C-BAR®

Product Guide Specification

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Product Guide Specification

Specifier Notes: This product specification is written according to the Construction Specifications Institute (CSI) Format, including MasterFormat (1995 Edition), SectionFormat, and PageFormat, contained in the CSI Manual of Practice.
This section must be carefully reviewed by the Engineer to meet the requirements of the project and local building code. Coordinate with other specification sections and the drawings.
Delete all "Specifier Notes" after editing this section.

SECTION 03205

FIBER REINFORCED POLYMER (FRP) BARS FOR CONCRETE REINFORCEMENT

Specifier Notes: This section covers Marshall Composite Systems C-BAR® deformed fiber reinforced polymer (FRP) bars for concrete reinforcement.

One of the main reasons for considering FRP bars for concrete reinforcement is that steel corrodes in concrete subjected to harsh environments, resulting in loss of strength and structural integrity. Highway structures are particularly prone to this corrosion, as they are exposed to the outdoor environment and to deicing salts in colder climates. It is essential that all tensile reinforcing elements, including FRP bars to be used in concrete structures, retain sufficient strength capabilities during the expected life of the concrete structure.

C-BAR® deformed FRP bars are a suitable alternative to steel reinforcing bars when reinforced concrete is:

1. Exposed to deicing salts.
2. Built in or close to seawater.
3. Subjected to other corrosive agents.
4. Required to maintain low electric conductivity or electromagnetic neutrality.
5. Required to save weight. C-BAR® deformed FRP bars are 25% of the weight of equivalent size steel bar.

Consult Marshall Composite Systems, LLC for a copy of the C-BAR® Deformed FRP Bar Recommended Design Manual and assistance in editing this section for the specific application.

Specifier Notes: The references below should be referred to by the Engineer regarding the application of FRP bars for concrete reinforcement. Also, refer to Marshall Composite Systems Research Summary Bulletins for detailed information.

ACI 318-95, "Building Code Requirements for Concrete" (1995), American Concrete Institute, Detroit, MI, 347 pp.
ACI 440R-96, "State-of-the-Art Report on Fiber Reinforced Plastic Reinforcement for Concrete Structures" (1996), American Concrete Institute, Detroit, MI, 68 pp.
"Placing Reinforcing Bars" (1992), Concrete Reinforcing Steel Institute, Schaumburg, IL.
"Recommendation for Design and Construction of Concrete Structures Using Continuous Fiber Reinforcing Materials" (1997), Japan Society of Civil Engineers, Tokyo, Japan, 325 pp.

PART 1 GENERAL

1.1 SECTION INCLUDES

A. Deformed fiber reinforced polymer (FRP) bars for concrete reinforcement.

1.2 RELATED SECTIONS

Specifier Notes: Edit the following list as required for the project. List other sections with work directly related to the FRP bars.

A. Section 03300 - Cast-in-Place Concrete.

B. Section 03400 - Precast Concrete.

Specifier Notes: List standards referenced in this section, complete with designations and titles. This article does not require compliance with standards, but is merely a listing of those used.

1.3 REFERENCES

A. ACI 117 - Specifications for Tolerances for Concrete Construction and Materials.

B. CRSI Placing Reinforcing Bars.

1.4 DESIGN REQUIREMENTS

Specifier Notes: At this time, there are no standard code specifications for the reinforcement of concrete members with FRP bars. Consult Marshall Composite Systems, LLC for complete structural design recommendations with C-BAR® deformed FRP bars and for updates on the ongoing efforts in design codes within American Concrete Institute, Japan Society of Civil Engineers, and Canadian Society of Civil Engineering.

A. Do not substitute FRP reinforcing bars for steel reinforcing bars on an equal area basis, due to differences in material properties.

B. Specifically design reinforced concrete members for FRP bars, taking into account properties of material and effects on strength, deflection, and crack width.

C. In most cases, deflection will control design of concrete structures reinforced with FRP bars based on value of modulus of elasticity of FRP bars.

D. In most cases, concrete reinforced with FRP bars can be designed either through Ultimate Design Method or Working Stress Method (Alternative Design Method). In the case of the Working Stress Method, working stress of FRP bars shall be limited to a maximum of 25 percent of the guaranteed design strength.

1.5 SUBMITTALS

A. Comply with Section 01330 – Submittal Procedures.

B. Product Data: Submit manufacturer’s product data, including material and mechanical properties.

C. Test Reports: Submit manufacturer’s certified test reports for source quality control testing for material and mechanical properties performed by an independent testing agency.

1. Each bar size.
2. Each type of fiber reinforcement specified.
3. Each type of resin matrix specified

1.6 QUALITY ASSURANCE

Specifier Notes: Describe requirements for a meeting to coordinate the placing of the FRP bars and the concrete.

A. Preplacement Meeting: Convene a preplacement meeting [2] [_____] weeks before the start of placing of FRP bars. Require attendance of parties directly affecting work of this section, including the Contractor, Engineer, concrete subcontractor, and FRP bar manufacturer's representative. Review placing of FRP bars and coordination with other work.

1.7 DELIVERY, STORAGE, AND HANDLING

Specifier Notes: C-BAR® deformed FRP bars are made with a matrix of synthetic resin, rendering them liable to surface damage. Therefore, care is advised in the delivery, storage, handling, and placing of these bars. Should bars be damaged, coating the damaged areas with sealing compound available from Marshall Composite Systems LLC is required.

A. General: Deliver, store, and handle FRP bars in accordance with manufacturer’s instructions to prevent damage.

B. Storage:

1. Do not store FRP bars directly on ground. Place timber pallets under bars to keep them free from dirt and mud and to provide easy handling.
2. Store FRP bars under covers to avoid direct sunlight and chemical substances.

Specifier Notes: C-BAR® deformed FRP bars are very light and flexible. Hoisting bundles of FRP bars should be performed carefully. Use a spreader bar during hoisting so the FRP bars will not bend excessively and can be handled with ease.

C. Handling: Use a spreader bar when hoisting bundles of FRP bars.

PART 2 PRODUCTS

2.1 MANUFACTURER

A. Marshall Composite Systems, LLC, 2873 22nd St. NE, Salem, OR 97302.
Phone (503)726-0526. Web Site http://www.marshallcomposite.com.

2.2 FIBER REINFORCED POLYMER (FRP) BARS FOR CONCRETE REINFORCEMENT

A. Fiber Reinforced Polymer (FRP) Bars: C-BAR® Deformed FRP Bars for concrete reinforcement. Surface of FRP bar is provided with reinforced lugs or protrusions that inhibit longitudinal movement of bar relative to concrete.

B. Binding Material: Binding material is composed of Urethane modified vinyl ester.

1. Volume Fraction: 35 percent.

C. Fiber Reinforcement:

1. Continuous Fibers in Bar: E-glass fibers.
    a. Volume Fraction: 60 percent.
2. Fibers to Reinforce Deformations: Ceramic fibers.
    a. Volume Fraction: 3 percent.

D. Manufacturing Process:

1. Reinforced surface deformations shall be molded into surface of bar without affecting integrity of unidirectional fibers in core of bar.

Specifier Notes: At the present, there are four available C-BAR® deformed FRP bar sizes. They are designated:
MIC-G#3-F110-6
MIC-G#4-F100-6
MIC-G#5-F90-5.8
MIC-G#6-F90-5.8

E. Configurations and Designations:

1. Deformations: FRP bar shall be configured as a deformed (ribbed) bar. Deformations shall be molded to surface of bar in-process. Deformations shall be made with urethane modified vinyl ester and reinforced with ceramic fibers.

2. Deformation Spacing and Height:

Bar Designation	Maximum Average Spacing, mm (in.)	Minimum Average Height, mm (in.)
MIC-G#3-F110-6	5.72 (0.225)	0.76 (0.030)
MIC-G#4-F100-6	7.47 (0.294)	1.02 (0.040)
MIC-G#5-F90-5.8	9.14 (0.360)	1.27 (0.047)
MIC-G#6-F90-5.8	11.4 (0.450)	1.52 (0.060)

3. Bar Identification: FRP bars shall be imprinted with bar identification.

Company Symbol (a)	Fiber Type (b)	Bar Size (c)	Grade (d)	Modulus of Elasticity (e)	Batch Number (f)
MCS	G	#4	F100	6	xx-xx-xx

a. Company Symbol: MCS, symbol to identify Marshall Composites Systems, LLC.
b. Fiber Type: A symbol to indicate type of fiber (i.e., G for glass, C for carbon, A for aramid, or H for a hybrid).

c. Bar Size: A numerical number corresponding to diameter of bar in number of eight of an inch.
d. Grade: A symbol corresponding to grade of bar corresponding to the minimum guaranteed design strength in units of 10 (i.e., F90, F100).

e. Modulus of Elasticity: A number corresponding to modulus of bar in units of million psi (i.e., 6, 10, 15)
f. Batch Number: A batch number identifying manufacturing date and lot number for reference and traceability.

F. Dimensions: Nominal Diameter and Sectional Area:

US Size	Nominal Diameter, inches	Area, in^2	Weight, lb/ft	Soft Metric Size	Nominal Diameter, mm	Area, mm^2	Weight, Kg/m
#3	0.375	0.110	0.10	#10	9.5	71	0.046
#4	0.500	0.196	0.17	#13	12.7	126	0.077
#5	0.625	0.307	0.28	#16	15.9	198	0.127
#6	0.750	0.442	0.41	#19	19.0	285	0.186

Specifier Notes: Consult Marshall Composite Systems, LLC for a complete description of the test procedure or refer to MCS Research Summary Bulletins for more details on the tensile properties of C-BAR® deformed FRP bars.

G. Tensile Properties:

Bar Size Designation		Tensile Modulus of Elasticity		Ultimate Tensile Strength		Guaranteed Design Tensile Strength		Allowable Tensile Stress (Working Stress Limit)		Ultimate Strain in Tension	Poisson's Ratio
		E_T		F_u		f_{fu}		$f_{f,a}$		ε_{fu}	μ
mm	in	Gpa	Msi	MPa	Ksi	MPa	Ksi	MPa	Ksi	%	
#10	#3	42	6	840	121	780	113	195	28	2.00	0.27
#13	#4	42	6	800	116	725	105	181	26	1.90	0.27
#16	#5	40	5.8	780	113	655	95	164	24	1.95	0.27
#19	#6	40	5.8	720	104	630	91	158	23	1.80	0.27

Specifier Notes: C-BAR® deformed FRP bars are made of a thermoset resin. Bending must be carried out before the full curing of the FRP bars. No field bending or alteration is possible. Consult Marshall Composite Systems, LLC for a complete description of the test procedure or refer to MCS Research Summary Bulletins for more details on shop bending of C-BAR® deformed FRP bars.

H. Shop Bending:

1. Shop bend uncured FRP bars with a gradual transition, avoiding sharp angles that might damage fibers, as specified in the following table.
2. Tensile Strength of a 90 Degree Bend: Approximately 50 to 60 percent of guaranteed design strength of a straight bar.

US Size	Nominal Diameter, Inches	90 and 180 Degree Bend Diameter D (inches)	Soft Metric Size	Nominal Diameter, mm	90 and 180 Degree Bend Diameter D (mm)
#3	0.375	2.875	#10	9.5	73
#4	0.500	3.313	#13	12.7	84
#5	0.625	6.063	#16	15.9	154
#6	0.750	8.875	#19	19.0	225

Specifier Notes: Consult Marshall Composite Systems LLC for a complete description of the test procedure or refer to MCS Research Summary Bulletins for more details on the coefficient of thermal expansion of C-BAR® deformed FRP bars.

I. Coefficient of Thermal Expansion (C.T.E.):

1. Longitudinal Direction: 8 x 10-6 per degree C (4.5 x 10-6 per degree F).
2. Transverse Direction: 32 x 10-6 per degree C (18 x 10-6 per degree F).

Specifier Notes: Consult Marshall Composite Systems, LLC for a complete description of the test procedure or refer to MCS Research Summary Bulletins for more details on the bond strength of C-BAR® deformed FRP bars.

J. Bond Dependent Factor and Development Length:

The Bond Dependent Factor, Kb = 0.80

US Size	Nominal Diameter, in	Development Length, in	Soft Metric Size	Nominal Diameter, mm	Development Length, mm

#3	0.375	6.0	#10	9.5	150
#4	0.500	7.5	#13	12.7	190
#5	0.625	9.0	#16	15.9	225
#6	0.750	12.0	#19	19.0	300

A minimum overlap length of 40 diameters is required.

Specifier Notes: Consult Marshall Composite Systems, LLC for a complete description of the test procedure or refer to MCS Research Summary Bulletins for more details on the durability of C-BAR® deformed FRP bars.

K. Durability:

1. Increase in Mass of C-BAR® Reinforcing Bars in an Alkaline Solution (pH 12.5) at 60 Degrees C for 49 Days:

C-BAR® Sample	% Increase in mass	Average % Increase
DV1	0.31	0.3
DV2	0.22	
DV3	0.26	

2. Effect of Alkaline Solution (pH 13.5) on Tensile Strength Properties of C-BAR® Reinforcing Bars at 60 Degrees C:

Duration in 60 Degree C Solution pH 13.5	Avg. Peak Load (kN)	Avg. Peak Stress (MPa)	Avg. Disp. Stiffness (N/mm) **	Avg. Total Decrease in Peak Stress (%)	Avg. Total Decrease in Disp. Stiffness (%)
Control (Unconditioned)	133	717	6215	-	-
78 Days (approx. 11 weeks)	123	668	5880	7	5
118 Days (approx. 17 weeks)	110	595	6207	17	0
(approx. 25 weeks)	92	495	6329	26	-8

** Displacement stiffness was calculated by determining best fit line of linear section of Load vs. Elongation Graphs – not from peak values.

2.3 SOURCE QUALITY CONTROL

A. Quality Control Testing: Quality control shall be carried out by testing FRP bars before use, to ensure required performance. Test reports from testing conducted by an independent testing agency can be used when available. Perform following quality control tests in accordance with standard test methods:

1. Tensile strength, tensile modulus of elasticity, and ultimate strain.
2. Bent bars tensile strength.
3. Fatigue strength.
4. Bond strength.
5. Durability in alkaline environments.

PART 3 EXECUTION

3.1 EXAMINATION

A. Examine areas to receive FRP bars. Notify the Engineer if areas are not acceptable. Do not begin placing FRP bars until unacceptable conditions have been corrected.

3.2 PLACING

Specifier Notes: Placing of FRP bars is performed similarly as for uncoated steel reinforcing bars, and common practices should apply with some key exceptions, as specified below.

A. Place FRP bars in accordance with CRSI Placing Reinforcing Bars, unless otherwise specified.

B. Place FRP bars accurately in accordance with approved placing drawings, schedules, typical details, and notes.

C. Field Cutting:

1. Field cut FRP bars with high speed grinding cutter or saw. Do not shear bars.
2. Seal cut ends with end sealing kits available from manufacturer. Seal in accordance with manufacturer's instructions. FRP bars shall be delivered with sealed ends.

Specifier Notes: C-BAR® deformed FRP bars are made of a thermoset resin. Bending must be carried out before the full curing of the FRP bars. No field bending or alteration is possible.

D. Field Bending: Do not field bend FRP bars.

E. Securing: Secure FRP bars in formwork to prevent displacement by concrete placement or workers.

F. Supports: Place and support FRP bars accurately using plastic or non-corrosive chairs before concrete placement is started.

G. Fastening: Fasten FRP bars with coated tie wire, stainless steel tie wire, or nylon ties.

H. Form Ties: Use plastic or nylon form ties.

Specifier Notes: Research is currently being conducted on the use of grout-filled or resin-filled sleeves similar to the double-frustrum-shaped sleeve used as a mechanical splice connection. The Engineer must approve the use of these sleeves.

I. Splicing: Use lap splices, whenever continuity is required in the reinforcement. Do not use mechanical connections or welded splices.

J. Tolerances: Do not exceed placing tolerances specified in ACI 117.
K. Cleaning: Remove form oil from FRP bars by wiping bars with solvents before placing concrete.

END OF SECTION