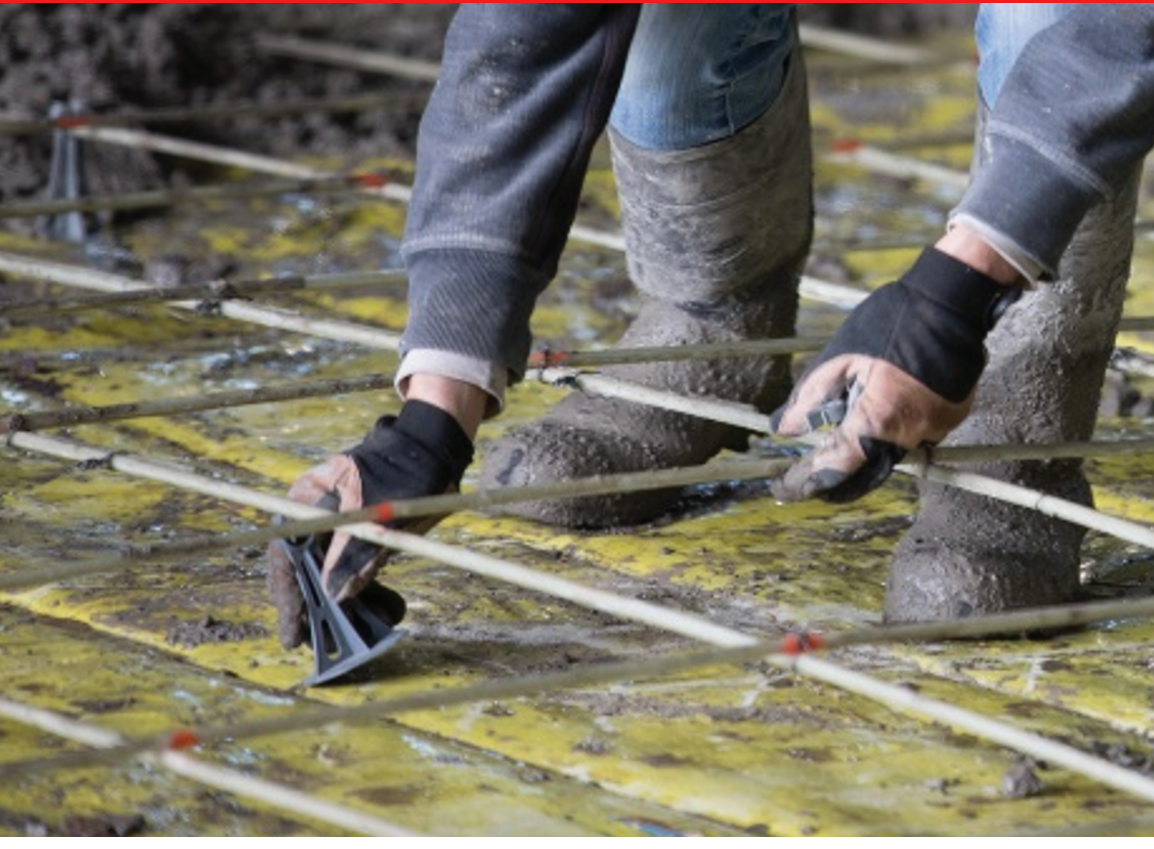
Recommended Practice Guidelines for FRP Bars in Pre-Engineered Projects



MNL-6(23)

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Recommended Practice Guidelines for FRP Bars in Pre-Engineered Projects

This educational document for using FRP reinforcement has been made possible in part by the sponsorship of NEx. NEx is a subsidiary of the American Concrete Institute that partners with leading organizations focused on accelerating the use and technology of nonmetallic materials and products in construction.

The authors would like to thank and recognize NEx and its member companies* for providing insight, guidance, and resources for the development of this document.

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Recommended Practice Guidelines for FRP Bars in Pre-Engineered Projects
ISBN 978-1-64195-227-9

Managing Editor: William J. Gold, P.E.
Engineering Editor: William J. Gold, P.E.
Technical Editors: Emily Bush and Carl Bischof
Art Program: Robert Hogston and Aimee Kahaian
Page Design & Composition: Susan Esper, Gail Tatum, and Ryan Jay
Manufacturing: Marie Fuller

First Printing: September 2023
Printed in Eau Claire, Wisconsin.

American Concrete Institute/NEx
38800 Country Club Drive
Farmington Hills, MI 48331
USA
www.concrete.org
+1.248.848.3700

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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.

Each chapter of this manual was reviewed by at least two reviewers, who provided valuable comments, suggestions, and insights. This manual would not be possible without the contributions of these reviewers, and their efforts are highly appreciated. The following reviewers are acknowledged and thanked:

Gusai Al Aithan
Gregg Blaszak
Vicki Brown
Francisco de Caso
Aparna Deshmukh
Jonathan Fischer
Doug Gremel
Maria Lopez de Murphy
Antonio Nanni
Jay Pease
Carol Shield
Doug Tomlinson
Jerzy Zemajtis

Keywords: compressive strength; cover; durability; fire; footings; foundations; GFRP reinforcement; modulus of elasticity; reinforcement; slabs; splicing; walls.

William J. Gold
Managing Editor

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-

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

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

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 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

Galen-Panamerica/Binevir
1206 Stirling Rd, Ste 6A/B, Dania Beach, FL 33004 USA http://galenpanamerica.com, +1 305-833-7066, email: info@galenpanamerica.com

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%

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™ 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.

200A Hanlan Road Woodbridge, Ontario L4L 3R7
www.mstbar.com, +1 855-740-0377, email: info@mstbar.com

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%

Neuvokas Corporation
3206 #6 Road, PO Box 220 Ahmeek, MI 49901 USA www.gatorbar.com, +1 906-934-2661, email: info@gatorbar.com

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
One Owens Corning Parkway, Toledo, OH 43659 www.owenscorning.com/pinkbar+, +1 855-OC-Rebar, email: https://www.owenscorning.com/en-us/contact-us

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%