BEST PRACTICES FOR USING FRP IN STRENGTHENING CONCRETE STRUCTURES

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INTRODUCTION

The use of fiber-reinforced polymers (FRP) as reinforcement for concrete structures is quickly gaining attention and adoption. They are lightweight, have high strength-to-weight ratio, simple repair techniques, corrosion resistance, and these require less rework on existing structures. These factors are advantageous in the rehabilitation of concrete structures. The rehabilitation and protection of concrete has been a consistent challenge in many chemical containment and severe-service immersion environments. In a number of other environments, exposure to marine and environmental conditions are just as harsh over a longer period of time.

The performance of an FRP system is highly dependent on the quality of the installation. Project specifications must clearly define tested and accepted FRP systems and the requirements for the specialty contractors who perform the work. The personnel installing the FRP systems should be experienced and certified by the system manufacturer to ensure that they have been properly trained. It is common to find these important specification requirements copied and pasted from other specifications and not applicable due to the lack of understanding for addressing issues that arise from utilizing FRP in the field. Specifications must also outline requirements for documented experience, references, and acceptance criteria for final inspection. Examples of these requirements are listed in ACI 440.2R[1] and ASME RTP-1[2] which are considered comprehensive documents that deal primarily with FRP construction for different industries.

SURFACE PREPARATION

To ensure optimal utilization of the unique strength characteristics of FRP reinforcement, proper application procedures should be outlined and followed.

The surface must be prepared by removing all loose materials, laitance and other bond-inhibiting materials in accordance with SSPC-SP 13/NACE No. 6[3], and provide a minimum surface profile of ICRI CSP 4 - 5 (Fig. 1). ICRI 310.2R[4] should be used as a guideline for achieving the required substrate profile. Cement laitance at the concrete surface must be removed by abrasive blasting or mechanical abrasion, and the resulting surface vacuumed to remove dust that might negatively affect the adhesion of FRP to the concrete. Additionally, in the case of new concrete, it must be properly cured for a minimum period of 28 days.

Fig. 1: Concrete pillar prepared to an ICRI CSP 5 in the test area

Surface preparation and finish requirements are critical issues for FRP applications. If not properly considered, both can have detrimental effects on performance and cause an issue with lack of adhesion. Careful consideration must be given to the proper surface preparation. Sharp corners, bugholes, and other substrate defects can have a large cost impact because they must be removed by grinding. Cracks or spalls will also add to the project cost as they must be repaired before FRP reinforcement can be applied. It is also important to note that adding mortar or waterproofing layers on the concrete substrate, before applying the FRP reinforcement, may also result in a lower adhesion to the surface, which may affect the longevity of the reinforcement over time, especially if temperature changes are dramatic within the region.

APPLICATION

The polymers used to wet out the fabric consist of both a resin and hardener. The resin-to-hardener ratio is critical and should be confirmed with the manufacturer prior to mixing (Fig. 2 shows improper mix results). This formulation also changes with ambient temperature since the gel times (pot life) will vary and the working time will decrease dramatically when temperature increases.

Fig. 2: Improper mix ratio of FRP resulted in failure

The primer is usually applied to the surface before adding the FRP layers to promote adhesion. When wetting out the mat with resin, all areas of the mat must be fully saturated with resin to prevent dry spots and air bubbles forming in the interface. Fully saturating the carbon or glass fiber is recommended. Pre-wetting the fiber before installation and using a primer is necessary to help with the adhesion to the substrate, as shown in Figure 3. The bonding of the fiber to the substrate is affected by immersing the fiber in a matrix of epoxy resin or other types of resin for the desired performance criteria. The substrate to which the FRP is to be adhered must have sufficient strength to transfer the load from the FRP to the structure. This can be an issue when concrete quality is poor or in bad condition and does not achieve the recommended 4000 psi (27.6 MPa) compressive strength. Mechanical means may also be employed to ensure the laminate bonds securely to the substrate.

The moisture condition of the substrate can have an effect on the bonding of the FRP. If the substrate concrete isn't adequately conditioned with water to a saturated surface dry condition, the moisture imbalance will cause the water to penetrate through the concrete surface to the FRP coating, resulting in osmotic blistering. It is also important to point out that it is best to apply laminate on top of concrete when it is cooling down in order to prevent off-gassing that may interfere with the adhesion strength. As with any application of coatings on top of concrete, moisture plays a large role in the recommended time for application in humid environments. This is why it's important to use a moisture meter to ensure water will not interfere with the adhesion strength. Either way, the bond strength can be weakened at the interface if the surface is wet or not fully cured.

QUALITY CONTROL

Quality control of the FRP reinforcement is important during its application. Usually, a visual inspection, thickness measurements, cure testing, and bond strength testing are a few of the measures implemented. The finished FRP surface should be level and smooth without any defects, such as cracks, wrinkles, voids, sagging, delamination, dry spots or fiberglass fibers exposure. Both the edges and the overlap areas should be bonded tightly and evenly. The mesh of the fiberglass cloth should be fully filled with epoxy adhesive.

Fig. 3: Proper resin wet-out saturation

ASME RTP-1 and ACI 440.2R provide additional information with respect to inspection and testing. Defect criteria are listed in these documents and ASTM C582[5], with respect to the acceptable amount of air bubbles, voids, wrinkles and inclusions. After the FRP resin is completely cured, hardness should be measured at three evenly distributed points along the surface using the barcol hardness meter as shown in Figure 4. In order to ensure an adequate cure, the barcol hardness measurement should not be less than 30 in accordance with ASTM D2583[6]. In addition, an acetone wipe test should also be performed to ensure the resin has fully chemically cured. The manufacturer will provide the end user with the necessary information regarding the performance and hardness values for verification.

According to ASTM D7234[7], the tensile pull-off adhesion test should be used to measure adhesion strength and to verify that the acceptance criteria has been met. This test procedure includes adhering a test dolly to the coated surface (Fig. 5) and pulling the dolly by exerting a tensile force perpendicular to the surface in an effort to remove the dolly with the FRP laminate attached from the substrate. It is recommended that a two-part epoxy adhesive be used for this test because regular moisture cured adhesive may result in adhesion failures. The force at which failure occurs, and the type of failure mode obtained, is recorded as a measurement of the tensile bond strength properties.

TESTING PROGRAM

To illustrate the performance of these techniques, new concrete blocks were prepared with different ICRI concrete surface profiles using mechanical power tool techniques and abrasive-blasting methods. These blocks were primed with a high-elongation primer and an epoxy vinyl ester resin matrix with 1.5 ounces (44 ml) Type E chemical resistant (ECR) glass reinforcement mat.

The table (Fig. 6) shows the results of the adhesion testing.

The favorable results seen from the test program show the importance of surface preparation and laminate quality. It is also important to point out that the results from these tests can vary dramatically due to the irregular consistency of the concrete substrate. As a result, utilizing a standard deviation formula between results is important and should include a maximum variance of less than 29%. If the variance is over 29%, then more tests need to be performed to meet the minimum requirements as referenced in ASTM D4541[8]. Values above 200 psi (1.38 MPa) are considered marginal and values between 350-500 psi (2.41-3.45 MPa) are recommended depending on the concrete quality. Consulting with the material manufacturers is highly recommended to compare field results with lab tested values.

Fig. 4: Barcol hardness test for resin cure

Fig. 5: 2.0 in (50mm) test dolly adhered to a prepared FRP laminate

Method of Surface Preparation	Adhesion Strength (psi/MPa)	ICRI CSP
Mechanical Abrasion	542 (3.74)	3
Mechanical Abrasion	515 (3.55)	3
Mechanical Abrasion	592 (4.08)	3
Mechanical Abrasion	425 (2.93)	2
Abrasive Blasted	724 (4.99)	4
Abrasive Blasted	700 (4.83)	5

Fig. 6: Adhesion strengths for different types of surface preparation and ICRI CSP

CONCLUSION

There is no doubt that demand for FRP materials will continue to grow, as designers have become more and more comfortable with using FRP materials. Still, end users and contractors must remain aware of the challenges that the technology has with respect to concrete reinforcement. Without the proper attention to detail, there can be major issues and failures that affect the longevity. For a successful FRP reinforcement project, it is imperative that the correct application and quality control procedures be employed during the process and verified by qualified professionals before final approval. Given detailed specifications, clear expectation requirements, quality assurance through inspections and properly-trained and certified applicators, FRP strengthening can provide a great value to owners for many years to come.

REFERENCES

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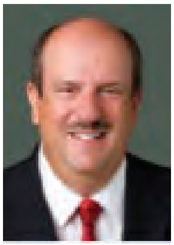

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