FRP 101

A Guide for Composite Strengthening

EDGE
STRUCTURAL
COMPOSITES

STRENGTH THROUGH TECHNOLOGY

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FRP composites are, as the name suggests, a composition of two or more materials which, when properly combined, form a different material with properties not available from the ingredients alone. Depending on the ingredients chosen and the method of combining them, a large variety of properties can be achieved. A brittle material can be made more ductile (flexible) by adding a softer material; conversely a soft material can be made stiffer. Wood is a good example of a composite. The cellulose fibers provide the strength and are held together by the resin (or sap). Reinforced concrete is another example. The steel re-bars provide excellent tensile strength and the concrete provides compressive strength and transfers the load between the steel bars.

Modern composites or FRP (Fiber reinforced polymers, or plastics) are the newest addition to the structural engineer's toolbox. Although the materials have been available for decades, a reduction in cost, combined with newer understanding of the versatility and benefits of the material properties, has allowed composites to move into mainstream construction.

Any material can be used for building a structure, even paper! The difference is in the properties of the material. For instance, steel and concrete are preferred over other materials because their properties allow for strong, yet compact elements. Even though paper could, in theory, be used, it is impractical because the columns would take up so much space that there would be no room for occupants!

Composite design, based upon well-established engineering practices, have different material and offer a number of distinct advantages over traditional repair and strengthening methods.

COST

Although composites are more expensive per pound than steel or concrete, significant savings on the overall cost of a project are realized for a number of reasons:

- Composites add little or no additional weight to a building, eliminating the need for costly foundation strengthening.
- Since composite strengthening is very thin (usually between 1/16″ and 1/8″) there is no loss of floor space and negligible or no change to the inner and outer shape and appearance of the structure. This makes it an ideal choice for historical structures.
- The application of composites is generally much faster than traditional materials and requires no heavy, noisy machinery. This allows the building to remain in use during the application.
- Composites do not corrode or rust making for a long lasting, no maintenance repair.

HISTORY

Structural adhesives as we know them today were first developed during WW2, primarily for bonding aircraft parts together. In the late 1940's the first fiberglass came on the market. Engineers soon realized that combining the glass with the adhesives was opening up a wealth of possibilities for new structural designs. Much of the development was driven by the aerospace industry during the cold war. New, stronger adhesives and resins were developed and new fibers such as Carbon fiber and Kevlar were commercialized.

The new materials were getting stronger and lighter and many different combinations were tried to allow the composites to perform specific functions and to operate under any conditions and environments.

By the 1970's the cost of the composites had dropped to a level where they became a viable choice for non-aerospace applications. Many automobile parts and boats were built with composites, Sporting goods such as golf clubs, bicycles, tennis racquets and fishing poles soon became common.

In the mid 1980's Dr Urs Maier from the Swiss national laboratory experimented with bonding composites to concrete beams and decks. Encouraged by the amazing results, he also wrapped columns and many other elements of a structure. The Japanese civil engineering community soon realized that this was the answer to their severe earthquake threat and they were the first to fully commercialize composites for repair and retrofit. To date many thousands of structures have been strengthened in Japan and it is now the material of choice for seismic strengthening.

The delay in getting composites widely accepted in the US construction industry is mainly due to the conservative nature of the engineering community. It took a few years of intensive research for standards to be set. The American Concrete Institute has now issued an extensive guide for the use of composites (ACI 440F). The ICBO (International Conference of Building Officials) has issued an acceptance criteria for composites and guides are being prepared by ASCE (American Society of Civil Engineers) and TMS (The Masonry Society). DOT's including Caltrans have issued or are in the process of issuing criteria for strengthening and repairing bridges, including entire bridge decks made from FRP composites and FRP re-bars.

Full scale structural testing of composites on columns, slabs beams and walls have clearly demonstrated the effectiveness of composites. In addition, many hundreds of research papers from the world's best universities have been published, supporting the of composite materials in construction.

WHAT ARE COMPOSITES?

FRP composites, as they are used today, consist primarily of two materials, fibers and a resin matrix. The fibers provide the strength and the resin matrix holds them in place and transfers the load evenly amongst the fibers. The resin also protects the fibers and bonds them to the surface, transferring the load from the structure into the fibers. The two most common fibers used are E-Glass and Carbon Fiber. Epoxy has been found to be the best resin.

E–GLASS

E-Glass is produced by melting a form of glass (Borosilicate) in a large vat. The molten glass is drawn through tiny platinum holes and cooled until it forms a thin fiber. The fibers are then cleaned and a chemical is applied to the surface to protect the fiber and promote adhesion to the resin. Once it has cooled it is gathered into bundles, which can then be woven into a fabric. Although E-Glass is cheaper than Carbon Fiber, the reduced strength requires 3 to 4 times as much material to achieve the same result. The extra material and labor makes E-Glass about as costly as Carbon. There are, however, certain applications where the properties of E-Glass make it the material of choice. Blast mitigation is one example.

CARBON FIBER

Carbon fibers are produced by carbonizing a pre-cursor fiber. The pre-cursor is usually PAN (poly-acrylonitrile) which is very similar to rayon. Some pre-cursors are made from pitch, but they produce an inconsistent lower grade carbon. The pre-cursor is drawn through an oven at about 2000∞ in an inert atmosphere and tensioned. The amount of tensioning and temperature determines the strength and stiffness of the fibers. Once all of the impurities have been burned off, the fiber is pure carbon. This is then cleaned and a chemical is applied to the surface similar to E-Glass. Once bundled, the fibers can then be woven into a fabric. Carbon fibers are very small, usually about 7 microns in diameter or approximately 5 million fibers per square inch!

The dry carbon fibers have about 10 times the strength of steel, 650,000 lbs per square inch. Once mixed with the resin, this drops to approximately 150,000 to 200,000 lbs per square inch, still significantly stronger than steel.

ARAMID FIBERS

Aramid fibers are extremely tough, high strength fibers made from an aromatic polyamide. DuPont's KEVLAR, is an example, and is often used in bullet resistant jackets. Although strong, aramid fibers have some characteristics, which make it less desirable for strengthening. For one, the fibers are hydroscopic, meaning that they tend to soak up water, and should only be used when they are completely protected from the environment. The fibers themselves are quite abrasive, and under repeated loading they can abrade against each other, weakening the laminate. Aramids are extremely difficult to cut, usually requiring specialized tools such as ceramic shears. One area that aramids excel is when they are incorporated into a blast mitigation upgrade.

EPOXY RESIN

Epoxy resins are two part polymers, which, during the cure, form strong molecular chains. They can be customized to produce any possible combination of properties such as high tensile strength, which tends to be brittle with low adhesive strength, or lower tensile strength resins with very high adhesion. For most strengthening needs high adhesion is the most important factor since the fibers have such high strength themselves. Epoxies are easy to mix and apply and have little or no odor. They have no VOCs (volatile organic compounds) and are not flammable. Cured epoxy is inert, making disposal easy. Overall epoxies are the most environmentally friendly resins available.

FIBERBOND PRODUCTS

FRP materials for use in the construction industry fall into two basic categories: cured-on-site and pre-cured. One analogy would be the difference between cast-in-place concrete and pre-cast concrete. The pre-cured is produced in a controlled, consistent way and is easily repeatable and shortens time on the jobsite, but does not adapt well to changes or differences encountered once on site.

Pre-cured composites can be either embedded in the structure, (FRP re-bar for example), or can be bonded on site to the structure.

The cured-in-place takes a little longer and is slightly less consistent, but it allows a lot of flexibility and adaptability on the jobsite and is much more versatile. Cured-on-site FRP composites can be used on a variety of surfaces and in very difficult areas, and are always bonded to the surface.

HOW DO THEY WORK?

The real advantage to using composites for strengthening or repairing buildings and bridges is that they can be designed to make the structure behave exactly as needed. Unlike steel, which is equally strong in all directions, composites have their strength in the direction of the fibers only and can be engineered to place the strengthening only in the direction needed. For example, a reinforced concrete column strengthened with steel or additional concrete not only increases the load the column will take but also stiffens the column, which is undesirable for seismic strengthening. FRP composites can be applied so that the column can be made more flexible (up to 7 or more times) or it can be made to take a greater load OR any combination of both flexibility and increased capacity.

Composites can also stiffen a structure where needed. Applied underneath a beam or deck they will allow much higher live or dead load without increasing the amount of flexure.

In a retrofit, the FRP does not take the load of the building. They allow the concrete and steel to work more effectively. For example concrete is excellent in compression but poor in tension. The application of FRP composites to concrete prevents tensile failure, which leads to failure of the reinforcing steel. On a column the steel takes the flexural load and the concrete holds the steel in place. In a seismic event, as the column flexes, one side is in tension, where concrete is poor and the other in compression. Cracks and holes will appear on the tension side. As the column flexes back the damaged tension side then gets in compression and the broken concrete falls out. As it continues to flex, more and more concrete cracks and falls out until there is not enough to hold the steel together and the steel buckles out. The FRP wrap confines the concrete and prevents it from falling away, which allows the steel to continue to flex and hold up the structure.Masonry often fails in a similar manner. The mortar has good compressive strength but no tensile capacity. As the wall bends the mortar on the tension side fails and the wall buckles more until the weight forces the wall out and it fails. Applying composites can increase the amount a masonry wall can flex by up to 45 times! This is because the composites, which have excellent tensile strength, prevent the mortar from failing.

TYPICAL INSTALLATIONS

Fiber Bond FRP composites are highly versatile and can be used on many different structures to achieve a wide variety of results. They are usually applied on concrete, masonry or wood. They can be used on other materials including steel, but those applications are not covered in this course or manual. FRP materials are used on a wide variety of different structural elements, not as some kind of voodoo material, but as an effective alternative to traditional materials.

Some typical reasons for strengthening with FRP are:

- **SEISMIC & WIND LOADS**. In an earthquake or high winds, a structure needs to be flexible to absorb the movement, but adding weight to the structure can increase the mass and therefore the chance that it will fail, which makes FRP an ideal choice.
- **CHANGE OF USE**. Sometimes a structure needs to perform in a manner that it wasn't designed for and needs to be strengthened to take the additional or changed loads. For example, adding heavy machinery to a roof.
- **CONSTRUCTION OR DESIGN ERRORS**. Sometimes long after a job has been completed, it is discovered that a contractor has left out some steel or the concrete wasn't what was specified or the engineer makes a mistake in the drawings. Fiber Bond FRP can be used to 'replace' missing steel or compensate for low concrete strength.
- **REPAIRS**. Some structures degrade simply due to time and environmental factors and with careful preparation can be restored to their original capacity or greater.
- **BLAST MITIGATION**. FRP materials are perfect for protecting structures from explosions, like bombs or industrial accidents, and preventing projectiles from damaging the structure. This application requires special design and use of different fibers and resins than are covered in this manual.
- **CORROSION**. Fiber Bond FRP is highly resistant to chemical degradation and can be used to repair and protect structures from aggressive chemical or environmental attack.

On columns, for example, wrapping FRP around the outside with the fibers horizontally is like adding more confining hoops. This prevents the vertical bars from buckling and allows the column to flex more or carry additional loads. This is the most common application on columns. Adding the FRP vertically adds to the stiffness of the column without adding to its load bearing capacity. Thus, using a combination of the two, the desired effect can be achieved. FRP can be applied to many different shapes of columns but it is most effective on circular columns & least effective on rectangular columns, where more layers may be needed.

Fiber Bond FRP composites are also very effective on both masonry and concrete walls. These installations are usually used to increase the flexural (bending) strength or the shear (tearing apart) strength. FRP does not usually increase the load bearing capacity of walls.

On floors or slabs, FRP can increase both the load bearing capacity and flexural strength of slabs. For example when columns are removed from the floor below or the load on the slab is increased, when a cutout has to be made, the FRP can be used to transfer the loads around the cutout, even when some of the re-enforcing steel has been cut.

Fiber Bond is often used on beams for flexural and shear strengthening. In a flexural application the FRP is usually applied to the bottom, and sometimes up the sides of the beam with the fibers running along the length of the beam. This not only increases the amount that the beam can flex, but also allows the beam to take more load. For shear strengthening, the FRP is applied in stirrups across the beam or perhaps at a 45∞ angle.

Some of the strengthening applications that you may see are:

- BRIDGES
- BUILDINGS, MASONRY, CONCRETE & STEEL FRAME
- PARKING GARAGES
- CHIMNEYS
- WATER TANKS
- INDUSTRIAL CONTAINMENT FACILITIES
- SILOS
- RETAINING WALLS
- TOWERS
- SUPPORT SLABS

FIBERBOND INSTALLATION GUIDE

1. STRUCTURE PREPARATION

Basic repairs must be made to the structure prior to strengthening with Fiberbond. Spalled concrete removed, corroded or damaged steel addressed and major cracks injected.

2. SURFACE PREPARATION

The surface to be repaired is typically abraded to smooth out irregularities, remove contaminants and radius sharp corners. This can be performed by shot or sand blasting, water jet or grinder.

3. PRIMER

In order to promote adhesion and prevent the surface from drawing resin from the FRP, a low viscosity epoxy primer is applied with a roller until the substrate is locally saturated.

4. PUTTY

An adhesive, high viscosity putty is applied when necessary to the surface to fill in 'bug holes' offsets or voids.

FIBERBOND INSTALLATION GUIDE

5. CUTTING FABRIC

In a clean area away from the resins, the fabric is carefully measured and cut in accordance with the specifications.

6. SATURATING FABRIC

On large, high volume projects, the fabric can be saturated using Edge Structural Composites' custom saturator. For lower volumes & shorter strips, the fabric can be either saturated on a table, or the surface can be coated with resin and the dry fabric applied.

7. APPLYING FABRIC

The pre-wetted, or dry, fabric is carefully laid onto the surface and smoothed out to remove air bubbles and ensure that the fibers are straight.

8. QUALITY CONTROL MONITORING

During the cure, 2 to 6 hrs depending on ambient conditions, the fabric is checked to ensure that all air bubbles are removed and that the fabric is not sagging. Edge Structural Composites highly recommends that a trained, qualified inspector monitor applications.

9. QUALITY ASSURANCE

Good record keeping in accordance with Edge Structural Composites QA/QC procedures ensures a successful repair.

10. TOP COAT

Once cured and inspected, Fiberbond can be coated with any coating, for aesthetic blending and low maintenance protection.