INTRODUCTION

1. Fiber-reinforced polymer (FRP) composites are constructed from high strength, high modulus fibers and a liquid resin or matrix that cures to form a hardened solid structural material. These materials are often used to construct commercial and military aircraft, boats, and various sporting goods (bicycles, fishing rods, skis and snowboards, etc.).

2. The fibers used with these materials are most commonly:
   a. Carbon fiber of various strengths and stiffnesses
   b. Glass fiber of various types (most commonly E-glass or S-glass)
   c. Aramid fiber (Kevlar® is a widely known brand of aramid fiber)
   d. Basalt fiber

The fibers are typically woven, stitched, or bundled together and supplied in various width fabrics that are field- or pre-saturated in resin. The fabrics can be unidirectional (i.e., the fibers running in the same direction) or multi-directional. The material properties of the system are related to the direction of the fibers and the density of the fiber strands.

3. Resins used to laminate the fabrics and adhere it to the structure vary but are generally:
   a. Epoxy resin (most often used)
   b. Polyurethane resin
   c. Polyester resin
   d. Vinyl ester resin

4. FRP composite systems are most often used on reinforced concrete, masonry, and wood structures as external reinforcement to supplement or restore the structural capacity of a member.

5. The most common strengthening applications achieved with FRP are:
   a. Strengthening structures in flexural and shear zones
   b. Providing confinement to compression members such as columns

FEATURES AND BENEFITS

1. FRP systems can be utilized to:
   a. Increase load bearing capacities of structures
   b. Repair damaged/deteriorated concrete or masonry structures to restore capacity
   c. Seismically retrofits of existing structures by increasing lateral load resistance of members
   d. Provide blast mitigation

2. Some advantages are:
   a. Adds minimal mass to the structure
   b. Minimizes service interruption
   c. Cost effective application
   d. No loss of head room or space
   e. Ease of application
   f. Conformable to complex geometries

3. Potential drawbacks are:
   a. FRP is typically not fire-resistant and therefore sacrificial during a fire event. Fire protection can be applied over repaired/strengthened areas to ensure the capacity of the structure is not compromised due to fire exposure.
   b. FRP has different ductility than concrete and masonry. As such, it should be designed carefully by knowledgeable professionals who understand the structural interaction between the original member and the FRP. Typically, the design is performed by system manufacturers who have the most extensive experience in the design.
   c. Some FRP resins and reinforcing materials are not resistant to long-term exposure to UV light. As such, the design should consider this limitation. Where the repaired member is expected to be exposed to UV light, the FRP should be coated with a suitable coating.
   d. Cold weather applications are limited to temperatures suitable for proper curing of the resin/adhesive.
   e. Protective coatings must be applied when exposed to UV light.
   f. Fire resistance of the systems is limited as are fireproofing options. Fireproofing will need to be installed over the system.
   g. FRP systems are designed to supplement the existing reinforcing system. They are seldom used as the primary reinforcing.
   h. FRP system installation requires knowledge and experience specific to the system. They must be applied by experienced and specialized contractors.
   i. FRP-system design requires knowledge of the interaction between the structural properties of the substrate and the FRP system. Conventional design methodologies are typically not applicable. In most cases, the system manufacturer has experienced designers who can design the system based on specified performance criteria.
TYPES OF FRP COMPOSITE SYSTEMS

1. Laminate Systems
Laminate systems consist of pre-cured composite materials delivered to the jobsite as a thin, flat plate (usually less than 1/16-inch thick and 2 to 6 inches wide). The laminates are cut to the desired length in the field and applied to the structure with a system-specific adhesive. This system is typically most suited for flat surfaces.

Laminate systems are unidirectional systems of the following types:
   a. CFRP (carbon fiber reinforced polymer), the most common
   b. GFRP (glass fiber reinforced polymer).

2. Wet Lay-up Systems
Wet lay-up systems are comprised of a FRP fabric and saturated with a system-specific resin (most commonly epoxy). The fabrics are constructed of individual fibers that are combined in “bundles” called tows or rovings and woven to form a fabric sheet. The fabric is delivered to the jobsite in dry sheets and saturated in the field using system-specific resins to form the composite system or is delivered as pre-saturated fabric. Wet lay-up systems allow the fiber to conform to round, rectangular, or irregular shapes.

Wet lay-up systems can be unidirectional (primary fibers all along the length of the fabric) or can be woven with fibers in multiple directions (bidirectional or multiaxial fabrics). Typical fabric types are:
   a. Unidirectional and bidirectional carbon fiber fabrics
   b. Unidirectional and bidirectional glass fiber fabrics
   c. Basalt fiber fabrics

3. Near-Surface Mounted Systems
Near-surface mounted systems (NSM) consist of a manufactured composite bar or strip that is installed with an epoxy adhesive into shallow grooves cut into the substrate. The bars are typically small enough to be installed in a groove that is roughly 1/2 inch wide and 1/2 inch deep. These systems are usually used as topside reinforcement on a surface that will receive traffic or wear.

NSM systems are commonly comprised of one of the following types:
   a. CFRP bars or strips
   b. GFRP bars or strips.

INSTALLATION CONSIDERATIONS

1. Surface Prep
   a. Surface must be clean, sufficiently dry, and sound with all surface defects removed or repaired.
   c. Roughen the surface to promote adhesion of the system. Refer to manufacture’s printed specifications to determine the concrete surface profile (CSP) needed for best bond.
   d. Fabric applications require that corners be rounded with all sharp edges removed prior to installation. This will help the fabric form a continuous bond to the substrate and reduce stress concentrations at corners.

2. Application of Laminate Strip
   a. Cut strips to desired length and clean prior to the application
   b. Mix and apply resin to the prepared surface
   c. Mix and apply resin to laminate strip
   d. Apply strip to substrate while resin is wet
   e. Apply pressure to entire length of strip to insure full contact
   f. Ensure full contact is maintained until the resin sets

3. Application of Fabric System
   a. Prime prepared surface per manufacturer’s recommendations
   b. Saturate fabric and apply to the primed substrate. Alternatively, apply resin to substrate and apply fabric into resin, followed by a second resin application. Ensure fabric is fully saturated by resin
   c. Apply multiple layers as required by specifications
   d. Apply protective topcoat to system

4. Application of Near Surface Mounted Systems
   a. Cut FRP reinforcing bars or strips to desired length and clean prior to the application
   b. Saw cut required groove into concrete substrate and clean groove of any residual dirt or debris. Ensure saw cutting does not damage existing reinforcing steel.
   c. Mix adhesive and partially fill the groove. If adhesive is viscous, ensure it is tooled to achieve full bond with substrate.
   d. Install FRP reinforcing bars or strips into groove, ensuring they are fully encapsulated by the adhesive.
   e. Fill any remaining portions of the groove with adhesive and clean any excess adhesive from around the groove.

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