

EXTERNALLY BONDED CFRP REINFORCEMENT

Part 1 General.

1.01 Summary

A. Section Includes:

1. Installation of externally bonded fiber reinforced polymer (FRP) laminates to reinforce concrete, masonry or wood structures, including beams, slabs, walls & columns.
2. Work Including:
Furnishing of materials, labor, equipment and all items necessary for repair of existing concrete, masonry & wood members and strengthening by the application of externally bonded FRP reinforcement as specified on the contract drawings and specifications, complete.
3. Cooperation and coordination with all other trades in executing the work described in the contract.

1.02 References

A. American Concrete Institute (ACI):

1. 318-95 Building Code Requirements for Structural Concrete
2. 440R-96 State-of-the-art Report on FRP Reinforcement for Concrete Structures
3. 503R-93 Use of Epoxy Compounds with Concrete
4. 515R-85 Guide to the Use of Waterproofing, Damp-proofing, Protective, Decorative Barrier Systems for Concrete
5. 546R-96 Concrete Repair Guide

B. American Society for Testing and Materials (ASTM):

1. D 3039-93 Test Method for Tensile Properties of Fiber Resin Composites
2. D 3528-92 Test Method for Strength Properties of Adhesives in Shear by Tension Loading of Single Lap Joint Laminated Assemblies
3. D 4541-93 Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Tester
4. E 84-94 Test Method for Surface Burning Characteristics of Building Materials

C. International Concrete Repair Institute (ICRI):

1. #03730 Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion

2. #03732 Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays
3. #03733 Guide for Selecting and Specifying Materials for Repairs of Concrete Surfaces

D. International Conference of Building Officials (ICBO)

1. AC 125 Acceptance criteria for concrete and reinforced and unreinforced masonry strengthening using fiber reinforced composite systems.
2. AC 178 Acceptance criteria for inspection and verification of concrete and reinforced and unreinforced masonry strengthening using fiber-reinforced polymer (frp) composite systems.

1.03 Submittals

A. Product Information

1. Manufacturer's product data sheets indicating physical, mechanical, and chemical characteristics of the materials used in the FRP system. Mechanical properties shall be reported as minimum acceptable or guaranteed values in accordance with Section 2.02.
2. Manufacturer's installation instructions, maintenance instructions, and general recommendations regarding each material.
3. Samples of all materials to be used, each properly labeled as specified in Section 2.01.
4. Manufacturer's Material Safety Data Sheets (MSDS) for all materials to be used.

B. Engineering Calculations

1. Two copies of the engineering calculations detailing the design of the FRP reinforcement and stating any assumptions regarding the condition of the existing structure.

C. Working Drawings

1. Working drawings prepared and sealed by a professional engineer detailing the locations, dimensions, and orientations of all FRP materials to be installed.

D. Quality Control Procedures

1. Bond testing program per the procedure described in Section 3.04.
2. Witness panel testing program per the procedure described in Section 3.04.

1.04 Quality assurance

A. Manufacturer / Supplier Qualifications:

1. The Manufacturer / Supplier must specialize in the manufacturing of the products specified in this Section with a minimum of 2 years experience
2. The Manufacturer / Supplier must support and instruct applicators in the installation of the products specified in this Section.

B. Applicator Qualifications:

1. Applicator must be approved by the Edge Structural Composites and have been trained by the Edge Structural Composites in the installation of the products specified in this section.
2. Applicator must have documented experience on at least 3 projects of a similar nature, using similar materials within the last 5 years.

1.05 Delivery and storage

1. The products shall be delivered and stored in original, unopened containers. Containers must be clearly marked with legible and intact labels listing the Manufacturer's name, brand name, product identification and batch number.
2. Stored fiber reinforcement and epoxies must be protected from dust, moisture, and chemical exposure. Cut fabric on clean surfaces.
3. Epoxies must be stored in areas with an ambient temperature between 45 and 80 °F (7 - 27°C) and away from direct sunlight, flame sources, or other hazards. Epoxy resins must be stored separately from hardeners. After the resin has been mixed with hardener, the mixed epoxy batch must be used within its pot life.
4. Fiber reinforcement must not be handled roughly. Fiber, once removed from the original roll, must be stored either in rolls with a radius greater than 8 in (200 mm) or by dry stacking flat

Part 2. Products

2.01 Manufacturers and Products

A. Acceptable Manufacturers and Products:

1. Fiber-Bond supplied by Edge Structural Composites, Inc., 145 Park Place Richmond, CA 94801, (510) 233-8654, Fax: (510) 233-8673, www.edgest.com
2. Substitutions: No substitutions allowed.

2.02 Materials

A. FRP Composite System

1. A single manufacturer/supplier shall supply all constituent materials of the FRP composite system including the fiber reinforcement, all polymers, and protective topcoats, where specified. FRP composite systems consisting of fiber reinforcement and polymers provided by more than one manufacturer/supplier are not allowed.
2. The FRP composite system Manufacturer/Supplier shall supply the tensile properties of the composite material as determined by testing in accordance with ASTM D 3039. The tensile properties of the composite system shall be based on a minimum of 25 tests and meet or exceed those tabulated below:

Property	Fiber-Based Properties		Laminate-Based Properties	
Fiber type - Carbon				
Ply Thickness	0.014 in.	(0.36 mm)	0.023 in.	(0.58 mm)
Ultimate Tensile Stress	650 ksi	(4,480Mpa)	150 ksi	(1,035Mpa)
Young's Modulus	34,000 ksi	(234,400Mpa)	10,100ksi	(70,000Mpa)
Rupture Strain	1.9%	1.9%	1.5%	1.5%

3. The FRP composite system shall exhibit the following durability in accordance with ICBO ES AC 125:

Percentage tensile strength retained after:	
10,000 hrs exposure to 100% humidity @ 38°C	100%
10,000 hrs exposure to Salt water	90%
10,000 hrs exposure to ph 9.5 solution	100%
Percentage tensile modulus retained after:	
10,000 hrs exposure to 100% humidity @ 38°C	90%
10,000 hrs exposure to Salt water	90%
10,000 hrs exposure to ph 9.5 solution	90%

4. The FRP composite system shall have a class 1 fire classification as tested in accordance with ASTM E-84.
5. The FRP system shall be VOC compliant for contact with potable water in accordance with EPA method 8260
6. The FRP system shall have successfully completed 10,000 hr environmental durability testing in accordance with ICBO ES AC 125.
7. The FRP system supplier shall provide, on request, independent results of large-scale structural evaluation of the FRP system on representative test specimens in accordance with ICBO ES AC 125.

B. Fiber Reinforcement

1. Carbon fiber reinforcement shall be delivered as a dry unidirectional fabric with a fiber areal weight of 9.6 oz/yd² (335 g/m²).

C. Polymer Resins

1. Polymer resins should be selected based on the ambient temperature of the site at the time of installation.
2. The following polymer components must be provided as part of the FRP composite system:
 3. An epoxy primer with a mixed viscosity of 400 cps at 77 °F (25 °C).
 4. An epoxy filler, to be used for filling surface voids, with a mixed viscosity of 45,000 cps at 77 °F (25 °C).
 5. A saturating epoxy resin with a mixed viscosity of 2200 cps at 77 °F (25 °C) and a sag resistance of 20 mils (500 micrometers).
 6. Do not dilute any resin, primer or adhesive with any solvent.
 7. Components, which have exceeded the shelf life, shall not be used.
 8. Any epoxy, which has exceeded its batch life, should not be used.

D. Protective Coatings

1. Urethanes, or epoxies.
2. Latex
3. Protective coatings other than those provided by the material Manufacturer/Supplier may be used provided such coatings have been approved by the material manufacturer.

Part 3. Execution

3.01 Examination

- A. Examine existing conditions to assess quality of concrete substrate, identify potential obstructions, and verify dimensions/geometry shown on shop drawings.

3.02 Preparation

A. Environmental Conditions

1. Do not install FRP when the ambient temperature is below 40 °F (5 °C) or above 130 °F (55 °C). In cold conditions, auxiliary heat may be applied to raise the ambient

temperature to a suitable level. Utilize clean heat sources for this purpose (e.g., electric or propane) that do not contaminate the substrate.

2. The presence of moisture inhibits the adhesion of the epoxies to the substrate. Do not install FRP when surface moisture is present on the substrate or when rainfall or condensation is anticipated in the work areas.
3. If water leakage exists through cracks or concrete joints, water flow must be stopped prior to FRP installation.

B. Site Conditions

1. 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 of blasting.
2. All adjacent areas not receiving FRP shall be protected with plastic sheeting.

3.03 Installation

A. Concrete Repair

1. Unsound areas of the concrete substrate (such as broken pieces, delaminated areas, etc.) must be removed to reveal sound material.
2. If corrosion of the existing steel reinforcement exists, the steel and concrete must be repaired before installation of the FRP. Any deteriorated concrete or corroding reinforcing steel must be repaired per ICRI Guideline #03730. DO NOT COVER CORRODING REINFORCING STEEL WITH FRP.
3. Voids in the concrete substrate greater than 0.50 in (500 mm) in depth must be filled with an appropriate repair mortar. The repair material shall be selected per ICRI Guideline #03733 and the project requirements. If required, the bond strength of the repair material to the existing concrete may be verified with pull testing per ASTM D 4541. Minimum direct pull-off strength required is 200 psi (1.4 MPa).
4. Cracks in the concrete substrate greater than 0.010 in (0.25 mm) wide must be injected with epoxy or similar material approved by the Engineer of Record.

B. Surface Preparation

1. 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 reference standard depicting a satisfactorily prepared substrate.
2. Uneven concrete surface irregularities (offsets) must be ground and smoothed to less than 0.04 in (1 mm).
3. When fiber reinforcement is run around outside corners or edges, these corners must be rounded to a radius of no less than 0.5 in (15 mm). Application of fiber reinforcement around inside corners shall be avoided. No detailing is required if fiber is run parallel to corners.
4. When bond of the FRP to the concrete substrate is required for structural performance, the surface of the concrete substrate must be profiled using abrasive blasting and/or disc grinding to a minimum ICRI CSP 3 (refer to ICRI Guideline #03732). Surface materials (laitance, surface lubricants, broken mortar pieces, paint coatings, staining, etc.) must be removed by abrasive blasting and/or disc grinding. Dust generated from surface grinding must be removed using a clean air blower or

other suitable means. If the dust has been removed by means of water washing, the surface must be thoroughly dried.

5. When structural performance relies only on the bond of the FRP to itself at lap splices, the substrate must be cleaned of any dust, debris, or laitance.

C. Application of Surface Primer

1. All surfaces must be clean, dry and free of all dust and debris.
2. Prepare epoxy primer in accordance with manufacturers instructions. Mix only the quantity of primer that can be used within its batch life. Batch life will be reduced in higher temperatures and when mixed in higher volumes. Adjust batch size accordingly. Do not use any epoxy, which has exceeded its batch life.
3. To avoid allowing primer to cure prior to FRP application, apply primer only to surfaces, which will be laminated within 3 hours.
4. Constituent parts must be accurately metered and thoroughly mixed for between 2 and 3 minutes. For large batches (over 1 gallon) use a mechanical mixer.
5. Apply primer to repair surfaces with a medium nap roller or non-shedding brush. Apply 2nd coat, if needed, to areas, which have thoroughly absorbed the 1st coat.
6. Using a brush, stipple primer into any voids, bug holes etc.

D. Application of filler/adhesive paste

1. All surfaces must be primed. Primer, which has cured for over 24hrs, must be abraded with a light sand sweep, sandpaper or abrasive pad.
2. Prepare epoxy filler/paste in accordance with manufacturers instructions. Mix only the quantity of filler that can be used within its batch life. Batch life will be reduced in higher temperatures and when mixed in higher volumes. Adjust batch size accordingly. Do not use any epoxy, which has exceeded its batch life.
3. To avoid allowing filler to cure prior to FRP application, apply primer only to surfaces, which will be laminated within 1 hour.
4. Constituent parts must be accurately metered and thoroughly mixed for between 2 and 3 minutes. For large batches (over 1 gallon) use a mechanical mixer.
5. Apply filler to surface voids using a steel or stiff plastic spreader. Ensure all voids and offsets are thoroughly filled and excess filler is removed.

E. Application of FRP Reinforcement

1. All surfaces must be primed and, where needed, filled. Primer & filler, which has cured for over 24hrs, must be abraded with a light sand sweep, sandpaper or abrasive pad unless still tacky to the touch.

2. Prepare epoxy saturating resin in accordance with manufacturers instructions. Mix only the quantity of epoxy that can be used within its batch life. Batch life will be reduced in higher temperatures and when mixed in higher volumes. Adjust batch size accordingly. Do not use any epoxy, which has exceeded its batch life.
3. Fabric should be pre cut to required lengths and widths and clearly labeled.
4. Using a roller, apply a coat of mixed resin to a suitable worktable, which has been protected with plastic sheeting. Lay pre cut fabric onto resin coat and press down with a soft plastic spreader. Apply more resin to the fabric and spread evenly until fabric is fully covered and saturated thoroughly with resin. Allow to sit for 1 minute, applying more resin if needed. Squeegee off excess resin if necessary and roll fabric onto a plastic tube with approx 4" diameter.
5. Apply saturated fabric to repair surface. Orient fibers as detailed in project drawings and within specified tolerances. Fibers shall be laid taut and without wrinkles. Using soft plastic spreaders and (suitably protected) hands, smooth out wet fabric ensuring full contact with the surface and to remove trapped air. Fibers must be straight and aligned correctly. Apply additional saturating resin, if needed, during the smoothing out to assist in handling.
6. To join ends of fabric, overlaps in the longitudinal direction must be a minimum of 6". Additional saturating resin can be used to insure complete bonding between layers and lack of voids. No overlap is needed between adjacent bands of fabric. Overlaps must be staggered for multiple layers.
7. For applying additional layers, follow items 3 through 6.
8. Check applied laminates after 30 - 45 minutes and again prior to gel stage to ensure that no voids or delaminations are present.
9. The installed composite must be protected from rain, direct sunlight, dust, sand etc for 24 hrs.
10. Use of a manufacturer approved mechanical saturator is recommended for large projects. Refer to manufacturer's installation manual for instructions.

F. Application of Protective Coatings

1. Protective coatings may be applied as a final, outermost layer to the externally bonded FRP reinforcement.
2. Protective coatings shall not be applied before the final resin coat has become tack free.
3. The surface to which the protective coatings are to be applied must be cleaned of any dust or debris using a dry cloth or brush. The surface must also be free of any moisture, oils, or other substances that would prohibit bond of the coating.

3.04 Field Quality Control

A. Supervision

1. A field supervisor, trained by Edge Structural Composites shall observe all aspects of onsite preparation and material application including surface preparation, resin component mixing, application of primer, application of resin and fiber sheet, curing of composite, and the application of protective coatings.
2. Newly installed FRP composite shall materials shall be visually inspect to insure complete saturation, full contact between layers and to substrate, proper fiber orientation, and lack of wrinkles, bubbles, and voids.

B. Inspection for Voids/Delaminations

1. After allowing at least 24 hours for initial resin cure to occur, perform a visual and acoustic tap test inspection of the layered surface.
2. Large delaminations shall be marked for repair. Small delaminations less than 2 in² (1300 mm²) in size and which are not localized, do not require corrective action.
3. Large delaminations should be repaired by either injection with resin or, by removing delaminated area and patching with new fabric, allowing a 6" overlap all around the repair. This is at the discretion of the inspector.

C. Bond Testing

Direct tension pull-off tests may be conducted to evaluate the bond of the FRP system.

1. Test Conditions

- A. The FRP system shall be allowed to cure a minimum of 48 hours before execution of the direct tension pull-off test
- B. The locations of the pull-off test shall be representative and on flat surfaces. If possible, pull-off tests shall be conducted on areas of the FRP system subjected to relatively low stress during service.

2. Test Frequency

- A. Perform a minimum of one pull-off test per 500 ft² (45 m²) of installed FRP reinforcement.
- B. Pull-off tests must be performed on each area of fiber sheet installed on a single day.
- C. Pull-off tests must be performed on each type of concrete substrate or for each surface preparation technique used if variations in such conditions exist.

3. Test Procedure

- A. The FRP surface to which the adhesion fixture is to be mounted shall be sanded smooth with medium grit sandpaper, rinsed with water, and allowed to dry.
- B. Attach the adhesion fixture with the designated bonding agent. Leave to cure in accordance with bonding agent manufacturer's instructions.
- C. Core drill or square cut around the perimeter of the adhesion fixture through the FRP laminate and into the substrate concrete using carbide tipped or diamond core bit or cutting wheel. Cut to a depth of 0.25 to 0.5 in. (6 - 12 mm) into the concrete.

- D. Position the detaching assembly over the adhesion fixture and attach the adhesion fixture to the detaching assembly. Align perpendicularly. Adjust the detaching-assembly legs as required.
 - E. Take up the slack in the adhesion tester by screwing down the adjustment knob.
 - F. Set the force indicator to the zero mark.
 - G. Apply a manual or mechanised loading force to provide a constant cross head speed until the adhesion fixture detaches from the concrete element.
 - H. The loading rate shall be such that the fixture detaches in less than 100 seconds.
- 4. The failure mode must be cohesive failure within the concrete
 - 5. The tensile bond strength must be in excess of 200 psi (1.4 MPa) or as specified within project drawings or specifications.
 - 6. Repair the tested areas in accordance with Section 3.05 of this specification.

D. Witness Panel Testing

- 1. Witness panels shall be fabricated on site using the same methods used to apply the FRP system to evaluate the tensile properties of the materials. Witness panels shall be prepared on a smooth surface such as a sheet of glass. Witness panels may be tested or retained for future testing.
- 2. Panels shall be fabricated as a minimum 12" x 12" (300mm x 300mm) laminate of two stacked layers of identical fiber orientation.
- 3. The witness panels shall be allowed to cure on-site for a minimum of 72 hours before delivery to test agency.

A. Frequency

- 1. Two witness panels shall be fabricated near the start and end of each workday.

E. Report

- 1. The contractor shall submit a quality control report to the Engineer of Record identifying the trained field supervisor, describing the inspection of the completed installation, and detailing the results of the bond testing.
- 2. The report shall include details of field locations of materials used for fabrication of witness panels.

3.05 Repair of Damaged or Defective Areas

- A. Repair of all the defective work after the minimum cure time for the FRP laminates shall comply with material and procedural requirements defined in this specification or as provided by the manufacturer according to the type of defect, the type of application, and the materials used.
- B. Repair all defects in a manner that will restore the system to the designed level of quality. Removal of defective sections shall be replaced and properly spliced with non-damaged areas. Splice locations shall be prepared for bond by abrading cured surfaces. Voids shall be prevented.
- C. The Owner's representative shall approve repair procedures for conditions that are not specifically addressed in this specification. All repairs and touch up shall be made to the satisfaction of the Owner's representative and Engineer of Record.