PRESERVATION OF MISSOURI TRANSPORTATION INFRASTRUCTURES

Master Materials and Construction Specifications

VALIDATION OF FRP COMPOSITE TECHNOLOGY THROUGH FIELD TESTING

Prepared for:
Missouri Department of Transportation
University of Missouri-Rolla
Project RI 02-022

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EXECUTIVE SUMMARY

This document of specifications covers materials and construction requirements for strengthening of reinforced concrete (RC) bridges with composite materials. This document was prepared by University of Missouri-Rolla for MoDOT, as partial results of the project "Validation of FRP Composite Technology Through Field Testing". This project was conducted under a joint MoDOT – UMR University Transportation Center – Private Sector funding initiative.

This document, intended to be used on FRP-related bridge-strengthening projects, explains the concrete repairs, surface preparation, materials specification, storage, handling, installation process, etc, for the five different technologies, namely: manual lay-up carbon FRP laminates; near surface mounted (NSM) carbon FRP bars; adhered pre-cured carbon FRP laminates; steel reinforced polymer (SRP) laminates; and mechanically fastened carbon FRP laminates.

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A Concrete Repair

A.1 Site Demolition

A.1.1 General

A.1.1.1 References

The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by the basic designation only.

AMERICAN NATIONAL STANDARDS INSTITUTE (ANSI)
CODE OF FEDERAL REGULATIONS (CFR)

A.1.1.2 General Requirements

Do not begin demolition until authorization is received from the MoDOT-designated engineers (Engineer). Continuously remove rubbish and debris from the project site. Store materials that cannot be removed daily in areas specified by the Engineer.

A.1.1.3 Submittals

Submit the following documentation to the Engineer prior to receiving authorization to proceed with demolition:

Statements

a. Demolition plan
b. Notification of demolition and renovation

Submit proposed demolition and removal procedures to the Engineer for approval before work is started.

B.1.1.1.3.1.1 Required Data

The demolition plan shall include procedures for coordination with other work in progress, a detailed description of methods and equipment to be used for each operation, and the sequence of operations.

A.1.1.4 Dust and Debris Control

Prevent the spread of dust and debris and avoid the creation of a hazard or nuisance in the surrounding area. Minimize the dust impact on environment. Prevent unpermitted discharges into the soil, and Bridge. Prevent all debris, concrete cutting, chipping, demolition, and repair according to State regulations. The contractor must install protection in the work area to avoid that any material enters into the soil or water in accordance to State regulations.

A.1.1.5 Protection

A.1.1.5.1 Traffic Control Signs

Where driver safety is endangered in the area of removal work, use traffic barricades with flashing lights. Notify the Engineer prior to beginning such work.

A.1.1.5.2 Existing Work

Protect existing work that is to remain in place, be reused, or remain the property of the Government. Repair items which are to remain or which are to be salvaged that are damaged during performance of the work to their original condition, or replace with new. Do not overload structural elements. Additional structural supports and reinforcement must have Engineer approval.

A.1.1.5.3 Facilities

Protect electrical and mechanical services, utilities, and facilities. Where removal of existing utilities and pavement is specified or indicated, provide approved barricades, temporary covering of exposed areas, and temporary services or connections for electrical and mechanical utilities.

A.1.1.6 Burning

Burning will not be permitted.

A.1.2 Execution

A.1.2.1 Existing Facilities to be Removed

A.1.2.1.1 Concrete

Break out the concrete and prepare repair surface as detailed in the Contract Drawings.

A.1.2.2 Title to Materials

Except where specified in other sections, all materials and equipment removed, and not reused, shall become the property of the Contractor and shall be removed from Government property. The Government will not be responsible for the condition of, loss of, or damage to, such property after contract award. Materials and equipment shall not be viewed by prospective purchasers or sold on the site.

A.1.2.3 Cleanup

A.1.2.3.1 Debris and Rubbish

Remove and transport debris and rubbish in a manner that will prevent spillage into streets or adjacent areas. Clean up spillage from the site and adjacent areas daily.

A.2 Deck Repairs

A.2.1 General

This specification covers the use of prepackaged cementitious concrete repair materials and procedures for making partial-depth repairs in accordance with the Contract Drawings.

A.2.1.1 References

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

AASHTO T 2771989	Standard Method of Testing for Rapid Determination of the Chloride Permeability of Concrete

AMERICAN SOCIETY FOR TESTING AND MATERIAL (ASTM)

ASTM C 309 (1994)	Liquid Membrane-Forming Compounds for Curing Concrete
ASTM A 615	1993 Deformed and Plain Billet-Steel Bars for Concrete Reinforcement
ASTM C 33	1993 Concrete Aggregates
ASTM C 109	1991 Standard Method for Compressive Strength of Hydraulic Cement Mortars
ASTM C 157	Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete
ASTM C 490	Standard Practice for Use of Apparatus for the Determination of Length Change of Hardened Cement Paste, Mortar, and Concrete
ASTM C 496	1990 Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens

ASTM C 882 1991 Test Method for Bond Strength of Epoxy-Resin Systems Usedwith Concrete (modified for cementitious material)
ASTM C884 1987 Test Method for Thermal Compatibility Between Concrete and an Epoxy-Resin Overlay

AMERICAN CONCRETE INSTITUTE (ACI)
ACI 301 (1994) Structural Concrete for Buildings

A.2.1.2 Description Of Work

Concrete repair work must be accomplished prior to the application of composite upgrade materials. The concrete repair work consists of several parts:

a. Partial-depth repairs of deteriorated concrete.
b. Removal of sound concrete along some of the construction joints on the underside of the deck to establish a suitable surface profile flush with the adjacent surfaces.
c. Sealing construction joints and cracks on the top of the deck to prevent water from wetting the underside of the deck where FRP material is to be installed.

The repair work shall proceed by removing concrete from the deteriorated areas identified, cleaning the area by abrasive blasting, placing bonding agents, placing repair materials, finishing and texturing, curing, and, finally, sealing joints and saw overcuts.

A.2.1.3 Locations

The contractor will designate the locations and boundaries of each repair area that can affect the performance of the strengthening system. The Contractor will remove all unsound concrete and expose the rebar as necessary based on the repair criteria so that no visible corrosion is evident beyond normal “mill scale.”

A.2.1.4 Weather Limitations

Halt work when the weather conditions are inclement and will detrimentally affect the quality of patching concrete. Windy conditions and rain will effect the concrete curing. Apply patching materials only when the atmospheric and surface temperature ranges are suitable for the specified material. Halt work if the temperature is below 40°F (4°C). Follow manufacturer’s instructions for weather conditions and temperature ranges. Patches placed during adverse weather conditions may have to be removed and replaced.

A.2.2 Materials

A.2.2.1 Material Specifications

The materials used shall meet the requirements of the following Specifications as well as other MoDOT-designated engineers (Engineer) approved Proprietary repair materials:

AASHTO M-80 & M-6	Aggregate
AASHTO M-148	Curing compound
AASHTO M-194	Concrete admixtures

A.2.2.1.1 Cementitious Patch Material

The product shall be prepackaged by the manufacturer with premeasured, properly proportioned components. It shall be suitable for the hand-packed repair method (see Contract Drawings) and shall have the following properties:

a. Minimum pot life of 15 minutes at 75°F (24°C).

b. Bond strength per ASTM C 882 modified for cementitious material at 28 days: 2,200 psi minimum.

c. Maximum permeability of 1,000 coulombs per AASHTO T 277.

d. Drying shrinkage: Specimens shall be prepared per ASTM C 157 as modified to use molds per ASTM C 490 (3 by 3 by 11.25 inches (8 by 8 by 29 cm)) with a 10-inch (25 cm) gauge length. The molded specimen shall be covered with a water-saturated rug or burlap during the first 7 days. After the 7 day wet curing period the mold shall be removed and the specimen cured for an additional 28 days at 46 to 54 percent relative humidity at 70 to 76°F (21 to 25°C). The ultimate shrinkage to be reported is that value measured at the end of the 35th day. Allowable shrinkage shall not exceed 0.05 percent.

e. Minimum compressive strength per ASTM C 109 modified for cementitious material shall be 3,000 psi (21 MPa) at 3 days.

f. The water to cementitious ratio shall not exceed 0.40.

A.2.2.1.2 Aggregate

If aggregate is added to the prebagged mixture, then all tests for acceptance criteria per paragraph A.2.2.1.1 shall be conducted with the added aggregate. Aggregate added to the repair material, if allowed by the manufacturer, shall be 3/8-inch (1 cm) minus, clean, well graded, saturated surface dry material, having low absorption and high density, and conform to ASTM C 33. Aggregate must be approved for use by the Engineer.

A.2.2.1.3 Reinforcing Bars

ACI 301 unless specified otherwise. ASTM A 615, Grade 60 bars.

A.2.3 Equipment

A.2.3.1 Concrete Saw

The concrete saw shall be equipped with a diamond blade(s) or approved equal. The saw shall be capable of sawing concrete to the specified depth without damaging the surrounding concrete. Depth of cut shall be adjusted so as to avoid cutting the existing steel reinforcement.

A.2.3.2 Concrete Removal Equipment

The Contractor shall provide equipment capable of removing the deteriorated concrete in the repair area to the depth required without damaging the sound concrete surrounding or below the repair.

A.2.3.2.1 Brooms, Shovels

Stiff-bristled brushes shall be used to apply the bonding agent. Shovels may be used to place the repair materials, if appropriate.

A.2.3.2.2 Abrasive Blasting or Mechanical Scarification

Abrasive blasting or mechanical scarification shall be capable of removing all contaminants and loose particles from the surface of the steel reinforcement and concrete in the repair area. The equipment shall be fitted with suitable traps, filters, drip pans, or other devices to prevent oil, fuel, grease, or other undesirable matter from being deposited on the cleaned surface.

A.2.4 Construction Method

A.2.4.1 Determination of Repair Areas

The contractor shall determine areas to be repaired by using a hammer or other techniques to determine the extent of the unsound concrete. The Contractor shall mark the boundaries of the repair area. Holes through the deck will be either filled with low shrinkage concrete. All previous built-up repairs under the deck that interfere with areas to be structural upgraded must be modified to achieve a compatible surface profile with the adjacent concrete surfaces.

A.2.4.2 Concrete Removal

The deteriorated material in the repair area shall be removed using the methods specified in this section. A saw cut shall be made around the perimeter of the repair area to provide a vertical face at the edges and sufficient depth for the repair.

The saw cut shall have a minimum depth of ½ inch (13 mm). Depth of the cut shall be selected to preclude cutting reinforcing steel bars.

Concrete within the repair area shall be broken out to a minimum depth of 2 inches (51 mm) or until sound concrete is exposed.

Remove loose concrete from the designated areas. Inspect the cavity for remaining unsound concrete by tapping with a hammer or steel rod. In areas where tapping indicates unsound concrete, remove additional concrete. Make the entire cavity at least 2 inches (5 cm) deep. Where rebar is exposed remove all corrosion by abrasive blasting or mechanical means to a near white metal condition as per recommendations of patch material manufacturer, prior to installing patch material. Continue to "chase" all corroded steel reinforcement until no corrosion is visible beyond normal "mill scale." Prepare surfaces by abrasive blasting or mechanical scarification to achieve a uniformly rough surface.

A.2.4.3 Surface Preparation

A.2.4.3.1 Concrete

Abrasive blast or mechanically scarify the exposed faces of the concrete to remove all loose particles, oil, dust, cement or slurry residue, paint, and other contaminants. Immediately prior to placing the concrete bonding agents, clean the exposed surfaces by compressed air blasting. All loose particles, oil, dust, cement or slurry residue, paint, and other contaminants shall be contained in accordance with State regulations.

A.2.4.3.2 Steel Reinforcement

Externally bonded FRP system should not be applied to concrete substrate suspected of containing corroded reinforcing steel. Reinforcing steel bars that have lost more than 25 percent cross sectional area must be repaired by welding a new segment of rebar of the same diameter to the existing rebar. Corroded or damaged rebar will be identified in the field by the Contractor and verified for replacement by the Engineer. The splice will cross the damaged length and the welds made at locations where the existing rebar is in excellent condition without loss of area. New reinforcing steel shall be ASTM A-615 Grade 60 and welded in accordance with the Structural Welding Code – Reinforcing Steel (AWS D1.4). The Contractor will remove any concrete that is damaged during the welding process. Abrasive blast or mechanically clean the steel to bright steel no more than 48 hours prior to application of concrete patch material. All loose particles, oil, dust, cement or slurry residue, paint, and other contaminants shall be contained according with state regulations.

A.2.4.4 Applying the Bonding Agent

Use a bonding agent recommended by the supplier of the repair material. It may consist of neat cement, cement-sand, or latex-cement slurry. Apply the bonding agent to a clean surface saturated dry concrete substrate and scrub it into the surfaces using a stiff-bristled brush. Bonding agents that contain epoxy will not be allowed.

A.2.4.5 Placing the Repair Material

Always place materials containing aggregate with a shovel to avoid segregation. Flowable materials may be placed by a bucket or other suitable means.

A.2.4.5.1 Proprietary Repair Materials

The application shall be in accordance with manufacturer's recommendations. Special attention shall be paid to pack the material below reinforcing bars and to working the material into the concrete substrate to achieve a sound bond. Use a hard wood dowel to ram the material tightly below and around reinforcing.

A.2.4.6 Finishing Requirements

Partial-depth repairs are usually small enough so that a stiff board resting on adjacent sound concrete can be used as a screed. Work the materials toward the perimeter of the patch to establish contact and enhance bonding to the existing slab. Make at least two passes with the screed to ensure a smooth repair surface that is level with the surface of the deck. Care should be taken to not "over-work" the surface.

A.2.4.7 Saw Overcuts

The saw cuts extending from the repair area into to the surrounding sound concrete must be filled with epoxy mortar or cement mortar.

B Manual Lay-up Carbon/Epoxy FRP Laminate

This specification defines the material and procedural requirements for the preparation and installation of carbon fiber-reinforced polymer (CFRP) laminate systems by manual lay-up for strengthening of reinforced and prestressed concrete (RC and PC) members. The manual lay-up CFRP laminates will be installed in accordance with the Contract Drawings.

B.1 General

B.1.1 Work to be Provided

The contractor shall complete the following work as shown on the Contract Drawings, details, and as specified herein:

- Provide scaffolding, working platforms, and access;
- Provide concrete surface preparation;
- Install Carbon/epoxy manual lay-up laminate reinforcement system; and
- Provide all required tests and inspections of the system.

B.1.2 References

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM C 882	Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear
ASTM D 638	Standard Test Method for Tensile Properties of Plastics
ASTM D 695	Standard Test Method for Compressive Properties of Rigid Plastics
ASTM D3039	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials
ASTM D 3171	Standard Test Method for Fiber Content of Resin-Matrix Composites by Matrix Digestion
ASTM D 3379	Standard Test Method for Tensile Strength and Young's Modulus for High-Modulus Single-Filament Materials
ASTM D 4258	Standard Practice for Surface Cleaning Concrete for Coating.
ASTM D 4541	Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 515.1R	A Guide to the Use of Waterproofing, Damp proofing, Protective, and Decorative Barrier systems for Concrete.
ACI 440.1R-03	Guide for the Design and Construction of Concrete Reinforced with FRP Bars
ACI 440.2R-02	Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures

NATIONAL ASSOCIATION OF CORROSION ENGINEERS (**NACE**)
NACE RP 0288 Inspection of Linings on Steel and Concrete
INTERNATIONAL CONCRETE REPAIR INSTITUTE (**ICRI**)
Guideline No. 03732 Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays
STEEL STRUCTURES PAINTING COUNCIL (**SSPC**)
SSPC-PA Guide 3 A Guide to Safety in Paint Application.

B.1.3 Submittals

Submit the following in accordance with paragraphs B.1.3.1 to B.1.3.3

B.1.3.1 Instructions

a. Manual Lay-up Carbon/Epoxy FRP Laminates
Submit supplier's printed instructions and include brand name, catalog numbers, and names of manufacturers. Include with instructions the quantity of material to be used on the job. Include copies of the Material Safety Data Sheets (MSDS) for all materials to be used at the job site.

b. Epoxy System
Submit supplier's printed instructions and include brand name, catalog numbers, and names of manufacturers. Include in the instructions detailed mixing and application procedures, quantity of material to be used per square foot, total quantity of material to be used on the job, minimum and maximum application temperatures, and curing procedures. Include copies of the MSDS for all materials to be used at the job site.

B.1.3.2 Certificates

a. Manual Lay-up Carbon/Epoxy FRP Laminates
For the fiber reinforcement, certify conformance to the requirements set forth in paragraph B.2.1

b. Epoxy Saturant/Adhesive System
For the Epoxy Primer/Sealer certify conformance to the requirements set forth in paragraph B.2.2. For the Epoxy Putty Surfacer/Void Filler, certify conformance to the requirements set forth in paragraph B.2.3. For the Epoxy Saturant, certify conformance to the requirements set forth in paragraph B.2.4

B.1.3.3 Records

a. Installers Qualifications

Throughout the progress of the work in this Specification, the Contractor will provide at least one (1) person who is thoroughly familiar with the specified requirements, completely trained and experienced with the necessary skills and who will be present on the site and direct all work performed under this Specification.

In performing the work of this Specification, the Contractor will use an adequate number of skilled workmen to ensure the laminate installation is in strict accordance with schedule, Specifications, and Contract Drawings.

b. Disposal of Material

All epoxy resins and adhesives shall be disposed of properly as indicated on the MSDS. All epoxy resins and adhesives shall be stored and transported as indicated on the MSDS. Spent shot blasting media shall be contained and disposed of properly as required by local authorities. All materials (e.g., epoxies, concrete, grout, abrasive media, etc.) shall be contained at the site in accordance with State regulations.

B.1.3.4 Quality Assurance

Prior to commencement of any work, the Contractor shall be responsible for arranging and conducting a meeting between the Contractor and MoDOT-designated engineers (Engineer) to discuss the project requirements. The Contractor shall review the requirements of the Specification and overall project requirements. All aspects of the project including containment, environmental control, surface preparation, strengthening system application, quality assurance, schedule requirements, and safety shall be reviewed and discussed. The Contractor shall request clarification of any ambiguities, and advise the Engineer of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

The Contractor shall provide repair damage caused by acceptance testing in accordance with paragraph B.5 of this Specification. The Contractor shall ensure the highest quality of workmanship at all times throughout the progression of the work. Only qualified installers having prior training and experience in the specified surface preparation and carbon laminate applications shall be assigned to perform the work described herein.

The Contractor shall provide full a inspection of the surface preparation and composite systems applications to ensure that the requirements of this Specification are in full compliance.

B.1.3.5 Delivery, Handling and Storage

All materials shall be delivered in "new" condition only, packaged in their original, unopened containers bearing the manufacturer's name, product identification, batch number(s), and shelf life expiration date.

All components of FRP system, especially fiber sheets, must be handled with care according to recommendation to protect them from damage and to avoid misalignment or breakage of the fiber by pulling, separating, or winkling them or by folding the sheets. After cutting, sheets shall be either stacked dry with separator or rolled gently at a radius no tighter than 12 in (305 mm) or as recommended by the manufacturer.

All materials shall be stored in a covered, well-ventilated area and protected from exposure to any detrimental conditions including, airborne contaminants, dirt, dust, sunlight, extreme cold, heat, rainfall, sparks, or flame.

When requested by Engineer, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 2 percent of the total material used on this job.

B.1.3.6 Safety

The processes described in this Specification involve potentially hazardous operations. The contractor shall take the necessary precautions in accordance with manufacturer's instructions, applicable MSDS, and the MoDOT's site safety requirements to ensure the safety of all personnel that may be affected by the work described in this Specification.

The Contractor shall be responsible for providing any and all safety equipment required for confined spaces, the use of any products, and/or equipment utilized during the progression of the work.

The Contractor shall establish and maintain safe working conditions throughout the progression of the work. The Contractor shall take immediate action to remedy any safety concerns and unsafe, or potentially unsafe, working conditions.
The Contractor shall provide safe access to all work areas for inspection by Engineer and/or designated representatives.

B.2 Products

B.2.1 Carbon Fabric

The Carbon fabric for manual lay-up system consists of uniaxial carbon fiber sheets for strengthening negative moment, positive moment, and shear region of RC and PC bridge

members. System components must be chemically and mechanically compatible and develop sufficient bonding so that individual component strengths and properties are not compromised. The system must be ultraviolet (UV) resistant so that properties are not degraded for 10 years. It is preferable that UV stabilizers or absorbers are added to the epoxy matrix rather than relying on a protective coating.

DESCRIPTION	(VALUE)[1]	
	US Customary	SI Units
Tensile Strength avg., per ASTM D 3379	500 ksi	3,400 Mpa
Tensile Strength min., per ASTM D 3379	450 ksi	3,100 MPa
Tensile Strength of fabric	3.3 kips/in width	5,800 N/cm
Tensile Modulus avg., per ASTM D 3379	33,000 ksi	230,000 MPa
Tensile Modulus min., per ASTM D 3379	30,000 ksi	210,000 MPa
Tensile Elongation, avg., per ASTM D 3039	1.5 percent	
Tensile Elongation, min., per ASTM D 3039	1.1 percent	
Total Carbon Fiber Design Area	0.0065 in^2/inch	0.016 cm^2/cm

( )[1] at 72°F (22°C) and 50 percent relative humidity

B.2.2 Epoxy Primer/Sealer

The epoxy primer/sealer seals the concrete surface while increasing its tensile strength. The primer/sealer is a 100 percent solids, two component epoxy with low viscosity and moisture tolerant. The viscosity must be less than 100 cps to insure penetration into the concrete. The primer/sealer must not contain organic solvents.

DESCRIPTION	VALUE	
	US Customary	SI Units
Bond Strength, per ASTM C882 (hardened concrete to hardened concrete, 14 day moist cure)	2,700 psi	19 MPa
Tensile Strength, per ASTM D 638	7,500 psi	52 MPa

B.2.3 Epoxy Putty Surfacer/Void Filler

The epoxy putty surfacer and void filler provides a void-free concrete surface for application of the carbon laminate. The surfacer/void filler should be a 100 percent solids thixotropic epoxy paste.

DESCRIPTION	VALUE	
	US Customary	SI Units
Compressive Strength, per ASTM D 695	8.6 ksi	59 MPa
Adhesive Strength to Concrete, per ASTM D 4541	exceed concrete strength	
Tensile Strength, per ASTM D 638	3.6 ksi	25 MPa
Tensile Modulus, per ASTM D 638	650 ksi	4,500 MPa
Shear Strength, per ASTM D 732	3.6 ksi	25 MPa

B.2.4 Epoxy Saturant

The epoxy saturant is the matrix that completely coats, envelops and binds the unidirectional carbon fiber sheets to the concrete. The saturant shall be a 100% solids, two component epoxy.

DESCRIPTION	VALUE	
	US Customary	SI Units
Compressive Strength, per ASTM D 695	8.6 ksi	59 MPa
Adhesive Strength to Concrete, per ASTM D 4541	exceed concrete strength	
Tensile Modulus, per ASTM D 638	650 ksi	4,500 MPa
Tensile Strength, per ASTM D 638	3.6 ksi	25 MPa
Flexural Strength, per ASTM D 790	6.8 ksi	47 MPa
Shear Strength, per ASTM D 732	3.6 ksi	25 MPa

B.3 Execution

B.3.1 Concrete Repairs

Restoration of the concrete cross section is addressed in section A. Restoration includes chipping and removing damaged concrete, replacing steel reinforcing when necessary, replacement concrete, and repairing cracks.

B.3.2 Surface Preparation

All concrete surfaces to be strengthened shall be thoroughly prepared to comply with the minimum requirement defined in this Specification.

Carefully examine the concrete surface to be strengthened. Verify that the concrete surfaces and cracks have been properly repaired prior to preparation. Consult the Engineer for final advice and approval of additional areas to be repaired and methods of repair.

Surface preparation of the base concrete shall be performed to the extent to completely remove all weathered concrete, laitance, loosely adhering concrete, and spalling. All bugholes and subsurface voids shall be opened. Concrete surface irregularities, fins, and/or sharp angles may result in separation and delamination of carbon laminate from the concrete. Concrete surface irregularities must be removed and smoothed to less than 40 mils (1 mm). All inside and outside corners and sharp edges shall be rounded or chamfered to a minimum radius of 1/2-inch (12.7 mm). Methods that bruise the concrete shall not be allowed

Difference of adjacent concrete surface levels must be no greater than 40 mils (1 mm) when prepared for laminate application. Concrete surface protrusions must be flattened. Small depressions on concrete surfaces must be filled with epoxy putty or mortar.

Presence of moisture may inhibit adhesion of primer and resin. Wet surfaces must be thoroughly dried before applying primer and resin. Do not apply primer or resin when rainfall or dew is present. Do not apply resin or primer when the humidity is greater than 85 percent. Do not expose primer, resin, or epoxy putty to rainfall, dew, or humidity in excess of 85 percent.

Perform abrasive blasting on concrete surfaces to be strengthened prior to composite material application to clean the concrete surfaces of dust, dirt, laitance, oil and any curing substance. The concrete surface should be prepared to a minimum concrete surface profile (CSP) 3 as defined as ICRI- Surface profiles.

Face shields, goggles, and gloves will be worn by workers removing concrete.

Maintain control of abrasive media, concrete chips, dust, and debris in each area of work. Clean up and remove such material at the completion of each day. All concrete chips, abrasive media, paint chips, dust, and other debris shall be contained in accordance with state regulations.

B.3.3 Carbon Manual Lay-up Laminate Installation

B.3.3.1 General

The carbon manual lay-up laminate system shall be installed in strict accordance with the manufacturer's written recommendation for procedures and equipment, in conjunction with the specific requirements defined herein. In the event of the conflict between the requirements of the Specification and the manufacturer's recommendations, this Specification shall take precedence.

It is possible that epoxy based materials used in the composite system may develop higher viscosity and/or cure slower and insufficiently at low ambient temperature. Do not apply the specified system when substrate temperatures are lower than 50°F (10°C).

Presence of moisture may inhibit adhesion of the system to the concrete substrate. Provide necessary weather protection to protect surfaces from rain or cold. Installation in rain is strictly prohibited.

All surfaces to receive the carbon fiber fabric shall be primed with the specified penetrating primer prior to application of any subsequent coatings.

Primer shall be mixed in accordance with the manufacturer's recommendations.

Do not mix any solvents with the epoxy primer. Volume of primer to be prepared at one time must be such that it can be applied within its batch life. A fixed primer

batch which has exceeded it batch life must not be used. The batch life may vary subject to ambient temperature or volume of the mixed primer batch and care must be taken accordingly. No primer coat shall be applied if ambient temperature is lower than 50°F (10°C).

Primer must be thoroughly mixed with hardener at the manufacturer's specified ratio in a mixing pot until it is uniform. At least two minutes of agitation is required by means of an electric hand mixer. Primer shall be applied by brush or roller. Alternatively, the primer may be spray applied with airless spray equipment, followed immediately by thorough backrolling to work the primer into the concrete surface. The primer shall be applied uniformly in sufficient quantity to fully penetrate the concrete and produce a non-porous film in the surface not to exceed 1 dry mil (25 μm) in thickness after full penetration. If necessary, a second coat shall be applied after the first coat has penetrated into the concrete. Volume of primer to be applied may vary depending on the coarseness of the concrete surface but a minimum of 0.46 lbs/yd^2 (0.25 kgm/m^2) and a maximum of 0.74 lbs/yd^2 (0.40 kgm/m^2) shall be applied.

Applied primer coat must be cured overnight or until it is tack free before subsequent applications can be made. Surface irregularities caused by primer coating must be ground smooth using a disc grinder. Minor surface defects that remain may be corrected using epoxy filler/surfacer.

Maintain control of primer resins in each area of work. Clean up and remove unused and discarded excess material at the completion of each workday.

B.3.3.2 Application of Filler/Surfacer

The filler/surfacer shall be applied to surfaces that have been primed with the specified penetrating primer. All bugholes and subsurface voids shall be filled.

The Filler/surfacer shall be troweled tight against the surface with opposing passes, in both to and from and left and right directions (four (4) way method). The filler/surfacer shall be applied in strict accordance with the manufacturer's recommendations. Do not mix any solvents with the epoxy surfacer/void filler. It is not desirable that the epoxy filler/surfacer cover the entire concrete surface.

Maintain control of epoxy putty filler material in each work area. Clean up and remove unused and discarded excess material at the completion of each workday.

B.3.3.3 Application of Carbon Fiber Sheet

Carbon fiber sheets will not be applied when the temperature is less than 50°F (10°C) or if surface moisture is present or anticipated.

The carbon fiber sheets must be cut beforehand into prescribed sizes using scissors or other appropriate shearing cutter. The number of sheets cut shall be limited to the number to be installed that day.

The primer and filler/surfacer must be thoroughly cured before applying the carbon sheets. The putty, if used in the FRP system, shall be applied as soon as the primer is not sticky to the finger. The primed surface must be roughened to an equivalent CSP 3 finish if it was applied more than a week in advance.

A saturant coating shall be roller-applied to the concrete surface and/or to the carbon fiber sheet. Rolling perpendicular to fiber direction is not allowed. The carbon fiber sheet shall then be installed by the manual lay-up method. The sheet will be properly aligned and set into the surface saturant. The sheet shall then be completely saturated with an application of a roller-applied saturant to the external surface. The process shall be carefully planned to allow sufficient working time for the rolling of the carbon fiber sheet and saturant to produce a uniform system that is completely free of voids and trapped air and to be completed within the time limits of the saturant pot life. The saturant coat shall be applied in strict accordance with the manufacturer's recommendations.

Special care shall be taken to minimize the elapsed time between mixing and application of the saturant to ensure the material is applied to the sheet at least 15 minutes prior to any thickening or gelling. The work time limitations will vary according to temperature, and can be determined by information obtained from the manufacturer and practical experience with the product. Do not mix any of the solvents with the epoxy saturant.

Ensure that the laminate is hand laid and cured without the aid of external heating or vacuum bags. The first layer can be applied directly to the uncured putty after coating the fiber sheet or the concrete surface with an epoxy saturate. Successive plies are added between layers of epoxy saturate. Excess saturate and bubbles are brushed, squeegeed, rolled, and otherwise "worked out" of each layer.

No holes will be cut in the composite to circumvent obstacles such as pipes, hangers, and drain holes. The carbon sheets must be split to circumvent these obstacles. No overlapping is required perpendicular to fiber direction. When the length of the sheet to be installed exceeds the length suggested by the manufacturer for proper installation, lap jointing becomes necessary. Lap splice length depends on the type of resin and fibers. For large coverage areas, all lap joints in the longitudinal direction of fibers must be made in a single day.

The installed carbon fiber system shall be completely free of laminate defects including air pockets, voids, unsaturated areas, sags, and inclusions. After the installed system has been allowed to cure a minimum of 24 hours, the Contractor shall repair all defects as necessary to comply with the requirements of this Specification.

In order to avoid vibration during the installation, traffic control must be used. Speed of the cars must be limited to approximately 15 mph.

The fiber plies shall be aligned on the structural member according to the Contract Documents. Any deviation in the alignment more than 5˚ (approximately 87 mm/m or 1 in/ft) is not acceptable. Once installed, the fibers shall be free of kink, folds and waviness.

Maintain control of epoxy resin saturant and carbon fiber material in each work area. Clean up and remove unused and discarded excess material at the completion of each workday.

B.4 Rework and Repairs

Applied composite systems that are found to be defective or damaged will be replaced if deemed necessary by MoDOT-designated engineers (Engineer) to render the repairs in full compliance with the requirements of this Specification. Rework and repair procedures shall comply with all material and procedural requirements defined in this Specification. Defects shall be repaired in a manner that will restore the system to the designed level of quality. Repair procedures for conditions that are not specifically addressed in this Specification shall be approved by Engineer on the case-by-case basis prior to initiating any repairs. All repairs shall be made to the satisfaction of Engineer. Inspection methods should be capable of detecting delaminations of 2 in^2 (1300 mm^2) or greater. Delaminations smaller than 2 in^2 (1300 mm^2) are permissible, so long as the defective area is less than 5% of the total laminate area or less than 10 of such delamination per 10 ft^2 (1 m^2). Delaminations less than 25 in^2 (16,000 mm^2) may require resin injection or ply replacement. Large delaminations greater than 25 in^2 (16,000 mm^2) can affect the performance of installed FRP. In this case, all voids, bubbles, and delaminations are to be repaired by epoxy injection or replacement of the laminate.

B.5 Acceptance Testing

Soundings of the strengthened areas will be done to check for voids, bubbles and delaminations. All voids, bubbles, and delaminations shall be repaired by epoxy injection or replacement. An acoustic tap test will be carried out with a hard object to identify delaminated areas by sound, with at least one strike per 0.1 m (1 ft^2).

After at least 24 hours for the initial curing of the resin and before applying the protective coating, a direct pull-off test (modified ASTM D 4541-93) that measures the bond between the laminate and existing concrete substrate in a composite system, shall be used for acceptance of the performance strengthening system. A core shall be drilled through

the carbon laminate strip 1/16 to 1/8 inch (1 to 2 mm) into the concrete substrate, providing an isolated test location for attachment of the pull-off tester. A tension device shall be loaded to failure during the test. The device will record the force causing the failure, which, if divided by the core cross sectional area will result in tensile strength. Upon failure of the core specimen, a visual examination of the failure plane location reveals whether the failure occurred at the bond line or within the substrate. Failure of the concrete is the only acceptable failure. Failure at the bond line at tensile stress below 200 psi (1.4 MPa) is unacceptable.

At a minimum, three pull-off tests with at least one test per span or one test per 93 m^2 (1,000 ft^2) of area strengthened with the carbon fiber strip system will be performed.

Any deviation from this requirement will require a meeting between the Contractor and Engineer to identify issues and remedies.

The test areas of the composite system shall be repaired to the satisfaction of Engineer in accordance with paragraph B.4

C Near Surface Mounted Composite Bar System

This specification defines the material and procedural requirements for the preparation and installation of a pultruded carbon/epoxy composite (CFRP) reinforcing bar system for post strengthening of the reinforced and prestressed concrete (RC and PC) members. The near surface mounted (NSM) CFRP bar may have either a circular or rectangular cross-section. The CFRP bar will be installed in accordance with the Contract Drawings.

C.1 General

C.1.1 Work to be Provided

The Contractor shall complete the following work as shown on the Contract Drawings, details, and as specified herein:

- Provide access for confined spaces
- Provide concrete surface preparation
- Install carbon/epoxy FRP bar system
- Provide all required tests and inspections of the strengthened system.

C.1.2 References

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM C 882	Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear
ASTM D 638	Standard Test Method for Tensile Properties of Plastics
ASTM D 695	Standard Test Method for Compressive Properties of Rigid Plastics
ASTM D3039	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials
ASTM D 3171	Standard Test Method for Fiber Content of Resin-Matrix Composites by Matrix Digestion
ASTM D 3379	Standard Test Method for Tensile Strength and Young's Modulus for High-Modulus Single-Filament Materials
ASTM D 4258	Standard Practice for Surface Cleaning Concrete for Coating.
ASTM D 4541	Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 515.1R	A Guide to the Use of Waterproofing, Damp proofing, Protective, and Decorative Barrier systems for Concrete.
ACI 440.1R-03	Guide for the Design and Construction of Concrete Reinforced with FRP Bars
ACI 440.2R-02	Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures

NATIONAL ASSOCIATION OF CORROSION ENGINEERS (NACE)
NACE RP 0288 Inspection of Linings on Steel and Concrete
INTERNATIONAL CONCRETE REPAIR INSTITUTE
Guideline No. 03732 Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays
STEEL STRUCTURES PAINTING COUNCIL (SSPC)
SSPC-PA Guide 3 A Guide to Safety in Paint Application.

C.1.3 Submittals

Submit the following in accordance with paragraphs C.1.3.1 to C.1.3.3

C.1.3.1 Instructions

a. Carbon/Epoxy FRP Bars
Submit supplier's printed instructions to include brand name, catalog numbers, and names of manufacturers. Include with the instructions the quantity of material to be used per square foot and total quantity of material to be used on the job. Include copies of the Material Safety Data Sheets (MSDS) for all materials to be used at the job site

b. Epoxy Adhesive System
Submit supplier's printed instructions and include brand name, catalog numbers, and names of manufacturers. Include in the instructions detailed mixing and application procedures, quantity of material to be used per square foot, total quantity of material to be used on the job, minimum and maximum application temperatures, and curing procedures. Include copies of the MSDS for all materials to be used at the job site.

C.1.3.2 Certificates

a. Carbon/Epoxy FRP Bars
For the composite bar, certify conformance to the requirements set forth in paragraph C.2.1.1

b. Epoxy Encapsulant System
For the Epoxy Adhesive, certify conformance to the requirements set forth in paragraph C.2.2.1. For UV protection certify conformance to the requirements set forth in paragraph C.2.2.2

C.1.3.3 Records

a. Installers Qualifications

Throughout the progress of the work in this Specification, the Contractor will provide at least one (1) person who is thoroughly familiar with the specified requirements, completely trained and experienced with the necessary skills, and who will be present on the site and direct all work performed under this Specification.

In performing the work of this Specification, the Contractor will use an adequate number of skilled workmen to ensure the installation is in strict accordance with schedule, Specifications, and procedures required by the Missouri Department of Transportation (MoDOT).

b. Disposal of Material

All polymer resins and adhesives shall be disposed of properly as indicated on the MSDS. All epoxy resins and adhesives shall be stored and transported as indicated on the MSDS. All materials (e.g., epoxies, grout, abrasive media, etc.) shall be contained at the site and in accordance with state Regulation.

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C.1.3.4 Quality Assurance

Prior to commencement of any work, the Contractor shall be responsible for arranging and conducting a meeting between the Contractor and MoDOT-designated engineers (Engineer) to discuss the project requirements. The Contractor shall review the requirements of the Specification and overall project requirements. All aspects of the project including containment, environmental control, surface preparation, strengthening system application, quality assurance, schedule requirements, and safety shall be reviewed and discussed. The Contractor shall request clarification of any ambiguities, and advise the Engineer of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

The Contractor shall provide repair damage caused by acceptance testing in accordance with paragraph C.4 of this specification. The Contractor shall ensure the highest quality of workmanship at all times throughout the progression of the work. Only qualified installers having prior training and experience in the specified surface preparation and carbon laminate applications shall be assigned to perform the work described herein.

The Contractor shall provide full a inspection of the surface preparation and composite systems applications to ensure that the requirements of this Specification are in full compliance.

C.1.3.5 Delivery and Storage

All materials shall be delivered in “new” condition only, packaged in their original, unopened containers bearing the manufacturer’s name, product identification, batch number(s), and shelf life expiration date.

All materials shall be stored in a covered, well-ventilated area and protected from exposure to any detrimental conditions including, airborne contaminants, dirt, dust, sunlight, extreme cold, heat, rainfall, sparks, or flame.

All components of FRP system, especially fiber sheets, must be handled with care according to recommendation to protect them from damage

When requested by Engineer, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 2 percent of the total material used on this job.

C.1.3.6 Safety

The processes described in this Specification involve potentially hazardous operations. The contractor shall take the necessary precautions in accordance with manufacturer's instructions, applicable MSDS, and the MoDOT's site safety requirements to ensure the safety of all personnel that may be affected by the work described in this Specification.

The Contractor shall be responsible for providing any and all safety equipment required for confined spaces, the use of any products, and/or equipment utilized during the progression of the work.

The Contractor shall establish and maintain safe working conditions throughout the progression of the work. The Contractor shall take immediate action to remedy any safety concerns and unsafe, or potentially unsafe, working conditions. The Contractor shall provide safe access to all work areas for inspection by Engineer and/or designated representatives.

C.2 Products

C.2.1 Carbon/Epoxy FRP Bars

The carbon/epoxy FRP bars are the reinforcing elements for the negative moment, positive moment and shear regions of RC and PC bridge members. The bars are pultruded carbon fiber reinforced epoxy.

C.2.1.1 Carbon Fiber Composite Bar

DESCRIPTION	(VALUE)[1]	
	US Customary	SI Units
Percentage of fiber area to total area of bar, per ASTM D 3171	60 percent min	
Tensile Strength, Ultimate, per ASTM D 3916	250 ksi min	1.72 GPa
Tensile Modulus Per ASTM D 3916	19,000 ksi	144 GPa
Tensile Elongation, Ultimate, per ASTM D 3916	1.3 percent	

( )[1] at 72°F (22°C) and 50 percent relative humidity

C.2.2 Epoxy Adhesive System

The carbon bars are embedded in an epoxy resin in slots cut in the concrete surface as shown in the Contract Drawings. The epoxy encapsulant system shall include a primer/sealer for the concrete surface, the epoxy adhesive encapsulating the composite bar, and an Ultraviolet (UV) protection layer. The system components must be chemically compatible so that individual properties are not compromised and so that solid bonding is developed. The system must be UV radiation resistant so that strengths are not degraded for 10 years.

C.2.2.1 Epoxy Adhesive

The epoxy adhesive that encapsulates the carbon bar is a two-part, 100 percent solids, high modulus, high-strength, moisture tolerant, highly filled epoxy. It must be chosen to be chemically and mechanically compatible with the carbon FRP Bars and the concrete. The adhesive must develop a solid, permanent bond with the carbon composite and with the concrete.

DESCRIPTION	(VALUE)	
	US Customary	SI Units
Compressive Strength, per ASTM D 695@ 90^0F	8.2 ksi	57 MPa
Adhesive Strength to Concrete, per ASTM D 4541	Exceed concrete strength	
Tensile Modulus, per ASTM D 638	320 ksi	2.2 GPa
Tensile Strength, per ASTM D 638	5.1 ksi	35 MPa
Flexural Strength, per ASTM D 790	7.4 ksi	51 MPa
Shear Strength, as per ASTM D 732	5.9 ksi	41 MPa
Adhesion Strength to Carbon Bar, per ASTM C 882 Plastic Concrete to Hardened Concrete (14 day moisture cure)	2.4 ksi	17 MPa

C.2.2.2 UV Protection

The carbon reinforcing bar and the epoxy system must be protected from ultraviolet UV radiation degradation. A durable polymer layer must be added over the adhesive system with UV absorbers or stabilizers.

The polymer layer shall consist of a low modulus, medium viscosity, epoxy resin binder combined with sand to act as a UV inhibitor and as an abrasive protective coating for the top deck surface. The sand/epoxy layer should be applied over the epoxy encapsulant before the latter has polymerized.

Epoxy Resin Binder:

DESCRIPTION	(VALUE)[1]	
	US Customary	SI Units
Compressive Strength, per ASTM D 695 at 90°F (32°C)	6.2 ksi	43 MPa
Adhesive Strength to Concrete, per ASTM D 4541	Exceed concrete strength	
Tensile Modulus, per ASTM D 638	540 ksi	3,700 MPa
Tensile Strength, per ASTM D 638	1.1 ksi	8 MPa
Flexural Strength, per ASTM D 790	2.6 ksi	18 MPa
Shear Strength, per ASTM D 732	2.7 ksi	9 MPa
Adhesion Strength to Carbon Bar, per ASTM C 882	2.2 ksi	15 MPa

Sand:

60 Grit (270 μm diameter) oven dried silica sand free of organic impurities.
Mix two (2) parts sand to one (1) part epoxy resin by volume

C.3 Execution

Surface Preparation Restoration of the concrete cross section is addressed in A. Restoration includes chipping and removing damaged concrete, replacing steel reinforcing when necessary, replacement concrete, and repairing cracks.

C.3.1 Surface Preparation

All concrete surfaces to be strengthened shall be thoroughly prepared to comply with the minimum requirement defined in this section.

Carbon bars can only be embedded after the concrete has been reconditioned and the cracks are filled. Carefully examine the concrete surface to be strengthened.

Verify that the concrete surfaces and cracks have been properly repaired prior to preparation. Consult the Engineer for final advice and approval of additional areas to be repaired and methods of repair.

Surface preparation shall be performed to the extent to completely remove all laitance, loosely adhering concrete, and spalling.

Prior to initiating reinforcing procedures, the Contractor shall test the bond strength of the epoxy system by preparing a test patch to the properly prepared concrete. The test patch area shall be prepared in accordance with the requirements of this Specification. After curing, the epoxy system's bond strength to concrete shall be determined in accordance with ASTM D 4541-93. Three pull-off tests will be performed where each pull-off will develop minimum bond strength to concrete fail the concrete substrate. All failures must be reported to Engineer immediately.

The surface area to be reinforced will be primed with the two-part, penetrating epoxy sealer primer. After the primer has cured 24 hours, the reinforcing slots are laid out and slots are cut in the deck with a concrete saw or router. The diameter of the carbon bars and the number of bars per slot determine the depth and width of slots. Multiple bars or twisted strands can be embedded in each slot. The slots will allow at least one-sixteenth (1/16) of an inch (1 mm) between the bars and concrete, at least one-sixteenth (1/16) of an inch (1 mm) between each bar in the slot, and at least three-eighths (3/8) of an inch (9 mm) clear cover. Slots will be cut in the range of three-fourths (3/4) of an inch (18 mm) deep and at one-half (1/2) of an inch (13 mm) wide. The spacing of the slots will be 4 inches (9 mm) on center. Other slot sizes and slot spacing must be approved by the Engineer.

Perform abrasive blasting on concrete surfaces to be strengthened. Use materials and methods for project work as used to produce sample preparation acceptable to the Engineer. Use abrasive of uniform size and angular shape so as to provide a uniformly etched profile.

Maintain control of concrete chips, dust, and debris in each area of work. Clean up and remove such material at the completion of each day. All concrete chips, abrasive media, paint chips, dust, and other debris shall be contained and prevented in accordance with state regulations.

C.3.2 Carbon Bar Installation

C.3.2.1 General

The carbon bar reinforced system shall be installed in strict accordance with the Contract Drawings, the specified procedures and equipment, and in conjunction with the requirements defined herein.

It is possible that epoxy based materials used in the composite system may develop higher viscosity and/or cure slower and insufficiently at low ambient temperature. Do not apply the specified system when substrate temperatures are lower than 50°F (10°C).

Presence of moisture may inhibit adhesion of the system to the concrete substrate. Provide necessary weather protection to protect surfaces from rain or cold.

Primer shall be mixed in accordance with the manufacturer's recommendations. The volume of primer to be prepared at one time must be such that it can be applied within its batch life. A fixed primer batch which has exceeded it batch life must not be used. The batch life may vary subject to ambient temperature or volume of the mixed primer batch and care must be taken accordingly. Do not mix any solvents with the epoxy primer.

Primer shall be applied by brush or roller. Alternatively, the primer may be spray applied with airless spray equipment, followed immediately by thorough backrolling to work the primer into the concrete surface. The primer shall be applied uniformly in sufficient quantity to fully penetrate the concrete and produce a non-porous film in the surface not to exceed one (1) dry mil (25 μm) thickness after full penetration.

C.3.2.2 Installation of Carbon FRP Bars

The slots are abrasively blasted to clean and remove all loose material. The slots are primed with two parts epoxy primer sealant and allowed to cure 24 hours.

The carbon bars are embedded in a two-part epoxy encapsulant. Two parts epoxy may be combined with one part 60 grit (270 μm diameter) sand by volume to extent the epoxy encapsulant. The slots are filled to within 1/8- to ¼-inch (3 to 6 mm) of the top surface with the epoxy/sand mixture and the bars are placed in the slots and pressed to the bottom of the slot. Before the epoxy/sand encapsulate mixture cures, the UV inhibitor layer can be applied directly to fill the slots completely. If the encapsulate is allowed to cure then the blush must be removed with abrasives and wiped clean with solvent prior to the application of the UV inhibitor. The UV inhibitor shall be placed so that there are no low spots, which would permit the pooling of water over the slots. The final layer shall be flush with the existing concrete surface.

The carbon bars shall be installed by hand. Bar splices and laps area not allowed. The process shall be executed to produce a uniform encapsulating system that is completely free of voids and trapped air. Epoxy parts shall be mixed and applied in strict accordance with the manufacturer's recommendations. Do not mix any solvents with the epoxies.

Special care shall be taken to minimize the elapsed time between mixing and application of the epoxy encapsulant to ensure the carbon bars are installed at least 15 minutes prior to any thickening or gelling. The work time limitations will

vary according to temperature, and can be determined by information obtained from the manufacturer and practical experience with the product.

The installed reinforcing system shall be completely free of defects including air pockets, voids, and inclusions. After the installed system has been allowed to cure a minimum of 24 hours, the Contractor shall repair all defects as necessary to comply with the requirements of this Specification.

Maintain control of epoxy resin and carbon bar material in each area of work. Clean up and remove unused and discarded excess material at the completion of each workday.

C.4 Rework and Repairs

Applied composite systems that are found to be defective or damaged will be replaced if deemed necessary by Engineer to render the repairs in full compliance with the requirements of this Specification. Rework and repair procedures shall comply with all material and procedural requirements defined in this Specification. Defects shall be repaired in a manner that will restore the system to the designed level of quality. Repair procedures for conditions that are not specifically addressed in the Specification shall be approved by Engineer on a case-by-case basis prior to initiating any repairs. All repairs shall be made to the satisfaction of Engineer.

D Bonded Carbon/Epoxy Pre-cured Laminate

This specification defines the material and procedural requirements for the preparation and installation of carbon/epoxy composite (CFRP) pre-cured laminate system for strengthening of the reinforced and prestressed concrete (RC and PC) members. The pre-cured CFRP laminates will be installed in accordance with the Contract Drawings.

D.1 General

D.1.1 Work to be Provided

The contractor shall complete the following work as shown on the Contract Drawings, details, and as specified herein:

- Provide scaffolding, working platforms, and access for confined spaces
- Provide concrete surface preparation
- Install pre-cured CFRP laminate reinforcing system
- Provide all required tests and inspections of the strengthened system

D.1.2 References

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM C 882	Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear
ASTM D 638	Standard Test Method for Tensile Properties of Plastics
ASTM D 695	Standard Test Method for Compressive Properties of Rigid Plastics
ASTM D3039	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials
ASTM D 3171	Standard Test Method for Fiber Content of Resin-Matrix Composites by Matrix Digestion
ASTM D 3379	Standard Test Method for Tensile Strength and Young's Modulus for High-Modulus Single-Filament Materials
ASTM D 4258	Standard Practice for Surface Cleaning Concrete for Coating.
ASTM D 4541-93	Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 515.1R	A Guide to the Use of Waterproofing, Damp proofing, Protective, and Decorative Barrier systems for Concrete.
ACI 440.1R-03	Guide for the Design and Construction of Concrete Reinforced with FRP Bars
ACI 440.2R-02	Guide for the Design and Construction of Externally Bonded FRP

Systems for Strengthening Concrete Structures
NATIONAL ASSOCIATION OF CORROSION ENGINEERS (NACE)
NACE RP 0288 Inspection of Linings on Steel and Concrete
INTERNATIONAL CONCRETE REPAIR INSTITUTE
Guideline No. 03732 Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays
STEEL STRUCTURES PAINTING COUNCIL (SSPC)
SSPC-PA Guide 3 A Guide to Safety in Paint Application

D.1.3 Submittals

Submit the following in accordance with paragraphs D.1.3.1 to D.1.3.3

D.1.3.1 Instructions

a. Pre-cured CFRP Laminates.
Submit supplier's printed instructions and include brand name, catalog numbers, and names of manufacturers. Include in the instructions the quantity of material to be used per square foot and the total quantity of material to be used on the job. Include copies of the Material Safety Data Sheets (MSDS) for all materials to be used at the job site.

b. Epoxy Adhesive System
Submit supplier's printed instructions and include brand name, catalog numbers, and names of manufacturers. Include in the instructions detailed mixing and application procedures, quantity of material to be used per square foot, total quantity of material to be used on the job, minimum and maximum application temperatures, and curing procedures. Include copies of the MSDS for all materials to be used at the job site.

D.1.3.2 Certificates

a. Pre-cured CFRP Laminates
For the composite pre-cured laminate, certify conformance to the requirements set forth in paragraph D.2.1.1

b. Epoxy Adhesive System
For the Epoxy Primer/Sealer, certify conformance to the requirements set forth in paragraph D.2.2.1.For the Epoxy Adhesive, certify conformance to the requirements set forth in paragraph D.2.2.2

D.1.3.3 Records

a. Installers Qualifications

Throughout the progress of the work in this Specification, the Contractor will provide at least one (1) person who is thoroughly familiar with the specified requirements, completely trained and experienced with the necessary skills to install Carbon/Epoxy Precured Laminates as external reinforcement, and who will be present on the site and direct all work performed under this Specification.

In performing the work of this Specification, the Contractor will use an adequate number of skilled workmen to ensure the installation is in strict accordance with schedule, Specifications, and required procedures required by the Missouri Department of Transportation (MoDOT).

b. Disposal of Material

All polymer resins and adhesives shall be disposed of properly as indicated on the MSDS. All epoxy resins and adhesives shall be stored and transported as indicated on the MSDS. All materials (e.g., epoxies, grout, abrasive media, etc.) shall be contained at the site in accordance with state Regulation.

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D.1.3.4 Quality Assurance

Prior to commencement of any work, the Contractor shall be responsible for arranging and conducting a meeting between the Contractor and MoDOT-designated engineers (Engineer) to discuss the project requirements. The Contractor shall review the requirements of the Specification and overall project requirements. All aspects of the project including containment, environmental control, surface preparation, strengthening system application, quality assurance, schedule requirements, and safety shall be reviewed and discussed. The Contractor shall request clarification of any ambiguities, and advise the Engineer of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

The Contractor shall provide acceptance testing in accordance with paragraph D.5 of this Specification.

The Contractor shall ensure the highest quality of workmanship at all times throughout the progression of the work. Only qualified applicators having prior experience and training in the specified surface preparation and pre-cured CFRP laminate reinforcement applications shall be assigned to perform the work described herein.

The Contractor shall provide a full inspection of the surface preparation and composite systems applications to ensure that the requirements of this Specification are in full compliance.

D.1.3.5 Delivery and Storage

All materials shall be delivered in "new" condition only, packaged in their original, unopened containers bearing the manufacturer's name, product identification, batch number(s), and shelf life expiration date.

All materials shall be stored in a covered, well-ventilated area and protected from exposure to any detrimental conditions including, airborne contaminants dirt, dust, sunlight, extreme cold, heat, rainfall, sparks, or flame.

When requested by Engineer, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 2 percent of the total material used on this job.

D.1.3.6 Safety

The processes described in this Specification involve potentially hazardous operations. The contractor shall take the necessary precautions in accordance with manufacturer's instructions, applicable MSDS, and the MoDOT's site safety requirements to ensure the safety of all personnel that may be affected by the work described in this Specification.

The Contractor shall be responsible for providing any and all safety equipment required for confined spaces, the use of any products, and/or equipment utilized during the progression of the work.

The Contractor shall establish and maintain safe working conditions throughout the progression of the work. The Contractor shall take immediate action to remedy any safety concerns and unsafe, or potentially unsafe, working conditions.
The Contractor shall provide safe access to all work areas for inspection by Engineer and/or designated representatives.

D.2 Products

The carbon/epoxy composite (CFRP) pre-cured laminate consists of carbon fiber strips, epoxy primer/sealant, epoxy putty surfacer/void filler, and epoxy adhesive. These components must be chemically and mechanically compatible and develop sufficient bonding so that individual component strengths and properties are not compromised.

D.2.1 Carbon/Epoxy FRP Pre-cured Laminate

The carbon pre-cured laminates will externally reinforce the concrete surface. The pre-cured laminate is pultruded high tensile carbon fiber in an epoxy matrix.

D.2.1.1 Carbon Fiber Composite Laminate

DESCRIPTION	(VALUE)[1]	
	US Customary	SI Units
Percentage of fiber area to total area of strip, per ASTM D 3171	60 percent min	
Tensile Strength, Ultimate, per ASTM D 3916	250 ksi min	1.72 GPa
Tensile Modulus Per ASTM D 3916	19,000 ksi	144 GPa
Tensile Elongation, Ultimate, per ASTM D 3916	1.3 percent	

( )[1] at 72°F (22°C) and 50 percent relative humidity

D.2.2 Epoxy Adhesive System

The epoxy system shall include a primer/sealer and a strip adhesive.

D.2.2.1 Epoxy Primer/Sealer

The epoxy primer/sealer seals the concrete surface while increasing its tensile strength. The primer/sealer is a 100 percent solids, two component epoxy with low viscosity and moisture tolerant. The viscosity must be less than 100 cps to insure penetration into the concrete. The primer/sealer must not contain organic solvents.

DESCRIPTION	VALUE	
	US Customary	SI Units
Bond Strength, per ASTM C882 (hardened concrete to hardened concrete, 14 day moist cure)	2,700 psi	19 MPa
Tensile Strength, per ASTM D 638	7,500 psi	52 MPa

D.2.2.2 Adhesive

The epoxy adhesive bonds the unidirectional carbon fiber strips to the concrete. The adhesive shall be a highly filled, 100 percent solids, high viscosity, two component epoxy paste that will develop the strength of the carbon strip without separating from the concrete deck.

DESCRIPTION	(VALUE)[1]	
	US Customary	SI Units
Compressive Strength ,per ASTM D 695	8.6 ksi	59 MPa
Adhesive Strength to Concrete, per ASTM D 4541	exceed concrete strength	

Tensile Modulus, per ASTM D 638	650 ksi	4,500 MPa
Tensile Strength, per ASTM D 638	3.6 ksi	25 MPa
Flexural Strength, per ASTM D 790	6.8 ksi	47 MPa
Shear Strength, per ASTM D 732	3.6 ksi	25 MPa

D.3 Execution

D.3.1 Surface Preparation

All concrete surfaces to be strengthened shall be thoroughly prepared to comply with the minimum requirement defined in this section.

Carefully examine the concrete surface to be strengthened. Verify that the concrete surfaces and cracks have been properly repaired prior to preparation. Consult the Engineer for final advice and approval of additional areas to be repaired and methods of repair.

Surface preparation of the base concrete shall be performed to the extent to completely remove all weathered concrete, laitance, loosely adhering concrete, and spalling. All bugholes and subsurface voids shall be opened. Concrete surface irregularities, fins, and/or sharp angles may result in separation and delamination of carbon laminate strips from the concrete. Concrete surface irregularities must be removed and smoothed to less than 40 mils (1 mm). Methods that bruise the concrete shall not be allowed.

Concrete surface protrusions must be flattened. Small depressions of concrete surfaces must be filled with epoxy putty.

Presence of moisture may inhibit adhesion of primer, void filler, and adhesive. Wet surfaces must be thoroughly dried before applying primer and resin. Do not apply primer or resin when rainfall or dew is present. Do not apply resin or primer when the humidity is greater than 85 percent. Do not expose primer, epoxy putty, or adhesive to rainfall, dew, or humidity in excess of 85 percent.

Prior to initiating surface preparation procedures, the Contractor shall first prepare a representative sample area. The sample area shall be prepared in accordance with the requirements of this Specification, and shall be used as a mutually agreed upon reference standard with the Engineer as depicting a satisfactorily prepared surface.

Perform abrasive blasting on concrete surfaces to be strengthened. Use materials and preparation as used to produce sample that is acceptable to the Engineer and methods conforming to project requirements.

Face shields, goggles, and gloves will be worn by workers removing concrete. Respiratory protection, such as dust masks or respirators, should be used during mixing and placing of resins if required by FRP system manufacturer.

Provide a uniformly etched profile. Prior to the application of the epoxy primer, ensure that the concrete surface roughness is equivalent to CSP 3 as defined by the International Concrete Repair Institute.

Maintain control of abrasive media, concrete chips, dust, and debris in each area of work. Clean up and remove such material at the completion of each day.

D.3.2 Pre-Cured CFRP Laminate Installation

D.3.2.1 General

Pre-cured CFRP Laminates shall be installed in strict accordance with the manufacturer's written recommendation for procedures and equipment, in conjunction with the specific requirements defined herein. In the event of the conflict between the requirements of the Specification and the manufacturer's recommendations, this Specification shall take precedence.

Installation of pre-cured FRP systems is generally similar to single ply wet lay-up. Surface preparation of the concrete substrate shall provide an open roughened texture.

It is possible that epoxy based materials used in the composite system may develop higher viscosity and/or cure slower and insufficiently at low ambient temperature. Do not apply the specified system when substrate temperatures are lower than 50°F (10°C).

Presence of moisture may inhibit adhesion of the system to the concrete substrate. Provide necessary weather protection to protect surfaces from rain or cold.

All surfaces to receive the pultruded pre-cured laminates shall be primed with the specified penetrating primer prior to application of any subsequent coatings.

Primer shall be mixed in accordance with the manufacturer's recommendations. Volume of primer to be prepared at one time must be such that it can be applied within its batch life. A fixed primer batch that has exceeded its batch life must not be used. The batch life may vary subject to ambient temperature or volume of the mixed primer batch and care must be taken accordingly. Uncured primer and primer components shall not be exposed to moisture. The priming procedure will

not commence during rainfall or in the case of predicted rainfall. Do not mix any solvents with the epoxy primer.

Pre-cured FRP system shall be cleaned, cut to the length specified in the Contract Documents, and placed into the wet adhesive within the pot life of the adhesive. Entrapped air between laminate and concrete shall be released, and excess adhesive shall be removed. Do not disturb the applied FRP system before the adhesive fully cures

Primer shall be applied by brush or roller. Alternatively, the primer may be spray applied with airless spray equipment, followed immediately by thorough backrolling to work the primer into the concrete surface. The primer shall be applied uniformly in sufficient quantity to fully penetrate the concrete and produce a non-porous film in the surface not to exceed 1 dry mil (25 μm) in thickness after full penetration. If necessary, a second coat shall be applied after the first coat has completely penetrated into the concrete. Volume of primer to be applied may vary depending on the coarseness of the concrete surface, but a minimum of 0.46 lb/yd^2 (0.25 kgm/m^2)and a maximum of 0.74 lb/yd^2 (0.40 kgm/m^2) shall be applied.

Maintain control of epoxy resins in each area of work. Clean up and remove such material at the completion of each workday.

D.3.2.2 Application of Pre-cured CFRP Laminate

Ensure that the laminate bonding surface is thoroughly cleaned until all epoxy, dust and other loose material is removed.

The concrete surface must be abrasive blasted to roughen the primed concrete surface where the pre-cured laminates will be applied. The roughened surface will be equivalent to concrete surface profile (CSP) 3 as defined as ICRI- Surface profiles. The surface must be vacuumed to remove all dust and debris prior to applying the carbon strips.

The highly filled epoxy adhesive will be applied to the surface for bonding the reinforcing strips. The adhesive is applied Δ-shaped across the strip width so that the center peak height is 1/20 of the width of the laminate strip. The extra adhesive is squeezed out when the laminate is pressed to the concrete surface. The laminates must be pressed to the concrete with a pressure of 10 psi (70 kPa) until the adhesive cures. Pressure may be applied using vacuum bags or by mechanical means.

The strips shall then be completely bonded to the concrete surface without bubbles, delaminations, or voids.

The process shall be carefully planned to allow sufficient working time for placing the carbon laminate strip to produce a uniform system that is completely free of voids and trapped air. The adhesive layer shall be applied in strict accordance with the manufacturer's recommendations. Do not mix any solvents with the epoxy adhesives.

Strip overlapping is not allowed.

Special care shall be taken to minimize the elapsed time between mixing and application of the adhesive to ensure the material is applied at least 15 minutes prior to any gelling. The work time limitations will vary according to temperature, and can be determined by information obtained from the manufacturer and practical experience with the product.

The installed carbon laminate strip system shall be completely free of defects including air pockets, voids, sags, and inclusions. After the installed system has been allowed to cure a minimum of 24 hours, the Contractor shall repair all defects as necessary to comply with the requirements of this Specification.

Maintain control of epoxy resins, putty, and laminate material in each area of work. Clean up and remove unused and discarded excess material at the completion of each workday.

D.4 Rework and Repairs

Applied composite pre-cured laminate that are found to be defective or damaged will be replaced if deemed necessary by the Engineer to render the repairs in full compliance with the requirements of this Specification. Rework and repair procedures shall comply with all material and procedural requirements defined in this Specification. Defects shall be repaired in a manner that will restore the system to the designed level of quality. Repair procedures for conditions that are not specifically addressed in the Specification shall be approved by the Engineer on a case-by-case basis prior to initiating any repairs. All repairs shall be made to the satisfaction of Engineer.

D.5 Acceptance Testing

Soundings of the strengthened areas will be done to check for voids, bubbles and delaminations. All voids, bubbles, and delaminations shall be repaired by epoxy injection or replacement.

The direct pull-off test (modified ASTM D 4541-93) that measures the bond between the laminate and existing concrete substrate in a composite system, shall be used for acceptance of the strengthening project. A core shall be drilled through the carbon laminate strip 1/16 to 1/8 inch (1 to 2 mm) into the concrete substrate, providing an isolated test location for attachment of the pull-off tester. A tension device shall be

loaded to failure during the test. The device will record the force causing the failure, which, if divided by the core cross sectional area will result in tensile strength (psi). Upon failure of the core specimen, a visual examination of the failure plane location reveals whether the failure occurred at the bond line or within the substrate. Failure of the concrete is the only acceptable failure.

At a minimum, three pull-off tests with at least one test per span or one test per 93 m^2 (1,000 ft^2) of area strengthened with the carbon fiber strip system will be performed.

Bond strength test procedures shall be approved by Engineer prior to testing.
Any deviation from this requirement will require a meeting between the Contractor and Engineer to identify issues and remedies.

The test areas of the composite system shall be repaired to the satisfaction of Engineer in accordance with paragraph D.4.

E Steel Reinforced Polymer Laminates

This specification defines the material and procedural requirements for the preparation and installation of Steel Reinforced Polymer (SRP) laminate systems for strengthening of reinforced and prestressed concrete (RC and PC) members. The manual SRP laminates will be installed in accordance with the Contract Drawings

E.1 General

E.1.1 Work to be Provided

The contractor shall complete the following work as shown on the Contract Drawings, details, and as specified herein:

- Provide scaffolding, working platforms, and access;
- Provide concrete surface preparation;
- Install Steel reinforced polymer laminate reinforcement system; and
- Provide all required tests and inspections of the system

E.1.2 References

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM C 882	Standard Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete by Slant Shear
ASTM D 638	Standard Test Method for Tensile Properties of Plastics
ASTM D 695	Standard Test Method for Compressive Properties of Rigid Plastics
ASTM D3039	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials
ASTM D 3171	Standard Test Method for Fiber Content of Resin-Matrix Composites by Matrix Digestion
ASTM D 3379	Standard Test Method for Tensile Strength and Young's Modulus for High-Modulus Single-Filament Materials
ASTM D 4258	Standard Practice for Surface Cleaning Concrete for Coating.
ASTM D 4541	Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 515.1R	A Guide to the Use of Waterproofing, Damp proofing, Protective, and Decorative Barrier systems for Concrete.
ACI 440.1R-03	Guide for the Design and Construction of Concrete Reinforced with FRP Bars
ACI 440.2R-02	Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures

NATIONAL ASSOCIATION OF CORROSION ENGINEERS (**NACE**)
NACE RP 0288 Inspection of Linings on Steel and Concrete
INTERNATIONAL CONCRETE REPAIR INSTITUTE (**ICRI**)
Guideline No. 03732 Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays
STEEL STRUCTURES PAINTING COUNCIL (**SSPC**)
SSPC-PA Guide 3 A Guide to Safety in Paint Application.

E.1.3 Submittals

Submit the following in accordance with paragraphs E.1.3.1 to E.1.3.2

E.1.3.1 Instructions

a. Manual Steel Reinforced Polymer Laminates.
Submit supplier's printed instructions and include brand name, catalog numbers, and names of manufacturers. Include with instructions the quantity of material to be used on the job. Include copies of the Material Safety Data Sheets (MSDS) for all materials to be used at the job site.

b.Epoxy System
Submit supplier's printed instructions and include brand name, catalog numbers, and names of manufacturers. Include in the instructions detailed mixing and application procedures, quantity of material to be used per square foot, total quantity of material to be used on the job, minimum and maximum application temperatures, and curing procedures. Include copies of the MSDS for all materials to be used at the job site.

E.1.3.2 Certificates

a. Steel Cord Laminates
For the steel cord laminate, certify conformance to the requirements set forth in paragraph E.2.1

b. Epoxy Saturant/Adhesive System
For the Epoxy Saturant, certify conformance to the requirements set forth in paragraph E.2.2

E.1.3.3 Records

a.Installers Qualifications
Throughout the progress of the work in this Specification, the Contractor will provide at least one (1) person who is thoroughly familiar with the specified requirements, completely trained and experienced with the necessary skills and

who will be present on the site and direct all work performed under this Specification.

In performing the work of this Specification, the Contractor will use an adequate number of skilled workmen to ensure the laminate installation is in strict accordance with schedule, Specifications, and Contract Drawings.

b. Disposal of Material

All epoxy resins and adhesives shall be disposed of properly as indicated on the MSDS. All epoxy resins and adhesives shall be stored and transported as indicated on the MSDS. Spent shot blasting media shall be contained and disposed of properly as required by local authorities. All materials (e.g., epoxies, concrete, grout, abrasive media, etc.) shall be contained at the site in accordance with state regulations.

E.1.3.4 Quality Assurance

Prior to commencement of any work, the Contractor shall be responsible for arranging and conducting a meeting between the Contractor and MoDOT-designated engineers (Engineer) to discuss the project requirements. The Contractor shall review the requirements of the Specification and overall project requirements. All aspects of the project including containment, environmental control, surface preparation, strengthening system application, quality assurance, schedule requirements, and safety shall be reviewed and discussed. The Contractor shall request clarification of any ambiguities, and advise the Engineer of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

The Contractor shall provide repair damage caused by acceptance testing in accordance with paragraph E.5of this Specification.
The Contractor shall ensure the highest quality of workmanship at all times throughout the progression of the work. Only qualified installers having prior training and experience in the specified surface preparation and steel laminate applications shall be assigned to perform the work described herein.

The Contractor shall provide full a inspection of the surface preparation and composite systems applications to ensure that the requirements of this Specification are in full compliance.

E.1.3.5 Delivery and Storage

All materials shall be delivered in “new” condition only, packaged in their original, unopened containers bearing the manufacturer’s name, product identification, batch number(s), and shelf life expiration date.

All materials shall be stored in a covered, well-ventilated area and protected from exposure to any detrimental conditions including, airborne contaminants, dirt, dust, sunlight, extreme cold, heat, rainfall, sparks, or flame.

When requested by Engineer, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 2 percent of the total material used on this job.

E.1.3.6 Safety

The processes described in this Specification involve potentially hazardous operations. The contractor shall take the necessary precautions in accordance with manufacturer's instructions, applicable MSDS, and the MoDOT's site safety requirements to ensure the safety of all personnel that may be affected by the work described in this Specification.

The Contractor shall be responsible for providing any and all safety equipment required for confined spaces, the use of any products, and/or equipment utilized during the progression of the work.

The Contractor shall establish and maintain safe working conditions throughout the progression of the work. The Contractor shall take immediate action to remedy any safety concerns and unsafe, or potentially unsafe, working conditions.
The Contractor shall provide safe access to all work areas for inspection by Engineer and/or designated representatives.

E.2 Products

E.2.1 Steel cord laminates

SRP cord tape reinforcement system consists of high steel cords formed by interwoven steel wires embedded within a polymer resin based product for strengthening negative moment, positive moment, and shear region of RC and PC bridge members. System components must be chemically and mechanically compatible and develop sufficient bonding so that individual component strengths and properties are not compromised.

DESCRIPTION	(VALUE)[1]	
	US Customary	SI Units
Tensile Strength avg.	460 ksi	3170 Mpa
Tensile Strength min.	345 ksi	2390 Mpa
Tensile Modulus avg.	30,000 ksi	206 GPa
Tensile Elongation, avg., per ASTM D 3552	1.73 %	

E.2.2 Epoxy Resin

The epoxy resin is the matrix that completely coats, envelops and binds the unidirectional steel cord tape sheets to the concrete. The epoxy adhesive shall be a 100% solids, two component epoxy paste, high modulus, high-strength, moisture tolerant, and highly filled epoxy. It must be chosen to be chemically and mechanically compatible with the steel cord laminate and the concrete. The adhesive must develop a solid, permanent bond with the steel cord laminate and with the concrete

DESCRIPTION	(VALUE)[1]	
	US Customary	SI Units
Compressive Strength ,per ASTM D 695	8.6 ksi	59 MPa
Adhesive Strength to Concrete, per ASTM D 4541	exceed concrete strength	
Tensile Modulus, per ASTM D 638	650 ksi	4,500 MPa
Tensile Strength, per ASTM D 638	3.6 ksi	25 MPa
Flexural Strength, per ASTM D 790	6.8 ksi	47 MPa
Shear Strength, per ASTM D 732	3.6 ksi	25 MPa

E.3 Execution

E.3.1 Concrete Repairs

Restoration of the concrete cross section is addressed in Section A. Restoration includes chipping and removing damaged concrete, replacing steel reinforcing when necessary, replacement concrete, and repairing cracks.

E.3.2 Surface Preparation

All concrete surfaces to be strengthened shall be thoroughly prepared to comply with the minimum requirement defined in this Specification.

Carefully examine the concrete surface to be strengthened. Verify that the concrete surfaces and cracks have been properly repaired prior to preparation. Consult the Engineer for final advice and approval of additional areas to be repaired and methods of repair.

Surface preparation of the base concrete shall be performed to the extent to completely remove all weathered concrete, laitance, loosely adhering concrete, and spalling. All bugholes and subsurface voids shall be opened. Concrete surface irregularities, fins, and/or sharp angles may result in separation and delamination of steel laminate from the concrete. Concrete surface irregularities must be removed and smoothed to less than 40 mils (1 mm). Because the steel cord is typically bent with mechanical equipment that

makes 90^o sharp bents, it is not recommended to round the corners in the concrete section as is typically done for FRP installation.

Difference of adjacent concrete surface levels must be no greater than 40 mils (1 mm) when prepared for laminate application. Concrete surface protrusions must be flattened. Presence of moisture may inhibit adhesion of resin. Wet surfaces must be thoroughly dried before applying resin. Do not apply resin when rainfall or dew is present. Do not apply resin when the humidity is greater than 85 percent. Do not expose resin, or to rainfall, dew, or humidity in excess of 85 percent.

Perform abrasive blasting on concrete surfaces to be strengthened.

Face shields, goggles, and gloves will be worn by workers removing concrete.

Provide a uniformly etched profile. Prior to the application of the epoxy primer ensure that the concrete surface roughness is equivalent to CSP 3 as defined by the International Concrete Repair Institute.

Maintain control of abrasive media, concrete chips, dust, and debris in each area of work.

Clean up and remove such material at the completion of each day. All concrete chips, abrasive media, paint chips, dust, and other debris shall be contained in accordance with state regulations.

E.3.3 Steel Reinforced Polymer (SRP) laminates Installation.

E.3.3.1 General

The SRP system shall be installed in strict accordance with the manufacturer's written recommendation for procedures and equipment, in conjunction with the specific requirements defined herein. In the event of the conflict between the requirements of the Specification and the manufacturer's recommendations, this Specification shall take precedence.

It is possible that epoxy based materials used in the composite system may develop higher viscosity and/or cure slower and insufficiently at low ambient temperature. Do not apply the specified system when substrate temperatures are lower than 50°F (10°C).

Presence of moisture may inhibit adhesion of the system to the concrete substrate. Provide necessary weather protection to protect surfaces from rain or cold. Installation in rain is strictly prohibited.

Epoxy resin shall be mixed in accordance with the manufacturer's recommendations. Do not mix any solvents with the resin. Resin must be thoroughly mixed with hardener at the manufacturer's specified ratio in a mixing pot until it is uniform.

At least four minutes of agitation is required by means of an electric hand mixer Volume of resin to be prepared at one time must be such that it can be applied within its batch life. A fixed resin batch which has exceeded it batch life must not be used. The batch life may vary subject to ambient temperature or volume of the mixed resin batch and care must be taken accordingly.

Epoxy resin shall be applied by brush or roller. Alternatively, the resin may be spray applied with airless spray equipment, followed immediately by thorough backrolling to work the coat into the concrete surface. The coat shall be applied uniformly in sufficient quantity to prime and seal the concrete.Volume of resin to be applied may vary depending on the coarseness of the concrete surface but a minimum of 1 kgm/m^2 and a maximum of 1.5 kgm/m^2 shall be applied.

Maintain control of coat resins in each area of work. Clean up and remove unused and discarded excess material at the completion of each workday.

E.3.3.2 Application of Steel Sheet

SRP sheets will not be applied when the temperature is less than 50^{o}F (10^{o}C) or if surface moisture is present or anticipated.

The SRP sheets must be cut beforehand into prescribed sizes using commercial quality medium to heavy handheld electric shears or other appropriate shearing cutter. The number of sheets cut shall be limited to the number to be installed that day. Avoid any tool that should damage, weaken the cords while cutting process.

A coating resin shall be roller-applied to the concrete to prime and seal the surface. The steel sheet shall then be installed by the manual lay-up method. The sheet will be properly aligned and pressed onto the wet epoxy resin on concrete to impregnate it. The sheet shall then be completely impregnate with an application of a second roller-applied epoxy resin to the external surface. The process shall be carefully planned to allow sufficient working time for the rolling of the steel sheet and resin to produce a uniform system that is completely free of voids and trapped air and to be completed within the time limits of the resin pot life. The epoxy resin coat shall be applied in strict accordance with the manufacturer's recommendations.

Special care shall be taken to minimize the elapsed time between mixing and application of the epoxy resin to ensure the material is applied to the sheet at least 15 minutes prior to any thickening or gelling. The work time limitations will vary according to temperature, and can be determined by information obtained from

the manufacturer and practical experience with the product. Do not mix any of the solvents with the epoxy saturant.

Ensure that the laminate is hand laid and cured without the aid of external heating or vacuum bags. The first layer can be applied directly to the concrete surface with an epoxy resin. Successive plies are added between layers of epoxy resin. Excess resin and are brushed, squeegeed, rolled, and otherwise "worked out" of each layer.

No holes will be cut in the composite to circumvent obstacles such as pipes, hangers, and drain holes. The steel sheets must be split to circumvent these obstacles. No overlapping is required perpendicular to fiber direction.

When the length of the sheet to be installed exceeds the length suggested by the manufacturer for proper installation, lap jointing becomes necessary. Lap splice length depends on the type of resin and laminates. For large coverage areas, all lap joints in the longitudinal direction of steel laminates must be made in a single day.

The installed SRP system shall be completely free of laminate defects including air pockets, voids, unsaturated areas, sags, and inclusions. After the installed system has been allowed to cure a minimum of 24 hours, the Contractor shall repair all defects as necessary to comply with the requirements of this Specification.

The steel laminate shall be aligned on the structural member according to the Contract Documents. Any deviation in the alignment more than 5˚ (approximately 87 mm/m or 1 in/ft) is not acceptable. Once installed, the fibers shall be free of kink, folds and waviness.

Maintain control of epoxy resin saturant and steel material in each work area. Clean up and remove unused and discarded excess material at the completion of each workday.

E.4 Rework and Repairs

Applied composite systems that are found to be defective or damaged will be replaced if deemed necessary by MoDOT-designated engineers (Engineer) to render the repairs in full compliance with the requirements of this Specification. Rework and repair procedures shall comply with all material and procedural requirements defined in this Specification. Defects shall be repaired in a manner that will restore the system to the designed level of quality. Repair procedures for conditions that are not specifically addressed in the Specification shall be approved by Engineer on the case-by-case basis prior to initiating any repairs. All repairs shall be made to the satisfaction of Engineer.

E.5 Acceptance Testing

The direct pull-off test (modified ASTM D 4541-93) that measures the bond between the laminate and existing concrete substrate in a composite system, shall be used for acceptance of the performance strengthening system. A core shall be drilled through the steel laminate strip 1/16 to 1/8 inch (1 to 2 mm) into the concrete substrate, providing an isolated test location for attachment of the pull-off tester. A tension device shall be loaded to failure during the test. The device will record the force causing the failure, which, if divided by the core cross sectional area will result in tensile strength (psi). Upon failure of the core specimen, a visual examination of the failure plane location reveals whether the failure occurred at the bond line or within the substrate. Failure of the concrete is the only acceptable failure.

At a minimum, three pull-off tests with at least one test per span or one test per 93 m^2 (1,000 ft^2) of area strengthened with the carbon fiber strip system will be performed.

Any deviation from this requirement will require a meeting between the Contractor and Engineer to identify issues and remedies.

The test areas of the composite system shall be repaired to the satisfaction of Engineer in accordance with paragraph E.4

F Mechanically Fastened FRP Laminate

This specification defines the material and procedural requirements for the preparation and installation of FRP fastened laminate system for strengthening of the reinforced and pre-stressed concrete (RC and PC) members. The mechanically fastened FRP laminates will be installed in accordance with the Contract Drawings.

F.1 General

F.1.1 Work to be Provided

The contractor shall complete the following work as shown on the Contract Drawings, details, and as specified herein:

- Provide scaffolding, working platforms, and access for confined spaces
- Install mechanically fastened FRP laminate reinforcing system
- Provide all inspections of the strengthened system.

F.1.2 References

The publications listed below form a part of this specification to the extent referenced. The publications are referred to within the text by the basic designation only.

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

ASTM D3039	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials
ASTM D 5766	Standard Test Method for Open Hole Tensile Strength of Polymer Matrix Composite Laminates
ASTM D 5961	Standard Test Method for Bearing Response of Polymer Matrix Composite Laminates
ASTM E 1190-95	Standard Test Methods for Strength of Power-Actuated Fasteners Installed in Structural Members

AMERICAN CONCRETE INSTITUTE (ACI)

ACI 440.1R-03	Guide for the Design and Construction of Concrete Reinforced with FRP Bars
ACI 440.2R-02	Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures

F.1.3 Submittals

Submit the following in accordance with paragraphs F.1.3.1 to F.1.3.2

F.1.3.1 Instructions

a. Mechanically Fastened FRP Laminates.
Submit supplier's printed instructions and include brand name, catalog numbers, and names of manufacturers. Include in the instructions the quantity of material to be used per square foot and the total quantity of material to be used on the job. Include copies of the Material Safety Data Sheets (MSDS) for all materials to be used at the job site.

b. Fasteners
Submit supplier's printed instructions and include brand name, catalog numbers, and names of manufacturers. Include in the instructions the quantity of material to be used per strip and the total quantity of material to be used on the job.

F.1.3.2 Certificates

a. Mechanically Fastened FRP Laminate.
For the composite Mechanically Fastened FRP Laminate certify conformance to the requirements set forth in paragraph 0

b. Fastener
For fastener, certify conformance to the requirements set forth in paragraph F.2.2

F.1.3.3 Records

a. Installers Qualifications
Throughout the progress of the work in this Specification, the Contractor will provide at least one (1) person who is thoroughly familiar with the specified requirements, completely trained and experienced with the necessary skills to install mechanically fastened FRP laminates as external reinforcement, and who will be present on the site and direct all work performed under this Specification.

In performing the work of this Specification, the Contractor will use an adequate number of skilled workmen to ensure the installation is in strict

accordance with schedule, Specifications, and required procedures required by the Missouri Department of Transportation (MoDOT).

b. Disposal of Material
All materials shall be contained at the site in accordance with state regulation.

F.1.3.4 Quality Assurance

Prior to commencement of any work, the Contractor shall be responsible for arranging and conducting a meeting between the Contractor and MoDOT-designated engineers (Engineer) to discuss the project requirements. The Contractor shall review the requirements of the Specification and overall project requirements. All aspects of the project including containment, environmental control, surface preparation, strengthening system application, quality assurance, schedule requirements, and safety shall be reviewed and discussed. The Contractor shall request clarification of any ambiguities, and advise the Engineer of any potential conflicts and/or any technical requirements that appear improper or inappropriate.

The Contractor shall ensure the highest quality of workmanship at all times throughout the progression of the work. Only qualified applicators having prior experience and training in the specified surface preparation and Mechanically Fastener CFRP laminate reinforcement applications shall be assigned to perform the work described herein.

The Contractor shall provide a full inspection of the surface preparation and composite systems applications to ensure that the requirements of this Specification are in full compliance.

F.1.3.5 Delivery and Storage

All materials shall be delivered in “new” condition only, packaged in their original, unopened containers bearing the manufacturer’s name, product identification, batch number(s), and shelf life expiration date.

All materials shall be stored in a covered, well-ventilated area and protected from exposure to any detrimental conditions including, airborne contaminants dirt, dust, sunlight, extreme cold, heat, rainfall, sparks, or flame.

When requested by Engineer, the Contractor shall provide batch samples of any materials that are used throughout the progression of the work. Batch samples will not exceed 2 percent of the total material used on this job.

F.1.3.6 Safety

The processes described in this Specification involve potentially hazardous operations. The contractor shall take the necessary precautions in accordance with manufacturer's instructions, applicable MSDS, and the MoDOT's site safety requirements to ensure the safety of all personnel that may be affected by the work described in this Specification.

The Contractor shall be responsible for providing any and all safety equipment required for confined spaces, the use of any products, and/or equipment utilized during the progression of the work.

The Contractor shall establish and maintain safe working conditions throughout the progression of the work. The Contractor shall take immediate action to remedy any safety concerns and unsafe, or potentially unsafe, working conditions.

The Contractor shall provide safe access to all work areas for inspection by Engineer and/or designated representatives.

F.2 Products

The mechanically fastened FRP laminate system consists of FRP fiber strips, epoxy adhesive and fasteners. These components must be mechanically compatible and develop sufficient bonding so that individual component strengths and properties are not compromised.

F.2.1 FRP Strip

The FRP fiber laminate, used like external flexural reinforcement, is a high bearing strength pre-cured strip. Fibers in this strip are a combination of unidirectional carbon and glass continuous strand mats.

FRP Fiber Composite Laminate

DESCRIPTION	(VALUE)[1]	
	US Customary	SI Units
Percentage of fiber area to total area of strip, per ASTM D 3171	60 percent min	
Tensile Strength, Ultimate, per ASTM D 3916	120 ksi	0.83 GPa
Tensile Modulus Per ASTM D 3916	8,800 ksi	66 GPa
Tensile Elongation, Ultimate, per ASTM D 3916	1.3 percent	

( )[1] at 72°F (22°C) and 50 percent relative humidity

F.2.2 Epoxy Adhesive System

The epoxy adhesive will fill all the gaps between fasteners and concrete, and between fasteners and laminate. In this way, it is partially possible to avoid rigid rotations of the fasteners and improving the engagement the system fastener-laminate-concrete.

DESCRIPTION	(VALUE)	
	US Customary	SI Units
Compressive Strength, per ASTM D 695@ 90^0F	8.2 ksi	57 MPa
Adhesive Strength to Concrete, per ASTM D 4541	Exceed concrete strength	
Tensile Modulus, per ASTM D 638	320 ksi	2.2 GPa
Tensile Strength, per ASTM D 638	5.1 ksi	35 MPa
Flexural Strength, per ASTM D 790	7.4 ksi	51 MPa
Shear Strength, as per ASTM D 732	5.9 ksi	41 MPa
Adhesion Strength to Carbon Bar, per ASTM C 882 Plastic Concrete to Hardened Concrete (14 day moisture cure)	2.4 ksi	17 MPa

F.2.3 Fastener

The fasteners shall be heat treated, high strength carbon steel, zinc treated. The fastener will include a washer, provided to spread out the load and providing clamping. It must include washers to avoid stress concentration and damage to the carbon laminate. Shear capacity of fasteners must be higher than the bearing capacity of the entire system fastener-laminate-concrete.

F.3 Execution

F.3.1 Surface Preparation

A concrete surface to be strengthened does **not require** any surface preparation more than the minimum smoothing of surface.

F.3.2 Mechanically Fastened FRP Laminate

F.3.2.1 General

Mechanically Fastened FRP Laminate shall be installed in strict accordance with the manufacturer's written recommendation for procedures and equipment, in conjunction with the specific requirements defined herein. In the event of a conflict between the requirements of the Specification and the manufacturer's recommendations, Specification shall take precedence.

Installation of Mechanically Fastened FRP systems is generally similar to Pre-cured Strip system, described in part D of these Specifications. Nevertheless, surface preparation of concrete substrate is not critical, but is more convenient to obtain a flat and smooth surface that will lead to an evenly distributed in-plane load transfer.

Mechanically Fastened FRP laminates must be pre-drilled, according to the design. In case the drawings of the bridge are not available, and the concrete cover is greater than 2 in (10 cm), cover surfaces receiving the reinforcement will be scanned with a rebar locator to determine the exact location of steel reinforcement.

Mechanically Fastened FRP systems shall be cleaned and cut to the length specified in the Contract Documents; Holes must be first drilled on the concrete surface, through a pre-holed laminate to a depth of at least ½ in. Fasteners must then be driven into the concrete using an electrical drill with torque control as specified by the manufacturer.

F.3.2.2 Application of Fastened FRP Laminates

Holes are drilled in the concrete surface, to a depth of at least ½ in. or one diameter deeper than the embedment required. The holes are filled with adhesive epoxy. The epoxy adhesive will fill all the gaps between fasteners and concrete, and between fasteners and laminate. In this way, it is partially possible to avoid rigid rotations of the fasteners and improving the engagement the system fastener-laminate-concrete. Mechanically Fastened FRP laminates system shall be completely free of defects, voids, sags, and inclusions. Fasteners will be inserted through the holes using manual drillers. Normally the fasteners do not require any specific installation torque and the maximum torque is a value normally specified by Contractor. The Contractor shall repair all defects as necessary to comply with the requirements of this Specification.

Clean up and remove unused and discarded excess material at the completion of each workday.

F.4 Rework and Repairs

Applied composite mechanically fastened FRP laminates that are found to be defective or damaged will be replaced if deemed necessary by the Engineer to render the repairs in full compliance with the requirements of this Specification. The holes can be relocated in accordance with the Engineer. Rework and repair procedures shall comply with all material and procedural requirements defined in this Specification. Defects shall be repaired in a manner that will restore the system to the designed level of quality. Repair procedures for conditions that are not specifically addressed in the Specification shall be

approved by the Engineer on a case-by-case basis prior to initiating any repairs. All repairs shall be made to the satisfaction of Engineer.