UNIVERSITY OF MICHIGAN

REPAIR AND STRENGTHENING OF REINFORCED CONCRETE BEAMS USING CFRP LAMINATES

Volume 7: Technical Specifications

by

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16. Abstract

Repair and strengthening techniques using glued-on carbon fiber reinforced plastic (CFRP) plates (also called sheets, tow sheets, and thin laminates) form the basis of a new technology being increasingly used for bridges and highway superstructures.

The study described in this report (Volumes 1 to 7) focused on the use of carbon fiber reinforced plastic (CFRP) laminates for repair and strengthening of reinforced concrete beams. Its primary objectives are: 1) to ascertain the applicability of CFRP adhesive bonded laminates for repair and strengthening of reinforced concrete beams; 2) to synthesize existing knowledge and develop procedures for implementation in the field; 3) to identify key parameters for successful design and implementation; and 4) to adapt this technique to the specific conditions encountered in the state of Michigan.

This report consists of 7 volumes:
Volume 1 - Summary Report
Volume 2 - Literature Review
Volume 3 - Behavior of Beams Strengthened for Bending
Volume 4 - Behavior of Beams Strengthened for Shear
Volume 5 - Behavior of Beams Under Cyclic Loading at Low Temperature
Volume 6 – Behavior of Beams Subjected to Freeze-Thaw Cycles
Volume 7 – Technical Specifications

Volume 7 (this volume) provides technical specifications based on information provided by the manufacturers of the two CFRP strengthening systems used and augmented by the experience accrued during the course of this investigation. Since the adhesive-bonded plate repair and strengthening technique applies to plain, reinforced and prestressed concrete structures, as well as steel and timber structures, the experience gained during this project and the technology transfer developed cover a wide range of future applications.

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PREFACE

This project titled: *"Repair and Strengthening of Reinforced Concrete Beams using CFRP Laminates"* is aimed at providing experimental verification and recommendations for implementation of a new technology, in which thin fiber reinforced plastic laminates are glued-on the surface of concrete beams in order to strengthen them.

The primary objectives of the project were:

- To ascertain the applicability of Carbon Fiber Reinforced Plastic (CFRP) glued-on plates for repair and strengthening of concrete beams;
- To synthesize existing knowledge and develop procedures for implementation in the field;
- To adapt this technique to the specific conditions encountered in the state of Michigan.

The project consisted of 8 tasks as follows:

- A report containing a literature review and a comprehensive synthesis of the latest state of knowledge on the glued -on FRP technique (Task 1);
- Laboratory testing and verification of the selected CFRP glued-on technique according to the proposed experimental program: bending (Task 2), shear (Task 3), freeze-thaw (Task 4), temperature and high cyclic amplitude load (Task 5);
- An interim and final report summarizing the experimental results (Task 6). The interim report will cover the bending and freeze-thaw tests;
- A summary of field specifications and "how to" details for implementation in field applications;
- Guidelines for design based on the experience developed from the experimental work (Task 7);
- Field monitoring of application of the technique to one bridge selected by MDOT (Task 8a);
- Bridge testing before and after application of the glued-on plate (Task 8b to be conducted by professor A. Nowak, U of M)

This volume provides technical specifications based on information provided by the manufacturers of the two CFRP strengthening systems used and augmented by the experience accrued during the course of this investigation.

1. INTRODUCTION

The technical specifications presented here are part of a research project at the University of Michigan supported by the Michigan Department of Transportation and the Great Lakes Center for Truck and Transit Research. The project title is "Repair and Strengthening of Reinforced and Prestressed Concrete Beams Using Carbon Fiber Reinforced Plastic (CFRP) Glued-on Plates". The study is aimed at providing experimental verification and recommendations for implementation of a new technology, in which thin fiber reinforced plastic laminates are glued-on the surface of concrete beams in order to strengthen them.

The primary objectives of this project are to ascertain the applicability of CFRP glued-on plates for repair and strengthening of concrete beams, to synthesize existing knowledge and develop procedures for implementation in the field, and to adapt this technique to the specific conditions encountered in the State of Michigan. As part of the tasks of this research project, this report is to present a summary of field specifications and "how to" details for implementation in field applications.

1.1. Limitations

These specifications present the synthesis and the comparison of the application procedures based on the information extracted from different commercial and research sources. In case of use of a particular FRP system, the application procedure provided by the material supplier should be followed.

1.2. Disclaimer

The successful application and use of these technical specifications is sole responsibility of the user and is dependent on the application of sound judgement by qualified professional engineer with a thorough understanding of concrete behavior and structural mechanics.

2. SPECIFICATIONS FOR THE USE OF CARBON FIBER REINFORCED PLASTIC (CFRP) LAMINATES FOR REPAIR AND REHABILITATION OF CONCRETE STRUCTURES

2.1. DESCRIPTION

Thin fiber reinforced plastic laminates, particularly carbon fiber reinforced plastic (CFRP) laminates are externally epoxy bonded to the surface of reinforced and prestressed concrete beams in order to strengthened them. The amount and localization of the CFRP laminate for a particular strengthening solution should be defined by a registered or licensed structural engineer.

2.2. MATERIALS

Materials required for this work are related with the particular strengthening system used. Refer to appendix A, special provision for strengthening with Sika® Carbodur® (taken from Engineering Guidelines for the use of Carbodur ® (CFRP) laminates for structural strengthening) and to appendix B, special provision for strengthening with the MBrace strengthening system (taken from Master Builders Technologies- Restoration products. Specification Bulletin: MBrace™ Composite Strengthening System with carbon fiber reinforcement for concrete substrates).

Properties of currently available commercial composite sheets are summarized in Table 2.1. The characteristics of the proprietary adhesives are summarized in Table 2.2. The information presented was provided by the supplier of the corresponding strengthening system. It should be noticed that MBrace™ CF 130 carbon fiber sheet is the same material as the Forca Tow sheet FTS C-130.

A. Delivery, storage, and handling

Delivery of the specified product(s) must be in original, unopened containers with the manufacturers name, labels, product identification, and batch numbers.

Storage and conditioning of the specified product(s) must be as recommended by the manufacturer.

Table 2.1 Data Summary for Commercial FRP

Property \ Product	Sika *CarboDur*	Tonen *Forca Tow Sheet*		Mitsubishi *Replark*
Type / Grades	Type S512 Type S812 Type S1012	FTS-C1-20 FTS-C 130 (MBrace CF 130) FTS-C 530 (MBrace CF 530)	FTS-GE-30 FTS-GT-30 MBrace EG 30	Type 20 (MRK-M2-20) Type 30 (MRK-M2-30) Type MM (MRK-M4-20) Type HM (MRK-M6-30)
Type of Fibers	Carbon fibers Toray T300 &T700	High tensile CF High tensile CF High modulus CF	E-Glass Fibers T-Glass Fibers E-Glass Fibers	Standard Modulus CF Standard Modulus CF Medium Modulus CF High Modulus CF
Type of Matrix	epoxy resin matrix	epoxy resin matrix	epoxy resin matrix	Epoxy resin matrix
Tensile Strength	2,400 MPa all grades	3,480 MPa 3,480 MPa 2,942 MPa	1,516 MPa 2,694 MPa 1,516 MPa	3,400 MPa 3,400 MPa 2,900 MPa 1,900 MPa
Modulus Of Elasticity (1000 N/mm^2 = 1 GPa)	155 GPa all grades	230GPa 230GPa 373 GPa	72.6 GPa 87.1 GPa 69.0 GPa	230 GPa 230 GPa 390 GPa 640 GPa
Ultimate Elongation At Break [%]	1.9 all grades	1.5 1.5 0.8	2.1 3.2 2.1	N.A.
Fiber Areal Weight g/m^2	N.A. Fiber volume >68%	200 300 300	300 300 300	200 300 300 300
Density ρ	1.6 g/cm^3	1.82 g/cm^3	2.55 g/cm^3 2.50 g/cm^3	1.6 g/cm^3
Thickness	1.2 mm all grades	0.11 mm 0.17 mm 0.17 mm	0.118 mm 0.120 mm 0.118 mm	0.11 mm 0.17 mm 0.17 mm 0.14 mm
Sheet width Cm	50 mm 80 mm 100 mm	50 cm all grades	50 cm all grades	25 cm all grades 33 cm all grades 50 cm all grades
Proprietary Adhesive	Sikadur 30 - Epoxy resin two components adhesive.	**For FTS C:** FP-NS, FP-NSS, FP-NSW, FP-S, FP-WE7, FP-WE7W, FR-E3P, FR-E3PS, FR-E3PW **For MBrace CF:** MBrace Primer, Putty, and Resin	**For FTS G:** Same as for FTS C1-C5 **For MBrace EG:** MBrace Primer, Putty, and Resin	Epotherm Primer, Putty and Resin
Lengths Available	Any length	Standard: 100 m.	Standard: 100 m.	Standard: 100 m

Note: the values of properties are given in a sequence corresponding to grade sequence.

N.A. = Information not available

Table 2.2 Comparison of Commercial Adhesives

Property \ Producer	Sika	Master Builders		Tonen									Mitsubishi					
Grade	Sikadur 30	MBrace Primer	MBrace Saturant	FP-NS	FP-NSS	FP-NSW	FP-S	FP-WE7	FP-WE7W	FR-E3P	FR-E3PS	FR-E3PW	PS301	PS401	PS318	L525	L700S	L700W
Material	Epoxy	Epoxy	Resin	Epoxy	Epoxy	Epoxy	Epoxy	Epoxy	Epoxy	Epoxy	Epoxy	Epoxy	Epoxy	Epoxy	Epoxy	Epoxy	Epoxy	Epoxy
Type	Adhesiv Mortar	Primer	Curing resin	Primer	Primer Summer	Primer Winter	Primer Penetr.	Primer Summer	Primer Winter	Resin Standard	Resin Summer	Resin Winter	Primer Fall/ Spring	Primer Spring/ Fall	Primer All year	Putty All year	Resin Spring/ Fall	Resin Winter
Appl. Temp. °C	10-38	5-38	10-38	15-25	25-35	5-15	5-35	15-25	5-15	15-25	25-35	5-15	5-25	20-35	5-35	5-35	15-35	5-15
Mixing Ratio:																		
• by weight				2:1	2:1	2:1	1:1	2:1	2:1	2:1	2:1	2:1	2:1	2:1	2:1	2:1	2:1	2:1
• by volume	3:1	3:1	3:1															
Viscosity, cps	N.A.	N.A.	1,600	2,000	2,000	1,300	90	45,000	45,000	20,000	20,000	10,000	500 (MPaS)	500 (MPaS)	17 (MPaS)	Putty	4,000 (MPaS)	3,500 (MPa S)
Pot Life, min		N.A.																
@30°C					40		120				40		25	140	> 120	30	50	
@23°C	70												40	240	> 120	50	70	20
@20°C			30	40	120	20	120	40	20	40	110	20						
@10°C							120		50			50	95		> 120	100	-	70
Setting Time, hrs	N.A.		N.A.															
@30°C											7	7	-	4.0	-	3.0	3.5	-
@23°C													3.5	7.0	2.5	3.5	6.0	3.5
@20°C				10	12	7	3	12	10	10	12	12	-	-	-	-	-	-
@10°C													6.5	-	4.0	5.0	-	6.0
Curing time, days	N.A.		N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.		-
@30°C																	5	-
@23°C																	7	7
@20°C																	-	
@10°C																	-	14
Compress.Strength (14 day), MPa	59.3 (23°C)	N.A.	88	N.A.									N.A.					
Shear Strength, MPa	24.8	17-19 (steel)	N.A.	12.5 MPa									N.A.					
Tensile Strength (7 day), MPa	24.8	13-15.8	78	N.A.									N.A.					
Elong. at Break	1%	20-30%	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Bond Strength:		17 MPa (steel)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
- Concrete to conc.	21.3MPa																	
- Concrete to steel	17.9MPa																	
Shelf Life	2 years		N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Storage Conditions	4-35°C	18-24C	cool-dry	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Color main agent	Light gray	Clear-Amber	Blue	N.A.									Pale yellow		Transp	White	Green and thixotropic liquid	

N.A. = Information not available

2.3. EQUIPMENT

The type of equipment needed according to the strengthening system used, location of the work and structural and environmental conditions will be defined by a specialized contractor. For equipment required to apply Sika® Carbodur® refer to appendix A, for Tonen MBrace strengthening system refer to appendix B.

2.4. EXECUTION

A. Assessment of existing conditions

The determination of strengthening technique should be supported by thorough examination of existing structural and environmental conditions such as:

- Conditions of the member;
- Concrete quality;
- Reinforcement configuration and location;
- Member geometry;
- Load conditions;
- Environmental exposure (road salt, UV light, freeze-thaw).

The inspection of the structure and the designing of repair and/or reinforcement level should be done by civil or structural engineers and/or professionals who are lawfully registered or licensed to do the job.

Complete working drawings shall be submitted by the Contractor for each installation of the beam/slab strengthening. The working drawings shall contain details of the width of the strips used, properties of materials used, joint and end details, and all other information required for the proper installation of the system.

B. Surface preparation

The following represents a synthesis of the surface preparation recommendations taken from commercial information and also from research sources. Before application of a particular system, one should refer to the appropriate commercial specifications. All possible bonding surfaces involved in the strengthening system (concrete, FRP, steel) should be prepared.

<u>Concrete Surfaces</u>

- In order to provide open roughened texture the application of the following surface preparation techniques and/or inspection steps can be necessary:
  - Sandblasting (high pressure sand abrading);
  - High-pressure water washing;

- Bush-hammering (heavy impact method; can only be used if specifically requested by the Engineer in charge of the surface preparation step);
- Disk abrading (grinding).

- For a new concrete structure, the design engineer must specify the minimum compressive strength allowable to apply the corresponding surface preparation.
- Surface must be free of standing water. Some types of adhesives require a dry surface. ASTM D4263 tests moisture in concrete by means of a plastic sheet method [ASTM-2].
- Watch for the formation of condensation (dew point).
- Removal of dust, grease, oils, curing solutions, or mold release agents, impregnations, waxes, foreign particles, disintegrated materials, paints, plasters, wall papers and other bond inhibiting materials (see surface contaminants below).
- Adhesion to exposed aggregates is generally better than to the hardened cement paste. The laitance must therefore be removed and the aggregate must be exposed as gently as possible.
- The surface to be coated must be even (on a length of 2 meters, unevenness may not exceed 10 mm [SCD-1]). Steps and formwork marks must not be greater than 0.5mm.
- Filling of gaps, cavities and uneven portions of structure with appropriate repair mortar specified by the system producer (see surface defects below). According to Sika, an epoxy repair mortar should be applied (e.g., Sikadur 30 with the addition of 1 part sand to make an epoxy mortar) [SCD-1]. At the direction of the Engineer in charge, the adhesive strength of the concrete surface should be verified after preparation by random pull-off testing (ACI 503R, ACI-1). This testing should prove a minimum tensile strength of the adhesive interface specified by the system supplier (according to Sika, minimum tensile strength, 1.4 MPa with concrete substrate failure).
- The optimum roughness of the substrate (0.5-1.0 mm) can be achieved with sandblasting technique [SCD-1]. Protrusions, laitance, remains from formwork, dowels etc. must be removed. Visual check of the treated substrate surface for foreign matter and inclusions in the concrete is part of quality control.

1. **Surface contaminants.** Examples of the more common contaminants are provided [XX-46]:

a. **Curing compounds.** They are liquid solutions that are routinely applied to newly placed concrete surfaces to facilitate hydration curing by retarding water loss from evaporation. Some curing compounds may be compatible with coatings. In case of doubt consult with the supplier of the strengthening system and/or completely remove the curing compounds.

b. **Dust.** Dust may land on a cleaned surface as airborne fallout from industrial pollution or from work being performed in the immediate area. Dust should be removed by vacuum cleaning. An alternative method consists of blowing down clean, oil-free, compressed air. The method of dust removal should be approved by the engineer in charge of the repair work.

c. **Efflorescence.** It is a powdery white and sometimes crystalline deposit of water-soluble salts that migrate to the concrete surface with water. The salts are left on the surface when the water evaporates. Movement of the moisture and dissolved salts will be from the hot to the cold side of a wall. This efflorescence must be removed from the surface to prevent loss of coating adhesion.

d. **Laitance.** This is a weak layer of partially hydrated cement paste at the top surface of concrete. It is usually caused by extended open time during finishing in cooler temperatures and/or overworking (toweling/floating) the finish, and transporting cement fines to the surface. If laitance is not completely removed to sound concrete, it will result in loss of coating adhesion. Laitance may be from 1.6 mm to 3.2 mm thick.
e. **Form release agents.** They facilitate the removal of forms from cured concrete. Form release agents are inherently strong bond breakers. These agents can cause coating adhesion problems if they are transferred to the concrete.
f. **Oil, grease, tar, and gum.** May be found on concrete, usually floors, exposed to foot and vehicular traffic or machinery. These contaminants can penetrate deeply into concrete making effective removal difficult. If not removed they will cause adhesion problems for coatings and patching materials. They can also bleed through the coating to cause staining. Tar, gum, and bitumen-based materials will act the same as oil and grease. Hydraulic fluids and similar materials can penetrate deeply thereby requiring additional cleaning or substrate removal. After applying the corresponding cleaning method, inspection should be performed to establish the acceptability of the substrate for the application of coatings. Oil may be detected by a water break test. Clean potable water should be lightly sprinkled or sprayed (fine mist) on the surface. If the water wets and spreads out instead of beading up, the surface may be considered relatively oil and grease free. Gum may take on the appearance of an oil spot and will cause problems in coating delimitation if not properly removed

2. **Surface defects.**

a. **Fins.** They are high points in the form of ridges or knobs having a relatively sharp surface. Coatings applied over fins will be uneven and low in film thickness due to surface tension pullback of the coating at the fins' edges. Fins and projections should be removed by grinding or stoning to a flat plane surface followed by a light wire brushing to remove dusty laitance, followed in turn by a vacuum or air blast cleaning.
b. **Eggshell.** It is a very thin, sometimes translucent film of laitance and bleed water residues that forms over air pockets and bug holes in the concrete surface. This thin film is very easily broken open exposing the hole beneath. Eggshell areas should be located, broken open, cleaned out, and the resulting hole patched flush with the surrounding surface.
c. **Tie holes.** They are small holes remaining in the concrete surface after the concrete form tie bars have been removed. Tie holes should be cleaned out and patched flush with the surrounding surface.
d. **Sacking or rubbing.** It is the hand application of cement sand mortar extruded through a burlap sack. The mortar sack is rubbed over new concrete. Sacking can cover minor surface defects and fill small voids but it cures into an extremely weak layer having very poor cohesive (tensile) and bond strengths. If present, sacking must be removed prior to the application of any coating system.

3. **Internal contaminants and defects.**

Concrete may also contain chemical contaminants and hidden mechanical defects within itself. These contaminants and resultant defects can cause problems in both coatings and patching material performance. Soluble salts in the form of chlorides, sulfates and nitrates can cause decomposition and cracking of the concrete from strong expansive internal reactions. Chloride-

contaminated concrete substantially contributes to reinforcement corrosion as well as concrete that has become carbonated in the immediate area of the reinforcement.

Concrete and masonry deteriorated as a result of the expansive reactions caused by sulfates, nitrates, and other salts must be completely removed. The source of both salts and their water transport mechanisms must be eliminated or significantly reduced to realize future service life. Repairs due to reinforcement corrosion should always be performed in accordance with the International Concrete Repair Institute (ICRI) guidelines, document No. 037730 "Surface Preparation for the Repair and Deterioration Concrete Resulting from Reinforcing Steel Corrosion" [XX-48]

4. Cleaning and preparation methods

Cleaning and preparation should produce a clean sound surface having a roughness approximately equal to 60 to 80 grit medium sandpaper [XX-46]. Note that some of the methods indicated here may also be specified in the MDOT Standard Specifications for Construction.

a. **Steam cleaning.** Regulated by ASTM D 4258 [ASTM-3] and ASTM D 4261 [ASTM-4]. Steam cleaning machines produce quantities of wet or dry steam directed at the concrete in a high concentration and at a velocity sufficient to loosen, soften and remove the contaminants. Detergents, degreasers, and other chemicals are often added to the water to greatly increase their effectiveness. Their use should be authorized by the Engineer in charge. It should be noted that steam cleaning only removes surface contaminants and not those in the pores of the concrete.
b. **Shot blasting.** Regulated by [4259 [ASTM-5] and ASTM D 4258 [ASTM-3]. Centrifugal shot blasting is a very effective, clean, and dust-free method for removing hardened films of contamination and texturing horizontal concrete without water or chemicals. This process involves impacting the surface with high velocity steel shot abrasive. The shot blasting media is thrown against the concrete from an enclosed high velocity rotating paddle wheel. A separate dust collector then removes the abrasive, dust, and contaminants. The cleaned steel shot is then recycled to the blast wheel where the cycle repeats. Shot blasting provides a relatively uniform texture ranging from fine granular to a coarse sandpaper finish. Steel shot blasting is not very effective for the removal of rubbery elastomeric materials, however, in some instances, it may be used to clean them.
c. **Abrasive blast cleaning.** Blast cleaning is a method for preparing and texturing concrete surfaces by impact with a high velocity stream of fine mineral aggregate abrasives propelled by clean compressed air. Blast cleaning produces a textured, physically sound substrate free of surface contamination and fines. Surface hardness of concrete determines whether this method is applicable for a particular work. Test areas should be tried using the same equipment, air pressure, hose lengths, nozzle size, and abrasive. Sand abrasives should be selected according to the level of cleaning required. Mineral abrasives should have a sharp angular shape and be at least a 6.5 on the Mohs' mineral hardness scale. Abrasives containing free silica can not be used, as they can cause lung disease silicosis. Wet abrasive blast cleaning and equipment may be used when dust abatement is necessary. This abrasive method is not generally effective on rubbery elastomeric materials and should not be used for that purpose.

A comparison of different surface preparation techniques depending on the level of contamination and deterioration and the depth of removal of concrete cover is presented in the Table 2.3 below (based on Sika materials.) The bigger the contamination and the thickness of removed material are the more aggressive is the method that has to be applied.

Steel Surfaces

- Removal of grease, oil, rust and scale;
- Preparation – abrasive blasting;
- Eye inspection for the formation of condensation (dew point);
- If not bonded immediately, the surface has to be protected with compatible corrosion inhibitor.

Table 2.3 Methods of Concrete Surface Preparation

Preferred use for the surface conditions below	Method
Removal of oils, greases, proteins (water-soluble, agents water-emulsive)	Steam jets with added wetting agents
Removal of old paint	Steam jets with added wetting agents and sand
Removal of old paint, heavy contamination on low-strength surface areas of the concrete, damage from the road salts	Abrasive-blasting, Water sand-blasting, High pressure water-jets
Removal of thicker old coatings from deeper areas with low surface strength, deep-reaching contamination	Flame-cleaning and mechanical cleaning
Removal of deep-reaching road salts and other contamination.	Grinding and mechanical cleaning

FRP Sheets

- Place FRP fabric on even surface (such as table).
- Check the material for possible damages, cracks etc.
- For the Sika system, the CFRP strips have to be cut to proper length by metal saw or disk-cutter before application.
- For the Tonen system, the carbon fiber sheet must be cut beforehand into prescribed sizes using scissors and/or cutter.
- Sika recommends to wipe clean with appropriate cleaner (e.g. acetone). This operation removes soiling as well as carbon dust. Cleaning should be continued until white cloth remains white.
- Dry CFRP laminate with a clean rag (Sika).

C. Mixing of Adhesives

- Consult technical data sheet for specific type of adhesive.
- Protect adhesive and components from direct sunlight.
- Maintain appropriate proportions of components (parts by weight or parts by volume).
- Prepare only that quantity which can be used within its pot life.

- Premix each component in the original containers.
- Consult technical data sheet of components 1 and 23 to define which component should be added to. Generally hardening component is added to resin component.
- Mix the adhesive until uniform in consistency (uniform color). Use electric hand mixer for about 3 minutes or mix manually with the trowel or spatula. Mix with low speed so that as little air as possible is entrained (max. 500 rpm).
- Take care to scrape the sides of the pail during mixing.
- Do not use the epoxy resin if it has hardened lumps and high viscosity once the container was opened.
- The pot life of the adhesive begins when the resin and hardener are mixed.
- To obtain longer workability and pot life the following suggestions can be followed:

Pot life is longer at lower temperatures. If necessary the adhesive components can be chilled to room temperature before mixing. Adhesive prepared in smaller quantities has usually longer pot life.

D. Application to Structure

- Do not apply material if it is raining or snowing, or if they appear to be imminent.
- Precautions should be taken to avoid damage to any surface near the work zone due to mixing and handling of the specified material.
- If the system being used requires the primer (Tonen, Mitsubishi), apply according to manufacturer's specifications.
- Apply the mixed adhesive onto the concrete with trowel, float or spatula to form a layer of required thickness.
- The adhesive has to be applied with great care to the concrete surface to ensure that all the voids are filled and no cavities are left.
- Apply the mixed adhesive onto the CFRP laminate to form a layer of required thickness.
- Within the open time of the adhesive, depending on the temperature, place the FRP onto the concrete surface.
- Press the laminate into the adhesive using the hard rubber roller until the adhesive is forced out on the sheet sides (Sika) or forced into the fibers in the sheet (Tonen, Mitsubishi).
- Remove excess adhesive.
- Leave the applied layer undisturbed for at least 24 hours.
- When wrapping a right angled corner, this corner should be ground to be rounded enough to stick thoroughly around the corner.
- Repeat the application process for desired number of layers. Maintain proper width of glue line.
- Apply coating for protective or aesthetic finish (optional).
- During the curing time of the adhesive heavy traffic loads should be regulated in order to avoid a possible diminution of the bond strength of the adhesive to the concrete surface.

E. Additional Limitations and Requirements

- Consider that FRP materials are easily damaged in transport or in the field by cutting, bending, and trampling.

- The minimum age of concrete must fulfill the requirements of a particular system. In most cases, it should be 21-28 days unless special curing and drying conditions are provided.
- Do not thin the adhesive unless specified. Solvents will prevent proper curing.
- CFRP material is a vapor barrier after cure.
- Minimum substrate and ambient temperature depends on type of adhesive used. It has to be checked with data sheet.
- In extreme solar radiation, most cold-setting epoxy adhesives experience a reduction of shear modulus and shear strength.

F. Safety Precautions and First Aid

- Consults the material safety data sheet for the adhesive before application.
- Epoxy resins can cause skin sensitization or irritation (dermatosis) after prolonged or repeated contact. They can also be eye irritant or even cause burns.
- High concentration of vapor may cause respiratory irritation. Therefore adequate ventilation is necessary. Overexposure may affect liver, kidney, and/or central nervous system effects.
- Use of standard precautions such as safety goggles and chemical resistant gloves is recommended. Cover hands with barrier cream before starting work.
- In any case avoid direct contact with epoxy resin and limit exposure to a necessary minimum.
- In case of skin contact with epoxy resin wash immediately and thoroughly with soap and water. Contact physician if symptoms persist.
- In case of eye contact with epoxy resin wash immediately with plenty of water for at least 15 minutes. Immediately contact physician.
- In case of respiratory problems, remove person to fresh air. Contact physician if symptoms persist.
- In case of respiratory overexposure (excess of PELs) use the appropriate, properly fitted NIOSH/MSHA approved respirator.
- When sanding, possible exposure to crystalline silica (sand) dust may cause delayed lung injury and is listed as a suspect carcinogen by NTP and IARC. Use of appropriate dust protection is recommended.
- In case of spills or leaks, wear suitable protective equipment, contain spill, collect with absorbent material and transfer to suitable container. Ensure proper ventilation of the area.
- Uncured material can be removed with approved solvent.
- Cured material can only be removed mechanically.
- Dispose of in accordance with current, applicable local, state and federal regulations.
- Unused adhesives should not be discharged into drains, waterways or ground.
- Keep materials out of reach of children.

G. Commercial Systems - Comparison of Application Procedures

Application procedures for Sika® Carbodur® are introduced on appendix A. Application procedures for Tonen MBrace strengthening system are introduced on appendix B. Table 2.4 provides the comparison of application procedures for the three main strengthening systems evaluated here.

Table 2.4 Comparison of Commercial Application Procedures

Procedure	Sika *SikaDur*	Tonen Forca Tow Sheet	Mitsubishi *Replark*
FRP Cleaning	Yes (required)	Yes (required)	Yes (required)
Concrete Water Jet	Yes (allowed)	Yes (*)	Yes (*)
Concrete Sandblasting	Yes (required)	Yes (*)	Yes (*)
Concrete Grinding	Optional	Yes (required)	Yes (required)
Priming	No	Yes	Yes
Putty (Filler) application	Yes SikaDur 41	Yes	Optional
Undercoating - 1st Resin Coating for 1st and further plies	Yes	Yes	Yes
Protective overcoating - 2nd Resin Coating	No	Yes	Yes
Finishing and Painting	Optional	Optional	Yes

* Application procedure has been performed experimentally.

3. REFERENCES

ACI - American Concrete Institute

ACI-1 ACI 503R. Pull-Out Test of Driven Pins in Concrete.

ASTM – American Standard Specifications

ASTM-2 ASTM D 4263. Indicating Moisture in concrete by the Plastic Sheet Method.

ASTM-3 ASTM D 4258. Surface Cleaning Concrete for Coating.

ASTM-4 ASTM D 4261. Surface Cleaning Concrete Unit Masonry for Coating.

ASTM-5 ASTM D 4259. Abrading Concrete.

SCD – Sika (Carbodur)

SCD-1 Steiner W., "Strengthening of Structures with CFRP Strips", Advanced Composite Materials in bridges and Structures, El-Badry Editor, M., The Canadian Society for Civil Engineers, Montreal, Canada 1996, pp. 407-419.

Other Research Institutions

XX-46 Blaschko M., Niedermeier R., and Zilch K., "Bond Failure Modes of Flexural Members Strengthened with FRP", Proceeding of the Second International Conference on Composites in Infrastructure, H. Saadatmanesh and M.R. Ehsani, Editors, Tucson, AZ 1998, pp. 315-327.

XX-48 International Concrete Repair Institute (ICRI) Guidelines No. 03730. Surface Preparation Guidelines for the Repair of Deteriorated Concrete Resulting from Reinforced Steel Corrosion.

APPENDIX A: SPECIAL PROVISION FOR USING SIKA® CARBODUR® (CFRP) LAMINATES FOR STRUCTURAL STRENGTHENING

GENERAL

A. Description

This work shall consist of furnishing and installing Carbon Fiber Reinforced Plastic (CFRP) sheets to repair concrete bridge beams as shown on the plans.

B. Work including

1. Existing concrete shall be repaired and reinforced with dry, unidirectional carbon fiber fabric sheet.

2. The work is deemed to include furnishings of materials, labor, and equipment and all items necessary for repair and reinforcing of the concrete as specified on the contract drawings and specifications, complete.

3. Inspect the structural members to be reinforced with Carbon Fiber Reinforced Plastic (CFRP) on the contract drawings to check the location of and inspect cracks, and actual conditions of beams.

4. Install CFRP laminates to reinforce concrete members.

C. Submittals

1. Contractor's qualifications.

2. The epoxy/composite supplier shall submit product data indicating product standards, physical and chemical characteristics, technical specifications, limitations, installation instructions, maintenance instructions and general recommendations regarding each material.

3. The epoxy/composite supplier shall provide testing information to demonstrate system properties of material to be used.

4. The epoxy/composite supplier shall provide a two-year proven record of performance of beam/slab strengthening with carbon fiber materials, confirmed by actual field tests and five successful installations.

5. The epoxy/composite supplier shall provide field supervision specifically trained in the installation of CFRP laminates.

6. Samples of all materials to be used, each properly labeled as specified in MATERIALS.

7. Manufacturer's MSDS for all materials to be used.

8. Certifications (in time to prevent delay in the work) by the Producers of the materials that all materials supplied comply with all the requirements and standards of the appropriate ASTM and other agencies.

D. Project Record Documents

Working Drawings: Complete working drawings shall be submitted by the Contractor for each installation of the beam/slab strengthening. The working drawings shall contain details of the width of the strips used, properties of the materials used, joint and end details, and all other information required for the proper installation of the system.

E. Quality Control

1. Manufacturer/Contractor Qualifications

a. Materials Manufacturer/Supplier: Company specializing in the manufacturing of the products specified in this section with documented experience.

b. Materials Manufacturer/Supplier: Company must be certified by independent audit as ISO 9001.

c. Materials Manufacturer/Supplier: Company shall have in existence for a minimum of 10 years, a program of training, certifying, and technically supporting a nationally organized Approved Contractor program with annual re-certification of its participants.

d. Contractor qualifications: Contractor shall be an approved Contractor of the manufacturer/supplier of the specified product, who has completed a program of instruction in the use of the specified material, and provide a notarized certification from the manufacturer attesting to their Approved Contractor status.

e. A manufacturer's representative is required on site for initial placement of the strengthening system. Direction of the representative must be followed.

2. Quality Control

The contractor shall conduct a quality control program that includes, but is not limited to the following:

a. Inspection of all materials to assure conformity with contract requirements and that all materials are new and undamaged.

b. Inspection of all surface preparation prior to CFRP laminate application.

c. Inspection of work in progress to assure work is being done in accordance with established procedures and established Manufacturer's instructions and specified Engineer instructions.

d. Inspection of all work completed including sounding all repairs to check for debonding and correction of all defective work (see section EXECUTION, part J: quality control and Inspection).

F. Product Delivery, Storage and Handling

Deliver materials clearly marked with legible and intact labels with Manufacturer's name and brand name, product identification and batch number.

The product shall be in original, unopened containers.

Store materials in areas where temperatures conform with Manufacturer's recommendations and instructions.

G. Job Conditions

1. Environmental Conditions. Do not apply material if it is raining or snowing, or if they appear to be imminent. Follow manufacturer's recommendations concerning specific environmental conditions such as concrete and air temperature, dew point and humidity values (see see section EXECUTION, part A, E and F).

2. Protection: Precautions should be taken to avoid damage to any surface near the work zone due to mixing and handling of the specified material.

3. Work only in areas permitted by the Owner approved schedule.

4. Remove all tools, buckets and materials from work areas and store neatly at an approved location daily at the end of work.

5. Protect adjacent areas from damage and stains with appropriate barriers and masking. Repair all damage as a result of the work to its condition at the start of work, or if such cannot be determined, to its original condition.

6. Compliance with OSHA and all other safety laws and regulations is the exclusive responsibility of the Contractor.

H. Technical Support

The Contractor shall provide the services of a trained field representative at the work site at all times to instruct the work crew in the CFRP applications procedures.

1. The manufacturer's Field Representatives must be fully qualified to perform the work.

2. The contractor shall be completely responsible for the expense of the services of the required Manufacturer's Field Representative and the contract price shall include full compensation for all costs in connection therewith.

MATERIALS

A. Carbon fiber reinforced plastic (CFRP) laminates

Sika Carbodur system, as supplied by Sika corporation, Lyndhurst, NJ is considered to conform to the requirements of this specification.

B. Epoxy resin adhesive

Sikadur 30, as manufactured by Sika Corporation, Lyndhurst, NJ, is considered to confirm to the requirements of this specification.

C. Substitutions

The use of other than the specified products will be considered, providing the contractor requests their use in writing to the Engineer. This request shall be accompanied by (a) A certificate of compliance from an approved independent testing laboratory that the proposed substitute products meet or exceed the specified performance criteria (see Table 1.A below), tested in accordance with the specified test standards (see Table 1A below); and (b) Documented proof that the proposed substitute products have a two year proven record of performance of beam/slab strengthening with carbon fiber materials, confirmed by actual field tests and five successful installations that the Engineer can investigate.

EXECUTION

A. Preparing the substrate

The concrete surface must be clean and sound. It may be damp or dry, but free of standing water and frost. Remove dust, laitance, grease, curing compounds, impregnations, waxes, foreign particles, disintegrated materials and other bond inhibiting materials from the surface. The substrate shall first be thoroughly inspected and any unsound concrete must be removed. Prepare substrate by abrasive blasting or other mechanical means. All damaged areas (e.g. cracks, bug holes or surface defects) shall be repaired prior to placing Sika CarboDur. Cracks shall be

repaired using a structural injection resin and surface defects shall be filled and leveled with an appropriate repair mortar (e.g. Sikadur 30 with the addition of 1 part sand or Sikadur 43 Patch-Pak). Leveled surfaces shall not deviate more than 3 mm every 300 mm. The surface profile shall not have deviations larger than 3 mm. The adhesive strength of the concrete must be verified after surface preparation by random pull-off testing [ACI-1] at the discretion of the Engineer. Minimum pull off tensile strength requirement is 1.38 MPa.

Table 1A. Performance Criteria

	Property	Requirement
Carbon Fiber Reinforced Plastic (CFRP)	Ultimate tensile strength in longitudinal direction of fiber (ASTM D-3039)	2400 MPa
	Modulus of elasticity (ASTM D-3039)	150,000 MPa
	Elongation at break (ASTM D-3039)	>1.4%
	Fiber volumetric content	>60%
	Apparent density	1.6 g/cm^2
	Temperature resistance	500°C
	Thickness	1.2 mm
	Shelf life	Unlimited (with no exposure to direct sunlight)
Epoxy resin adhesive	Compressive strength (ASTM D-695)	62 MPa
	Tensile strength (ASTM D-638)	30 MPa
	Shear strength (ASTM D-732)	17 MPa
	Adhesive strength on concrete (ASTM C-882)	2 MPa
	Modulus of elasticity (ASTM D-638)	12,800 MPa
	Pot life (at 24°C)	70 minutes, minimum
	Density (A+B)	1.77 Kg/l

B. Unpacking Sika Carbodur laminate

CarboDur will normally arrive on site packed as a coil in a box. The contractor has the option of ordering material as custom cut lengths or as one continuous length to be cut at the job site. Once the lid is removed from the box, the coil of CarboDur must be handled carefully to facilitate controlled uncoiling. Care must also be used to avoid splitting the ends of the strip. Since loose carbon fibers may be present on the surface of Sika CarboDur, gloves, mask and goggles are recommended when handling the material.

C. Cutting the CarboDur laminate.

Carbodur laminates should be cut with tools using a "shearing" force (e.g. guillotine or heavy duty shears). Care must be taken to support both sides of the laminate when cutting. As an alternate method, a hacksaw or other abrasive cutting methods may be used. However, extra care must be taken to support the Carbodur laminate on both sides to avoid splintering. In addition, extra care must also be taken to avoid exposure to airborne carbon dust generated while cutting (i.e. use of NIOSH/MSHA mask, and gloves is recommended).

D. Preparation of laminate

Surface shall be wiped clean using appropriate cleaner. Using a clean white cloth wipe down the side which is to receive adhesive (this side is not labeled) with acetone until all residual carbon dust is removed (i.e. the white cloth remains white after wiping the laminate). In case where the design requires 'stacking' of the strips the bottom surface of the strip (which is labeled) shall be lightly sanded prior to the application of the second strip.

E. Mixing Sikadur 30

The ambient temperature and temperature of the epoxy components shall be between 10 and 38 degree Celsius at the time of mixing.

Premix A&B components. Proportion 1 part of component 'B' to 3 parts of component 'A' in a clean pail and mix thoroughly for 3 minutes using a Sika paddle on low speed (400-600 rpm) until all the colored streaks have disappeared. Take care to scrape the sides of the pail during mixing. Mix only that quantity which can be used within its pot life.

Components that have exceeded their shelf life shall not be used.

F. Application of Sikadur 30 to the substrate

The substrate temperature must be above 5°C at the time of application of the Sikadur 30. There should be no standing moisture (glistening) when the epoxy is applied. The moisture content of the surface must be less than 5%.

Apply neat Sikadur 30 to the substrate as a first coat using a spatula to form a uniform thickness of 1.6 mm and a width approximately 13 mm wider than the strip that is to be used.

G. Application of Sikadur 30 to the laminate

Clean the Carbodur strip (roughened side) with an appropriate cleaner (e.g. acetone). Dry the CFRP laminate with a clean rag. Apply neat Sikadur 30 to the side of the CarboDur strip opposite of the side labeled "KLEBERFEI" using a roof-shaped spatula to a nominal thickness of 1.6 mm. The best method to accomplish this is to fabricate a 'hopper' for the Sikadur 30 with the spatula at one end. The CarboDur strip is then pulled through the hopper under the Sikadur 30 and then past the roof-shaped spatula to produce a uniform cross section.

H. Applying CarboDur to the prepared substrate

After the CarboDur laminate and the substrate have been prepared with Sikadur 30, the strip is placed on the concrete (epoxy to epoxy). A rubber roller is then used to properly seat the strip using enough pressure so that the Sikadur 30 gel is force out on both sides of the laminate and so that the glue line does not exceed 3 mm. Excess gel should then be carefully removed. Do not disturb material for 24 hours following application Sikadur 30 will reach its designed strength in 7 days. High-build pigmented epoxy (Sikagard 670W) shall be applied as an overcoat for protection of the system against aggressive environments. A high-performance façade coating

(Sikagard 670W) shall be used for aesthetics and UV protection. Overcoat and topcoat color shall be gray.

I. Cleaning

- Uncured epoxy resins can be cleaned from tools with an approved solvent.
- Cured epoxy resins can only be removed by mechanical means.

J. Quality Control and Inspection

1. A qualified manufacturer's representative shall observe all aspects of onsite material preparation and application, including surface preparation, resin component mixing, application of Sikadur resin and Carbodur plate, curing of composite, and the application of protective coatings.

2. Inspection for Voids/Delaminations. After allowing at least 24 hours for initial resin cure to occur, perform a visual and acoustic tap test inspection of the layered surface. Voids larger than 160 mm^2 shall be repaired. If the total delamination area exceeds 10% of the bond surface area, all the voids shall be marked for repair. Treatment of the delaminated areas shall be done under direction of the qualified manufacturer's representative.

3. Report. The representative shall submit report to the Engineer. Contents shall include both in-process and final inspection details. Contents (as suggested in a private communication with the manufacturer's representative) shall include but may not be limited to :

- Ambient conditions at application.
- Tap test-scanning nap.
- Number and directions of plies applied.
- Cured resin cups.
- Laminated/cured FRP panels.
- Results of tension and pull off tests
- Surface hardness readings.
- Laminate thickness.

MEASUREMENTS AND PAYMENT METHODS

Payment for the CFRP sheets on concrete beams will be based on the area of concrete surfaces covered by the sheet and shall include all costs to furnish and install all layers of the sheet, including materials and labor. The cost of preparing the concrete surface for application of the FRP wrap is included in the payment. Individual layers of the sheet will not be paid for separately.

Item	Pay Unit
Carbon FRP Sheet	Square meter

Chipping and patching of deteriorated beams shall be paid for separately.

APPENDIX B: SPECIAL PROVISION FOR MBRACE COMPOSITE STRENGTHENING SYSTEM

GENERAL

A. Description

This work shall consist of furnishing and installing Carbon Fiber Reinforced Plastic (CFRP) sheets to repair concrete bridge beams as shown on the plans.

B. Work including

1. Existing concrete shall be repaired and reinforced with dry, unidirectional carbon fiber fabric sheet.

2. The work is deemed to include furnishings of materials, labor, and equipment and all items necessary for repair and reinforcing of the concrete as specified on the contract drawings and specifications, complete.

3. Inspect the structural members to be reinforced with Carbon Fiber Reinforced Plastic (CFRP) on the contract drawings to check the location of and inspect cracks, and actual conditions of beams.

4. Install CFRP laminates to reinforce concrete members.

C. Submittals

1. Contractor's qualifications.

2. The epoxy/composite supplier shall submit product data indicating product standards, physical and chemical characteristics, technical specifications, limitations, installation instructions, maintenance instructions and general recommendations regarding each material.

3. The epoxy/composite supplier shall provide testing information to demonstrate system properties of material to be used.

4. The epoxy/composite supplier shall provide a two-year proven record of performance of beam/slab strengthening with carbon fiber materials, confirmed by actual field tests and five successful installations.

5. The epoxy/composite supplier shall provide field supervision specifically trained in the installation of CFRP laminates.

6. Samples of all materials to be used, each properly labeled as specified in MATERIALS.

7. Manufacturer's MSDS for all materials to be used.

8. Certifications (in time to prevent delay in the work) by the Producers of the materials that all materials supplied comply with all the requirements and standards of the appropriate ASTM and other agencies.

D. Project Record Documents

Working Drawings: Complete working drawings shall be submitted by the Contractor for each installation of the beam/slab strengthening. The working drawings shall contain details of the width of the strips used, properties of the materials used, joint and end details, and all other information required for the proper installation of the system

E. Quality Control

1. Manufacturer/Contractor Qualifications

a. Materials Manufacturer/supplier Company must be specialized in the manufacturing of the products specified in this section.

b. Materials Manufacturer/Supplier Company must have been in business for a minimum of 5 years, with a program of training and technically supporting a nationally organized Contractor Training Program.

c. Contractor shall be a trained Contractor of the manufacturer/supplier of the specified product, who has completed a program of instruction in the use of the specified material, and provide a notarized certification from the manufacturer attesting to their Approved Contractor status.

d. A manufacturer's representative is required on site for initial placement of the strengthening system. Direction of the representative must be followed.

2. Quality Control

The contractor shall conduct a quality control program that includes, but is not limited to the following:

a. Inspection of all materials to assure conformity with contract requirements and that all materials are new and undamaged.

b. Inspection of all surface preparation prior to CFRP laminate application.

c. Inspection of work in progress to assure work is being done in accordance with established procedures and established Manufacturer's instructions and specified Engineer instructions.

d. Inspection of all work completed including sounding all repairs to check for debonding and correction of all defective work (see section EXECUTION, pat J.: repair of defective work).

F. Product Delivery, Storage and Handling

Deliver materials clearly marked with legible and intact labels with Manufacturer's name and brand name, product identification and batch number.

The product shall be in original, unopened containers.

Store materials in areas where temperatures conform with Manufacturer's recommendations and instructions.

G. Job Conditions

1. Environmental Conditions. Do not apply material if it is raining or snowing, or if they appear to be imminent. Follow manufacturer's recommendations concerning specific environmental conditions such as concrete and air temperature, dew point and humidity values.

2. Protection: Precautions should be taken to avoid damage to any surface near the work zone due to mixing and handling of the specified material.

3. Work only in areas permitted by the Owner approved schedule.

4. Remove all tools, buckets and materials from work areas and store neatly at an approved location daily at the end of work.

5. Protect adjacent areas from damage and stains with appropriate barriers and masking. Repair all damage as a result of the work to its condition at the start of work, or if such cannot be determined, to its original condition.

6. Compliance with OSHA and all other safety laws and regulations is the exclusive responsibility of the Contractor.

H. Technical Support

The Contractor shall provide the services of a trained field representative at the work site at all times to instruct the work crew in the CFRP applications procedures.

1. The manufacturer's Field Representatives must be fully qualified to perform the work.

2. The contractor shall be completely responsible for the expense of the services of the required Manufacturer's Field Representative and the contract price shall include full compensation for all costs in connection therewith.

I. Acceptable Manufacturers/Suppliers

The following vendors shall be used:

1. CFRP laminates: (Dry, unidirectional sheet only). MBrace Fiber Reinforcement Systems supplied by Master Builders, Inc. 23700 Chagrin Blvd., Cleveland, OH 44122 216-831-5500, 800-MBT-9990, Fax: 216-831-6910.

Epoxy resin adhesive: an approved epoxy system for application of MBrace Composite System. The epoxy system shall include:
Primer
Base Coat/Filler
Saturant
Topcoat
Submit proposed products to Engineer for approval, including thickness to be applied.

2. Substitutions: No substitutions allowed, except as requested by the Manufacturer/Supplier of the product and the Engineer.

MATERIALS

A. Carbon fiber reinforced plastic (CFRP) laminates

MBrace Fiber Reinforcement Systems supplied by Master Builders, Inc. are considered to conform to the requirements of this specification.

B. MBrace Primer

The MBrace clear epoxy primer is a low viscosity, 100%solids epoxy compound. When applied to concrete the surface is upgraded to give high tensile bond strength to the system being used. Use MBrace primer in compounds for filling air voids and bug holes in concrete walls.

C. MBrace Putty

MBrace putty adhesive is a 100%solids, nonsag paste epoxy material. Recommended uses include sealing surfaces prior to epoxy injection, bonding of rigid materials, and leveling uneven surfaces prior to application of the MBrace system.

D. MBrace Fiber Reinforcement Systems and MBrace Saturant resin

MBrace Fiber reinforcement materials are enveloped in MBrace saturant resin to yield a range of high performance features.

E. MBrace Topcoat

MBrace Topcoat is a decorative and protective coating for metal and concrete in environments where moderate to severe corrosion conditions exist.

EXECUTION

A. General preparation for Application

1. Ambient temperature. Conditions of CFRP process application must be examined carefully during the winter season and/or cold zones. Do not apply CFRP when ambient temperatures are lower than 5 degrees C. Auxiliary heat may be applied to raise surface and air temperature to a suitable range. Utilize "clean" heat source (electric, propane) so as not to contaminate bonding surfaces. Follow manufacturer's recommendations concerning specific environmental conditions such as concrete and air temperature, dew point and humidity values.

2. Condensation. Presence of moisture may inhibit adhesion of primer and/or resin. Do not apply CFRP when rainfall or condensation is anticipated.

3. Handling of Primer and Resin. Refer to Manufacturer's specifications. Do not dilute primer and resin with organic solvent. After the resin has been mixed with hardener, the mixed resin batch must be used within its batch-life. The mixed batch resin must not be used after expiration of its batch-life as increased resin viscosity will prevent proper impregnation of CFRP sheet.

4. Handling of Carbon Fiber (CFRP) Sheet. CFRP Sheet must not be handled roughly. CFRP sheet must stored either by being rolled to a radius greater than 300 mm or by being stacked after cutting. When multiple lengths of CFRP Sheet are adhered to a concrete surface, a 100 mm overlapping length must be applied in the longitudinal (fiber) direction. No overlapping is required in the lateral direction. For multiple overlaps, the lapping areas shall be distributed through the surface and shall not be coincident through the thickness.

B. Preparing the substrate

Disc sander, abrasive blasting or scarification to remove laitance and surface contaminants are required. Concrete must be thoroughly cured, free of oils, curing solutions or mold release agents, dust and must be dry at time of application. The moisture content of the surface, determined by ASTM D 4263, must be less than 5%.

Any steel reinforcement shall be cleaned and prepared thoroughly by abrasive cleaning, and the area patched prior to installation of CFRP laminates. Any deteriorated concrete or corroded reinforcing steel must be repaired according with the International Concrete Repair Institute (ICRI) guidelines, document No. 037730 "Surface Preparation for the Repair and Deterioration Concrete Resulting from Reinforcing Steel Corrosion". Do not cover corroded reinforcing steel with CFRP.

Leveled surfaces shall not deviate more than 3 mm every 300 mm. The surface profile shall not have deviations larger than 3 mm. Existing uneven surfaces must be filled with an appropriate cement based repair mortar. Protuberances greater than 1mm shall be ground or chiseled off. The strength of the interface between the repair mortar and the original concrete shall be at least 1.4 MPa using ASTM D-4541. The compression strength of the repair mortar shall be at least the same of the original concrete. MBrace Putty shall be used to fill small depressions and bug holes.

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 surface.

C. Application of MBrace Putty

Mechanically premix MBrace Putty resin (part A) individually and prior to adding hardener. After initial mixing, add MBrace Putty hardener and mix three minutes or until homogeneous. Apply the MBrace Putty adhesive to the substrate using a spring-steel trowel or other suitable implement. The application thickness and subsequent coverage rates will be highly dependent on the condition and profile of the concrete substrate. Surfaces shall be topcoated within two days to assure proper adhesion of the MBrace system to the substrate.

D. Application of Primer

Mix 3 volumes MBrace Primer Part A to 1 volume MBrace primer Part B. Mix for about 3 minutes. Agitation shall be by means of electric hand mixer. Use brush or short nap roller to apply two coats of MBrace Primer. Coverage may vary depending on the density of concrete. Alternatively, the primer may be spray applied with airless spray equipment, followed immediately by thorough back rolling 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 nonporous film in the surface not to exceed 50 micrometers in thickness after full penetration.

MBrace primer cures slowly at lower temperatures. Refer to manufacturer for working time, recoat time and time to be able to sustain traffic. Surface irregularities caused by primer coating must be ground and removed using disk sander, etc. if any minor protrusions on the concrete surface still remain, such surface defects may be corrected again using epoxy resin base coat-filler as needed.

When the primer coat has been left unattended for more than one week after the application, the surface of the primer coat shall be roughened using sandpaper. Do not wipe with solvent.

E. Cutting the laminate.

Carbon fiber sheet must be cut beforehand into prescribed sizes using scissors and/or cutter. The size of CFRP sheet to be cut is preferably less than 3 m in length, but may be longer if access allows.

F. Preparation of laminate

Surface should be wiped clean using appropriate cleaner. Using a clean white cloth wipe down the side which is to receive adhesive (this side is not labeled) with acetone until all residual carbon dust is removed (i.e. the white cloth remains white after wiping the laminate). In case where the design requires 'stacking' of the strips the bottom surface of the strip (which is labeled) should be lightly sanded prior to the application of the second strip.

G. Mixing MBrace Saturant resin

Mechanically premix the MBrace saturant resin (part A) individually prior to adding hardener. After initial mixing, add MBrace saturant hardener (part B) and mix one minute or until homogeneous. The mix ratio is 3 to 1 (parts A to part B) by volume.

H. Application of MBrace Saturant resin to the substrate

Apply neat MBrace saturant material to the primed substrate or to the MBrace CF 130 tow sheet as a prime coat using a roller, 9.5 mm nap recommended. Thickness should be approximately 500 micrometers. The color of the MBrace saturant material should be translucent blue.

I. Applying the laminate to the prepared substrate

The CFRP sheet is placed fiber side down onto the concrete surface onto which the wet saturant coat has been applied. After smoothing down by hand, the backing paper is peeled away. The surface of adherent CFRP Sheet must be squeezed in the fiber longitudinal direction using a deforming roller and rubber spatula in order to impregnate resin into the CFRP Sheet and to defoam the resin coat. At the overlapping location, additional resin shall be applied to the outer surface of the Carbon fiber sheet layer to be overlapped.

The CFRP sheet shall have a minimum of 30 minutes between application of sheet into first coat of wet saturant on the concrete and the application of the second coat. This is to allow epoxy impregnation. After 30 minutes apply a topcoat of MBrace saturant resin using a roller, 9.5 mm nap. This topcoat must be applied in fiber longitudinal direction, in order to impregnate and replenish resin into CFRP sheet using a roller in the same film thickness as detailed in item H above. The black tow sheet should be visible. The color of the application will vary due to overlaps and slight thickness variations. Overlap areas should also be translucent.

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 of gelling.

In case more than one layer of CFRP sheet must be laminated, the processes as detailed in sections H through I must be repeated. MBrace Topcoat and MBrace Topcoat ATX shall be used when the system will be subjected to sever and light duty environmental conditions. Brace Topcoat FRP shall be used for fire/smoke protection.

The work must be protected from rain, sand, dust, etc. by using protective sheeting and other barriers. Curing of adherent CFRP must be for no less than 24 hours.

J. Repair of Defective work

Repair of all the defective work (delamination areas) shall be done after the minimum cure time for the CFRP laminates. Comply with material and procedural requirements defined in this specification. Repair all defects in a manner that will restore the system to the designed level of quality. The Engineer 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 Engineer.

K. Testing of the Installed CFRP Laminates

Test all the repaired areas to check for voids, bubbles and delaminations. Repair all voids, bubbles and delaminations by approved methods per Manufacturer's direction.

L. Quality Control and Inspection

1. A qualified representative shall observe all aspects of onsite material preparation and application, including surface preparation, resin component mixing, application of primer, resin and CFRP Sheet, curing of composite, and the application of protective coatings.

2. Inspection for Voids/Delaminations. After allowing at least 24 hours for initial resin cure to occur, perform a visual and acoustic tap test inspection of the layered surface. Large delamination (larger than 1300 mm^2) shall be marked for repair. Voids between 1300 to 16,00 mm^2 shall be repaired by resin injection. For larger voids, the damaged reinforcement area shall be cut around the perimeter and peeled off the surface. The surface shall be smoothed with MBrace putty, primed, and additional MBrace plies shall be applied (with 100 mm overlap) onto the surface and cured in place.

3. Report. The representative shall submit report to the Engineer. Contents shall include both in-process and final inspection details. Contents (as suggested in a private communication with the manufacturer's representative) shall include but may not be limited to:

- Ambient conditions at application.
- Tap test-scanning nap.
- Number and directions of plies applied.
- Cured resin cups.
- Laminated/cured FRP panels.
- Results of tension and pull off tests
- Surface hardness readings.
- Laminate thickness

MEASUREMENTS AND PAYMENT METHODS

Payment for the CFRP sheets on concrete beams will be based on the area of concrete surfaces covered by the sheet and shall include all costs to furnish and install all layers of the sheet, including materials and labor. The cost of preparing the concrete surface for application of the FRP wrap is included in the payment. Individual layers of the sheet will not be paid for separately.

Item	Pay Unit
Carbon FRP Sheet	Square meter

Chipping and patching of deteriorated beams shall be paid for separately.