [60]	8700 [60]		
Guaranteed Ultimate Tensile Force of Bent Portion of Bar, kip [kN]	ASTM D7914		9.6 [42.7]	18.2 [81.0]	27 [120]	40 [178]	N/A	68.6 [305]	N/A	N/A	N/A		
Guaranteed Transverse Shear Strength, kips [kN]	ASTM D7617		33 [228]	33 [228]	33 [228]	33 [228]	30 [207]	29 [200]	29 [200]	29 [200]	29 [200]		
Guaranteed Bond Strength, psi [MPa]	ASTM D7913		3300 [23]	3300 [23]	3300 [23]	3000 [21]	3000 [21]	3000 [21]	3000 [21]	3000 [21]	3000 [21]		

Guaranteed and mean values are as defined in ASTM D7957.

Property	Test Method	Value
Glass Transition Temperature	ASTM E1356	235°F [113°C]
Alkali Resistance	ASTM D7705 Procedure A	90% retention
Degree of Cure	ASTM E2160	100%
Moisture Absorption to Saturation	ASTM D570, subsection 7.4	0.18%

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Design Values – GatorBar®

Property	Test Method	Bar Size											
		No. 2 [M6]	No. 3 [M10]	No. 4 [M13]	No. 5 [M16]	No. 6 [M19]	No. 7 [M22]	No. 8 [M25]	No. 9 [M29]	No. 10 [M32]	No. 11 [M38]	No. 12 [M40]	No. 13 [M50]
Cross Sectional Area, in.^{2} [mm^2]	ASTM D7205 11.2.5.1		0.11 [71]	0.20 [129]	Coming Summer 2023								
Guaranteed Ultimate Tensile Force, kip [kN]	ASTM D7205		17.1 [76.1]	30.4 [135]									
Mean Tensile Modulus of Elasticity, ksi [GPa]	ASTM D7205		6800 [47]	7100 [49]									
Guaranteed Ultimate Tensile Force of Bent Portion of Bar, kip [kN]	ASTM D7914		N/A	N/A									
Guaranteed Transverse Shear Strength, ksi [MPa]	ASTM D7617		26.8 [185]	26.8 [185]									
Guaranteed Bond Strength, psi [MPa]	ASTM D7913		1400 [10.0]	Test Pending									

Guaranteed and mean values are as defined in ASTM D7957.

Property	Test Method	Value
Glass Transition Temperature	ASTM E1356	243°F [117°C]
Alkali Resistance	ASTM D7705 Procedure A	>80% of initial mean ultimate tensile force
Degree of Cure	ASTM E2160	99.6%
Moisture Absorption to Saturation	ASTM D570, subsection 7.4	< 1.0%

Owens Corning Infrastructure Solutions
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Design Values – PINKBAR®+ Fiberglas™ Rebar

Property	Test Method	Bar Size											
		No. 2 [M6]	No. 3 [M10]	No. 4 [M13]	No. 5 [M16]	No. 6 [M19]	No. 7 [M22]	No. 8 [M25]	No. 9 [M29]	No. 10 [M32]	No. 11 [M38]	No. 12 [M40]	No. 13 [M50]
Cross Sectional Area, in.^{2} [mm^2]	ASTM D7205 11.2.5.1		0.11 [71]	0.20 [129]	0.31 [199]	0.44 [284]	0.60 [387]	0.79 [510]					
Guaranteed Ultimate Tensile Force, kip [kN]	ASTM D7205		16.0 [71.2]	24.7 [110]	41.8 [186]	57.3 [255]	78.3 [348]	102 [453]					
Mean Tensile Modulus of Elasticity, ksi [GPa]	ASTM D7205		6,800 [47]	6,800 [47]	8,700 [60]	8,700 [60]	8,700 [60]	8,700 [60]					
Guaranteed Ultimate Tensile Force of Bent Portion of Bar, kip [kN]	ASTM D7914		N/A	23.2 [103]	36.0 [160]	44.7 [199]	60.9 [271]	80.2 [357]					
Guaranteed Transverse Shear Strength, ksi [MPa]	ASTM D7617		22 [152]	22 [152]	22 [152]	22 [152]	22 [152]	22 [152]					
Guaranteed Bond Strength, psi [MPa]	ASTM D7913		1400 [10.0]	1400 [10.0]	1400 [10.0]	1400 [10.0]	1100 [8.0]	1100 [8.0]					

Guaranteed and mean values are as defined in ASTM D7957.

Property	Test Method	Value
Glass Transition Temperature	ASTM E1356	212°F [100°C]
Alkali Resistance	ASTM D7705 Procedure A	>85%
Degree of Cure	ASTM E2160	>75
Moisture Absorption to Saturation	ASTM D570, subsection 7.4	<0.75%

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Design Values – Durostone® FRP Rebar

Property	Test Method	Bar Size											
		No. 2 [M6]	No. 3 [M10]	No. 4 [M13]	No. 5 [M16]	No. 6 [M19]	No. 7 [M22]	No. 8 [M25]	No. 9 [M29]	No. 10 [M32]	No. 11 [M38]	No. 12 [M40]	No. 13 [M50]
Cross Sectional Area, in.^{2} [mm^2]	ASTM D7205 11.2.5.1		0.139 [90]	0.229 [148]	0.361 [233]	0.525 [339]		0.878 [566]					
Guaranteed Ultimate Tensile Force, kip [kN]	ASTM D7205		24.7 [110]	39.7 [177]	62.7 [279]	91.2 [406]		127.4 [567]					
Mean Tensile Modulus of Elasticity, ksi [GPa]	ASTM D7205		9,282 [64]	9,137 [63]	9,282 [64]	9,282 [64]		9,137 [63]					
Guaranteed Ultimate Tensile Force of Bent Portion of Bar, kip [kN]	ASTM D7914		12.81 [57]	22.7 [101]	28.55 [127]	51.48 [229]							
Guaranteed Transverse Shear Strength, ksi [MPa]	ASTM D7617		26.97 [186]	21.9 [151]	20.16 [139]	24.51 [169]		21.32 [147]					
Guaranteed Bond Strength, psi [MPa]	ASTM D7913		2,900 [20.0]	2,680 [18.5]	2,670 [18.4]	2,680 [18.5]		2,030 [14.0]					

Guaranteed and mean values are as defined in ASTM D7957.

Property	Test Method	Value
Glass Transition Temperature	ASTM E1356	226°F [108°C]
Alkali Resistance	ASTM D7705 Procedure A	>85%
Degree of Cure	ASTM D2160	
Moisture Absorption to Saturation	ASTM D570, subsection 7.4	0.09%