RECLAMATION
Managing Water in the West

Composite Structures for Immersion Applications

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Final Report ST-2016-4182-1

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Mission Statements

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Corrosion of immersed structures creates maintenance problems and expenses, causing loss of revenues related to water delivery and power generation. This is a common Reclamation problem and to date the only solution is additional and ongoing maintenance. The repair is often difficult and expensive due to material replacement and accessibility. The use of composites as a substitute for the traditional metallic materials is not standard or even typical for submerged structures due to the lack of experience and knowledge in Reclamation. Composites have specific properties including high strength-to-weight ratio, resistance to corrosion, durability, and ease of manufacturing making composites more favorable than the traditional materials.

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Executive Summary

Reclamation's immersed infrastructure include small slide gates, radial gates, bulkheads, and stoplogs. Historically constructed of steel and wood, these structures require replacement because of length of service and environmental deterioration. Composites have many favorable properties which make them advantageous for use in such applications including durability, corrosion resistance and high strength-to-weight ratio.

Fiber-reinforced polymers (FRP) have the potential for application in many Reclamation projects, especially in areas where structures are exposed to highly corrosive environments. FRP could replace traditional materials such as cast iron and stainless steel slide gates. FRP is advantageous because of its high strength-to-weight ratio, superior chemical resistance, and flexibility in design. Additionally, these composites have high fatigue resistance and less likely to fail when compared to metals under similar loads [1]. Because of these beneficial properties listed above, structures made of FRP composite materials often have an extended service life with less required maintenance than traditional materials, such as steel or wood. Correspondingly, while some composites currently have a high initial cost, their overall cost (life cycle cost) is often less due to lower installation, maintenance, and replacement costs.

Although many composite structures have been in service for over half a century with little signs of aging, there is a need for more research and trial testing regarding the structural capability and lifespan of these materials in various service conditions. The ability of FRP to be designed for particular conditions and applications ensures efficiency and longer service life.

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Introduction

A composite is defined as a heterogeneous material made from a combination of two or more materials, which when combined, have a unique set of properties [2]. These properties are largely dependent on the initial materials combined to form the composite, but the synergy between these components creates a single composite with superior performance. Thus, composite materials can be designed to have outstanding performance in a specific service environment by choosing component materials that may not be sufficient alone, but produce a “best of both worlds” scenario when combined. Composite have many properties, including corrosion resistance and high strength-to-weight ratio, which make them advantageous for use in submerged infrastructure applications such as small slide gates, bulkheads, and stoplogs. Historically, these structures were built with steel and wood; however, many of these structures are beginning to fail due to long times in service and environmental degradation.

Fiber-reinforced polymers (FRP) have seen broad usage for infrastructure applications. These materials are used both in repair and reinforcement of current installations, as well as the construction of new structures. In addition to flexible design capabilities, FRP are often easy to install in the field, because they are typically lightweight and can be made as a single structure. Most of these structures do not require field welding to connect the various components.

Reclamation has a need for materials that perform well in harsh service environments. Composites like FRP can achieve structural performance similar to or better than steel and wood for many applications, and, unlike steel and wood, they can also resist many types of harsh environments. At Reclamation facilities, materials are potentially exposed to many conditions: such as, wetting and drying cycles, freeze-thaw cycling, corrosive environments, and salt exposure environments. Composites are can be designed to perform well in all of these environments. One disadvantage of FRP is their susceptibility to degradation by ultraviolet (UV) light; however, options exist to resist UV degradation, with one being the addition of UV inhibitors.

Interest at Reclamation

Quite a few Reclamation submerged structures, such as gates, have exceeded their design life and require replacement or repair due to degradation. This is an opportune time to consider composites as a viable alternative to traditional materials. FRP composites have high strength properties while at the same time are typically lighter than other materials, about one seventh the weight of steel and half the weight of aluminum [3]. Reclamation has interest in composite materials that can reliably and cost-effectively replace existing components, while improving durability and reducing maintenance requirements.

Fiber-reinforced polymers have many advantages for low-risk infrastructure applications, including gate guides, small slide gates, radial gates, bulkheads, and stoplogs. In these structures, composites can be used because of their high strength and high resistance to many environmental exposures. Although continued development and focused research into component materials and manufacturing techniques has lowered costs, composites remain more expensive than traditional materials for most applications. However, because of their expected long lifetime and limited maintenance and repair requirements, these materials should be cost competitive with traditional materials over the service life of the structure. Reclamation should consider these life cycle costs on a case-by-case basis when considering composite materials as an option to traditional materials.

FRP Materials, Manufacturing, and Performance

FRP have two main components: the matrix and the reinforcement. The core constituent of all composite materials is the matrix, which for polymer-based composites is made of a resin. The other main component is the reinforcement, with glass and carbon fibers being the two most common types.

Matrix Materials

In a composite material, the resin distributes stress amongst the reinforcement to reduce the overall impact of an applied force. The resin also acts as the glue that holds the fibers together, protecting them from mechanical and environmental damage while maintaining the shape of the composite structure. The resin is responsible for the chemical properties of the composite, while the reinforcement creates the mechanical properties. The most popular resins are unsaturated polyesters, epoxies, and vinyl esters.

Polyester resins are the most popular resins because of their low cost. This polyester backbone is combined with a crosslinking monomer to form the resin material [4]. Styrene is the most common monomer used in this process, although the harmful toxins that it releases during manufacturing must be controlled. Polyester resins are the least resistant to moisture and tend to shrink while curing. There are many different types of polyester resins, each having a unique set of properties. Orthophthalic resin, commonly referred to as the general purpose resin, has strong bonding characteristics which provide good abrasion and impact resistance. Isophthalic polyester resins have very high heat resistance as well as good chemical and moisture resistance. This resin also has high tensile properties and a very fast curing time. It is often used for composites in corrosive environments. Dicyclopentadiene is an additive which is often combined with polyester resins to enhance the cosmetic appeal of a composite and to limit the styrene levels in the production of fiber-reinforced composites [5].

Epoxy resins are also commonly used as a matrix material in FRP. The active sites at each end of the polymer lend to strong matrix-fiber bonding. This gives epoxy resin composites high compressive strength, shear strength, flexural strength, and enhanced toughness. Epoxy resins also have high chemical resistance and good thermal and electrical properties [4]. Composites made with epoxy resins typically require a protective coating to limit UV degradation. While they have a long cure time, these resins have very low shrinkage while curing. Epoxy resins are also expensive, limiting the frequency of their use as resins in composites.

Vinyl ester resins have high chemical resistance and bond well to many types of reinforcement, because of the hydroxyl groups in their chemical structure. These resins are superior to polyester resins in the area of water absorption and do not shrink significantly during cure. Composites made from vinyl ester resins also have good toughness and high fatigue resistance, and are more elastic, yielding good impact resistance. Vinyl ester resins tend to be more expensive than polyester resins, but less expensive than epoxy resins [6].

Polyimides are another type of resin that is used for applications that experience temperatures above 160˚C. Polyimide resins are not commonly used in composites as they have a high water absorbance and break down easily [7].

Reinforcement

The fibers give strength to a composite material (see Figure 1). The most common types of fibers or reinforcement are glass, aramid, polyethylene, and carbon. Aramid fibers tend to be tougher and more flexible than carbon fibers, while carbon fibers are stronger [7]. In addition to giving the composite strength, reinforcement materials can alter the density, thermal expansion, electrical conductivity and vibration dampening of the matrix. Different fibers have different properties, which allow composite manufacturers to design and build composites with a unique set of characteristics. Fibers are thus chosen for a specific purpose in a specific application.

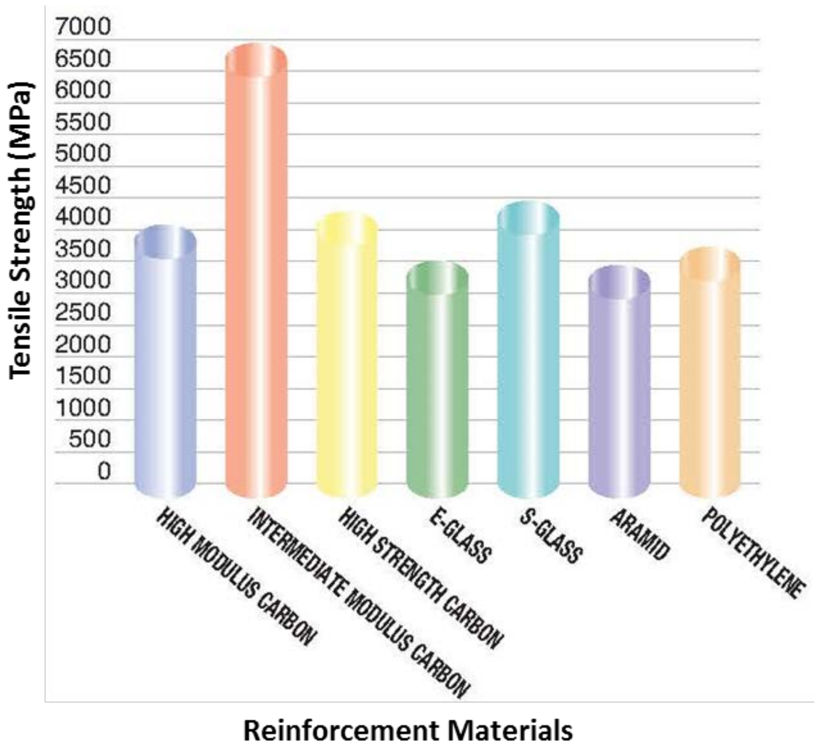


Figure 1. Comparison of tensile strengths of various reinforcement for composite materials such as FRP. [8]

Reinforcement in FRP composites can have many different forms including chopped mats, woven or non-woven fabrics, and surface veils. Within these forms, the fibers can be oriented in three ways; unidirectional, bidirectional, or multidirectional. Fibers aligned in a unidirectional orientation give the composite anisotropic properties. Anisotropy results in high strength in one direction. Woven fabrics are less frequently used because there is a likelihood of incomplete resin impregnation of the fibers. A surface veil can be used as a barrier against corrosion (degradation) by inhibiting micro-cracks on the surface of a composite. These micro cracks can allow water absorption into the resin matrix, leading to fiber degradation and loss of strength. Carbon veils can increase the chemical stability of a composite and are often used to minimize static electricity and to ground a structure.

Glass fibers are very common in composite materials because of their low cost. When compared to other reinforcement materials, glass fibers are very heavy (See Figure 2). Therefore, glass fibers are commonly used in composites with weight-independent applications. Fiberglass is a widely used composite material made with glass fibers. Glass fibers are manufactured by drawing molten glass through holes of varying diameters to produce filaments that are then wound into strands containing 102 or 204 filaments. There are three types of glass used to make the fibers: E-glass, S-glass, and C-glass. E-glass fibers are the most common because of their combination of low cost, high strength and water resistance. S-glass fibers are more expensive, but have the highest strength, while C-glass fibers offer more corrosion resistance (water resistance) [9]

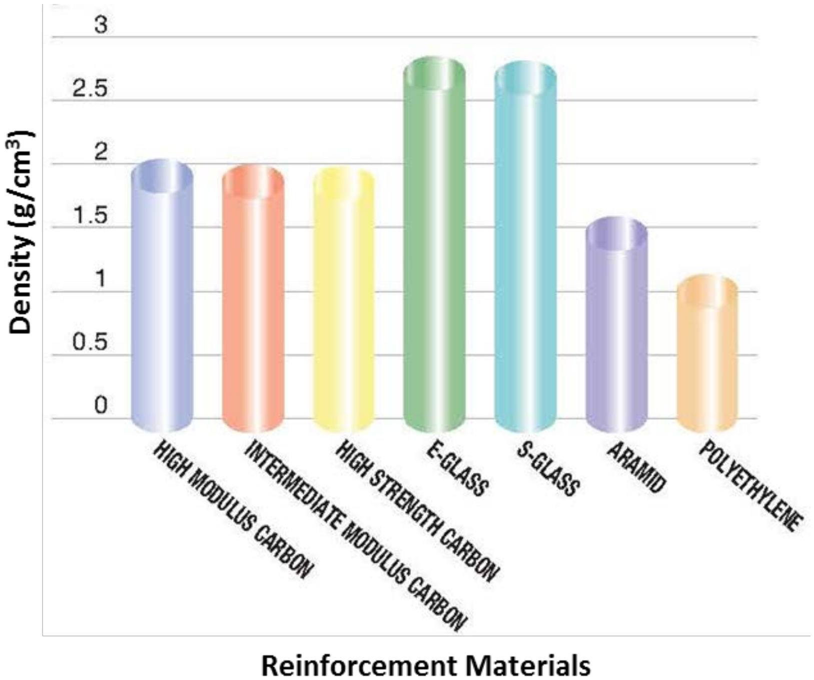


Figure 2. Densities of various reinforcements for composite materials such as FRP. [8]

Carbon fibers are typically used in composites where the weight of a structure is an important factor. These fibers are manufactured through the process of drawing polyacrylonitrile or pitch fibers under high heat and tension and cleaning them in an electrolytic bath. Carbon fibers are very resistant to environmental, chemical and thermal elements. As a result of their ability to withstand high temperatures and their very low weight, carbon fibers are predominantly used in the aerospace industry. These fibers have the highest strength and stiffness of all reinforcement but are not commonly used for small projects because of their high cost.

Additives

Many composite manufacturers offer customizable treatments, additives, fillers, or coatings for special applications or service requirements. Various fillers and inhibitors can be added to improve fire retardancy, mechanical properties, and UV degradation resistance. UV inhibitor is standard for many parts designed for outdoor applications, such as handrails, as is an industrial grade polyurethane coating used for additional protection against fading. Many products can also be colored for inspection, safety, or aesthetic purposes.

Additives are introduced in order to remove or add specific properties to a composite material or to reduce production costs. Possible functions of additives include reducing shrinkage while curing, improving conductivity, sealing molds, decreasing viscosity, improving ultraviolet radiation resistance, reducing vapors, or increasing fire resistance.

Fillers are used to lower the cost of producing composites by diluting expensive resins. Often, pure resins are not required for a composite material to have certain chemical properties, and adding fillers can reduce the cost of the composite material. Fillers can also be used to impart special properties to composites such as reducing shrinkage while curing and improving fiber uniformity [3].

Fiber-reinforced polymer composites are naturally combustible because of the organic composition of the polymer. Thus, fire-retardant additives are very common in many composite materials. Fires involving FRP composites are especially dangerous because they release high quantities of styrene. The most common fire-retardant additives are alumina trihydrate and calcium sulfate, silica, and calcium carbonate [3]. Brominated or chlorinated resins have better fire-retardant properties and are cheaper, but also tend to be more toxic and corrosive. Resins with metal hydroxides and phosphorus-based fire-retardants are less corrosive in composites [5]. Many fire retardant additives lower the mechanical properties of a composite; an important design consideration.

In cases where a manufacturer needs more time to mold the composite before the resin cures, inhibitors and initiators are added. Inhibitors slow the curing reaction by reacting with the free radicals in the resin before they form crosslinks with the fibers. Quinones are typically added as inhibitors [4]. Initiator additives are inserted after the inhibitors. When the initiators are added to a polyester resin, they cause the material to decompose, releasing free radical molecules, which then begin to form crosslinks with the fibers. At a point, the number of initiators forming crosslinks overcomes the amount of inhibitors, enabling the resin to cure by bonding to the reinforcement fibers.

Curing Process

Curing is an important part of the manufacturing process for FRP composite materials. In order to ensure the maximum service life of a composite material, it is imperative that the resin be fully cured before use. Without proper curing, a composite is more susceptible to degradation from moisture and other environmental elements, which will weaken the composite. The reinforcement can be susceptible to weakening for improperly cured composites. During the production of composites, heat and pressure are added to the mold to help speed up the process of curing the resin. Promoters added to the resin, can help accelerate the curing process. These additives are usually cobalt or aniline compounds [4].

There are two main types of resins: thermosets and thermoplastics. The difference between these resins is how they cure. Thermoset resins cure in the shape of the mold when they are heated. These are usually liquid or weak solids in their standard state. Curing a thermoset resin is an irreversible process that permanently molds the composite material into a specific shape. When the resin cures, crosslinks form between the resin and the reinforcement, giving the composite polymer its three-dimensional structure [3]. As a result, many composites with thermoset resins will maintain structural integrity in environments with elevated temperatures.

When thermoplastic resins cure, the composite undergoes physical property changes as opposed to chemical property changes seen in thermoset resins. When heat is added to thermoplastic resins, they become pliable and can be re-molded [3], then cure into a rigid, solid state. Because thermoplastic resins become pliable when heated, it is possible for them to be recycled into a different shape or material. This characteristic makes materials with thermoplastic resins easier to cure. The fluidity of these resins makes it easy to inject them into a mold to form the composite material. These resins are also self-lubricating and therefore have a number of industrial applications. Thermoplastic resins are often used in long, continuous composites as they have a high fracture toughness and impact tolerance, higher resistance to UV radiation, and are easier to manufacture [10].

The glass transition temperature (T_g) is an important property of a composite material. The T_g is an indication of the maximum service temperature at which the composite can maintain its mechanical properties. The T_g represents a softening point below the actual melting point of the material. At temperatures above the T_g of a resin, the strength of the composite decreases. Changes in the matrix of a composite are usually attributed to changes in its glass transition temperature. When a polymer is cooled below the glass transition temperature, it becomes hard and brittle, like glass. Above this temperature, the polymers are amorphous and rubbery [11].

Current Manufacturing Practices

As with the composite materials themselves, there are a number of different manufacturing techniques used depending on the structure and the available resources. When there is a need for the production of high volumes of a composite material, compression molding and pultrusion are the most common techniques. For the production of composites with a unique shape or in cases where there are fewer resources, hand lay-up, vacuum bag molding, or vacuum infusion are the most common manufacturing techniques [12].

In hand or manual lay-up, a mold of the desired structure is coated with a gel, as shown in Figure 3. The reinforcement is cut to size and placed in the mold. A laminating resin is poured into the mold and hand-rolled to remove the air bubbles. This is repeated for however many layers of reinforcement are needed.

The mold is then subjected to the conditions required for the resin to cure and the composite is removed. Hand lay-up enables a person to align the reinforcement fibers manually, ensuring anisotropic properties are in the desired direction. Because of the hand lay-up process, it is difficult to produce large volumes of composite materials using this method [4]. It is critical to perform the work in a timely manner so as to avoid curing of the resin prior to completion of the work.

Figure 3. Manual lay-up process for constructing a composite structure. Photo shows a worker applying resin with a roller to the reinforcing fabric. [13]

The spray-up process sprays resin onto the surface of the mold while simultaneously chopping and spraying the reinforcement onto the mold. The use of a spray gun to add the chopped reinforcement eliminates the ability to specifically align the reinforcement for directional strength in a composite material [14]. Spray-up can therefore only be used to manufacture isotropic composites. There is also a lower concentration of fibers in materials manufactured with this method, thus manual lay-up and spray-up are seldom used for producing structural components. This method also poses a health risk due to high styrene emissions during production.

Another common method for the production of low volumes of composites is vacuum bag molding. This manufacturing process is done in addition to the manual lay-up method in order to remove excess resin and entrapped air. In this process, a flexible film is placed over the composite before the resin has cured. The edges of the bag are then sealed and a vacuum is drawn. In some cases, a fabric is placed over the composite to absorb excess resin. A schematic of the setup is shown in Figure 4. The pressure created by this system also yields a higher fiber concentration in the composite. In addition vacuum bag molding limits styrene emissions during the process [4]. A comparison between a vacuum bagged part and the same part performed using the hand lay-up method is shown in Figure 5. The final product using the vacuum system produced a less shiny and lighter product. Figure 6 shows another finished product produced using the vacuum bag technique and shows how the technique is able to reach the intricate corners of the mold where hand lay-up may have problems.

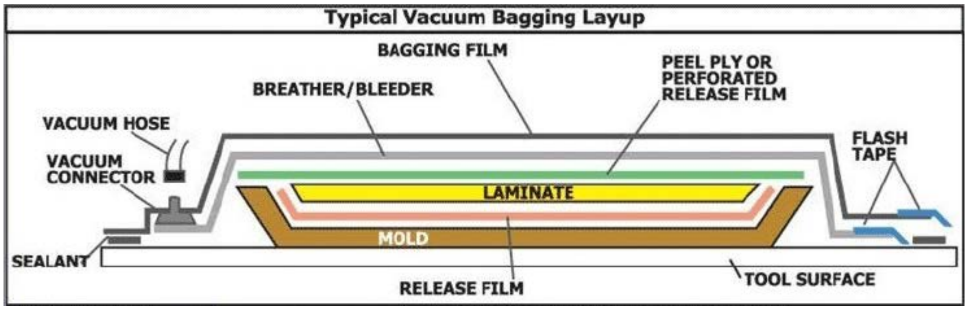


Figure 4. This image shows a method of "bagging without a bag", meaning that the mold itself serves as half of the bag, and the bag material is sealed to the mold, around the flange. Of course, you could just place your entire mold inside a large bag and seal it, too. [15]

Figure 5. The canopy on the left was vacuum bagged. The canopy on the right was a hand layup. The vacuum bagged version has much less resin on the inside, (less shiny) and it weighs 25 percent less. [15]

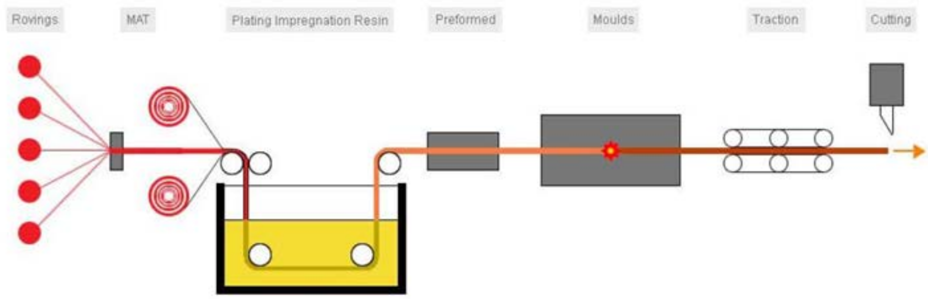
Figure 6. The top photo shows the glass is pulled down firmly into all the corners. The bottom photo shows the finished product which is very dry, light, and neat layup, thanks to the vacuum. [15]

Vacuum infusion is a similar process to vacuum bagging with the exception that the resin is injected into the mold after the reinforcement and gel have been compacted. To ensure that the resin is distributed evenly over the mold, a perforated film with tubing can be positioned over the mold and reinforcement. This process eliminates the possibility of excess resin in the final composite material or that excess resin will be used in the manufacturing process. It is easy to create large structures using this manufacturing process [4]. Manual lay-up, vacuum bag molding, and vacuum infusion are generally used for the production of a single composite structure or low volumes of composite structures. The addition of more molds can increase this volume.

Pre-impregnated fiber mats (prepregs) can be used to simplify and speed up the manufacturing process. These pre-impregnated materials are stored in a freezer to prevent the resin from curing prematurely. Specialized equipment places the fibers in the uncured resin, causing many pre-impregnated materials to have isotropic properties [**Error! Bookmark not defined.**]. There are two types of resins used depending on the desired properties for the final fiber-reinforced polymer composite. For prepregs with a thermoset resin, the fibers are positioned and the resin allowed to partially cure into the “B-stage” or a pliable solid state.

This state enables the material to be easily shaped. When curing prepregs with thermoset resins, heat is applied and the composite will permanently retain its shape. Materials pre-impregnated with thermoplastic resins are easier to handle, as they can be stored at room temperature. When the material is ready for use, it is heated and shaped. Vacuum bag molding is then used to partially pressurize and cure the pre-impregnated material [5].

Pultrusion is the technique commonly utilized to manufacture high quantities of FRP composites with a consistent cross section (Figure 7). Because of the speed and consistency of this predominantly automated technique, it is the most common technique for manufacturing fiber-reinforced composites used in civil applications [9]. Fibers are pulled through a resin bath and then pulled through a heated die, which cures the resin and consolidates the fibers [4]. This technique is typically for manufacturing rods, pipes, and rails.



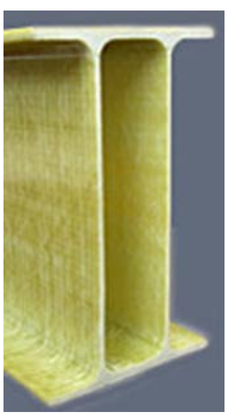


Figure 7. A schematic of the pultrusion process for the continuous production of profiles with constant cross-sections in composite glass, basalt, carbon and natural fiber materials is shown on top and a finished product, I-beam, on bottom. [16]

Another technique utilized for quickly producing large volumes of composite materials is compression molding. In this process, a mold is placed in a mechanical or hydraulic molding press, the reinforcement placed in the mold, usually by machine, and the resin added. The two halves of the mold are closed, pressure is applied, and the system is heated to 250-400˚F. The curing cycle in compression molding only takes about five minutes [4]. This process can also be performed with pre-preg fabrics as shown in Figure 8.

Figure 8. Pre-preg compression molding system showing how a mold or machine is used to form pre-preg fabrics into the final desired shape. These molds are sometimes heated to aid in the curing process. [17]

Performance and Cost

Composites have many properties that make them beneficial for use in a wide variety of structures. The fiber orientations, volume of fibers, rate of curing, and the individual properties of the constituent materials influence the properties of composites. The most valuable characteristic of composites is that they can be designed to have specific properties based on the environmental conditions and requirements of a structure. They are very durable, flexible, and easy to manufacture and assemble. In general, fiber-reinforced polymer composites have very high compressive, tensile and flexural strengths, good fatigue resistance, and low coefficients of friction. In comparison to traditional construction materials, composites have a very high strength-to-weight ratio (Figure 9). Composites are also resistant to corrosion, work well in extreme or fluctuating environmental conditions, and are good electrical insulators. Composites are less affected by physical aging as the fibers have little exposure to adverse environmental effects [1,4]. These are all properties that make composites more favorable than metals for many structures.

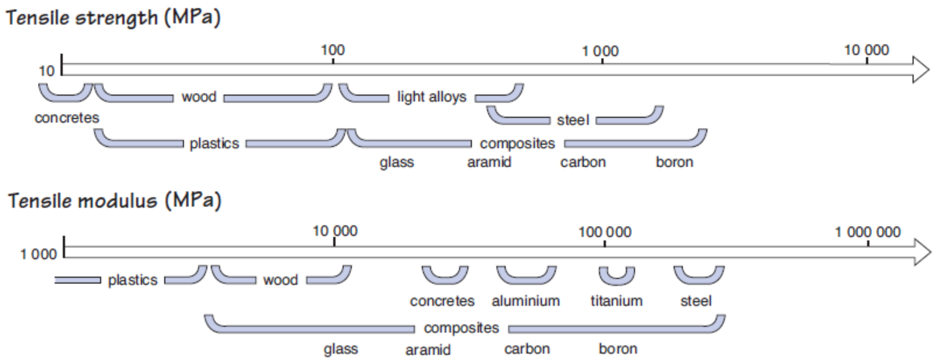


Figure 9. Tensile strength of composites in comparison to other materials. [8]

While there research has focused on minimizing the initial costs of constituent materials and manufacturing techniques, composites are initially more expensive than traditional materials. However, because of their long lifetime, easy installation and limited repair requirements, these materials can be much cheaper than traditional materials over their service life. Many composites have been in service for more than 50 years. Structures made from fiber-reinforced polymer composites have high resistance to environmental effects such as corrosion and erosion, making the lifetime cost overwhelmingly lower than that of traditional materials. In many cases, the cost of reduced service life of a structure is estimated. Material cost is a small fraction of this. A cost comparison of types of carbon fibers and glass fiber is shown in Figure 10.

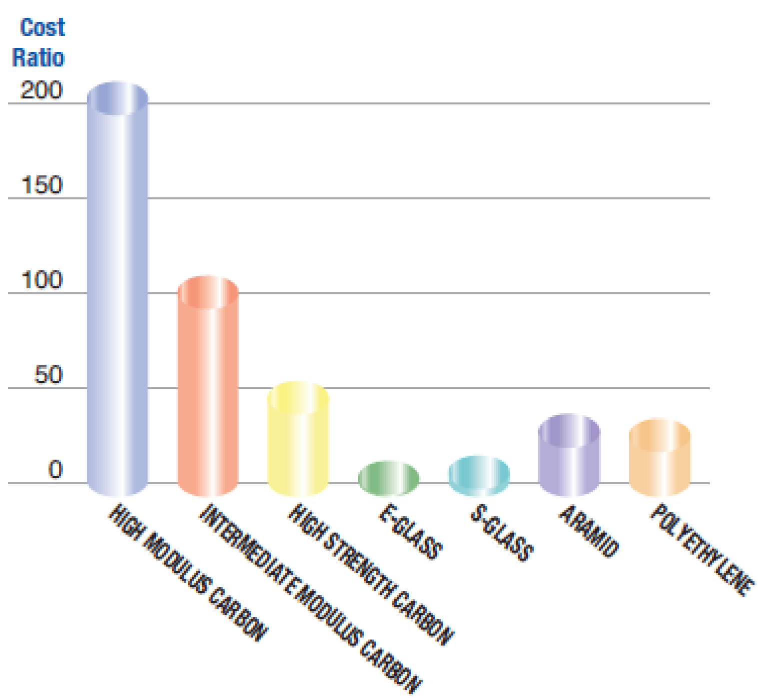


Figure 10. Cost ratio of common fiber reinforcements. [8]

Recommendations for Implementation

Implementation will require information about cost benefits analysis and life cycle costs to present to infrastructure designers, O&M personnel, and owners. One way to gain more information is to pursue introduction of composites for immersed structures such as a replacement for small, low risk cast iron slide gates. In these structures, composites should be utilized because of their high strength along with their low corrosivity and overall low reactivity to many environmental conditions.

FRP composites are readily available from Plasti-Fab [18] for slide gates, bulkhead gates, and stoplogs. All of these available products could be used as replacement components for low-risk infrastructure at Reclamation. These off-the-shelf commercial products have options for customization of specific attributes as needed for a given service condition. For example, additives can be used to improve corrosion resistance and UV resistance.

Gates

Cast and ductile iron slide gates such as those shown in Figure 11, 12, and 13 exhibit corrosion due to their service exposure. Many of these gates are not coated and often not able to be repaired due to the type of material. Stainless steel slide gates and outlet works creates corrosion not only at the stainless to mild steel transition area but also far away from the area (Figure 14). In addition corrosion occurs on the brass seats or seals as shown in Figure 15. Stainless steel is often not coated and more difficult to coat than mild steel; however, even if the bare area of stainless steel is reduced the galvanic couple will always exist. Corrosion can only be reduced but not mitigated, unless an alternative material is utilized.

Figure 11. Cast iron slide gate at Enders Dam exhibiting corrosion along the edges of the gate and the stem.

Figure 12. Cast iron slide gate at Kirwin Dam exhibiting significant corrosion along with the stoplog guides.

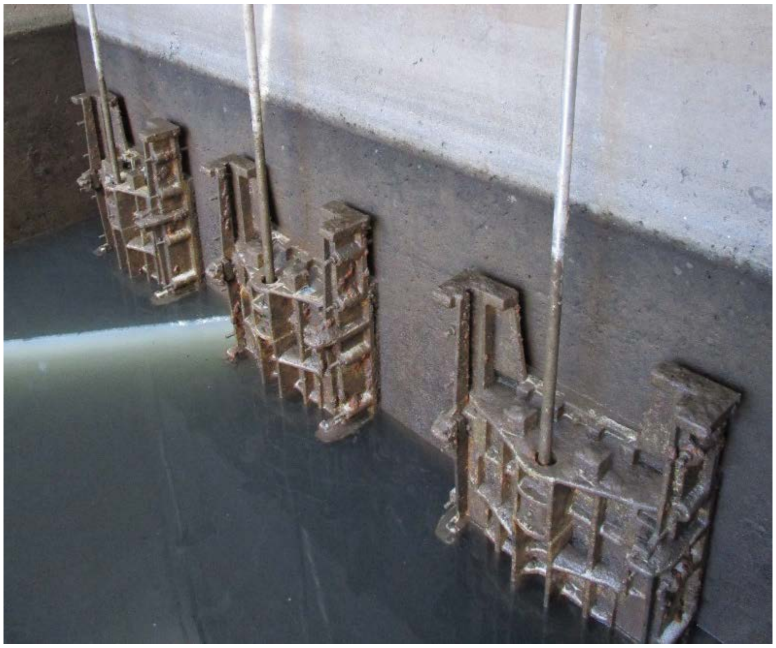


Figure 13. Cast iron slide gates at Marble Bluff Dam exhibiting corrosion of the surface and the guides.

Figure 14. Stainless steel welded to mild steel at Ridges Basin Dam. The uncoated stainless steel gate and gate housing is causing the mild steel to corrode and undercut the weld as well as causing corrosion downstream of this area.

Figure 15. The uncoated stainless steel is causing corrosion of the brass seats/seals and leakage at Ridges Basin Dam.

Four glass fiber reinforced polymer wicket gates were installed at the USACE Peoria lock and dam. These gates were constructed using prepreg glass fiber mats and pressure supplied by a vacuum bag method. Figure 16 shows the wooden constructed gates and FRP gates. The wooden gates get damaged or degraded, and the wood required to construct them is becoming more difficult to acquire. The gates also involve a significant amount of manual construction making the cost fairly high. The FRP gates are relatively cheaper due to the lack of manual construction required. The installed gates are shown in Figure 16.

Figure 16. USACE wicket gates at Peoria Lock and Dam. The wooden gate on the left is the wooden constructed style of gate and the gate in the middle is glass fiber reinforced gate being currently field-tested. The image on the right is the installed composite wicket gates being field-tested.

The FRP slide gate in Figure 17 is designed to withstand the specified maximum operating head and neoprene j-seals can be included to meet low leakage rates [18]. These types of gates can be used to replace not only standard mild steel, aluminum, stainless steel, cast iron, and ductile iron slide gates but also bulkhead style gates. FRP gates would eliminate many of the corrosion issues leading to excessive gate leakage and premature failure.

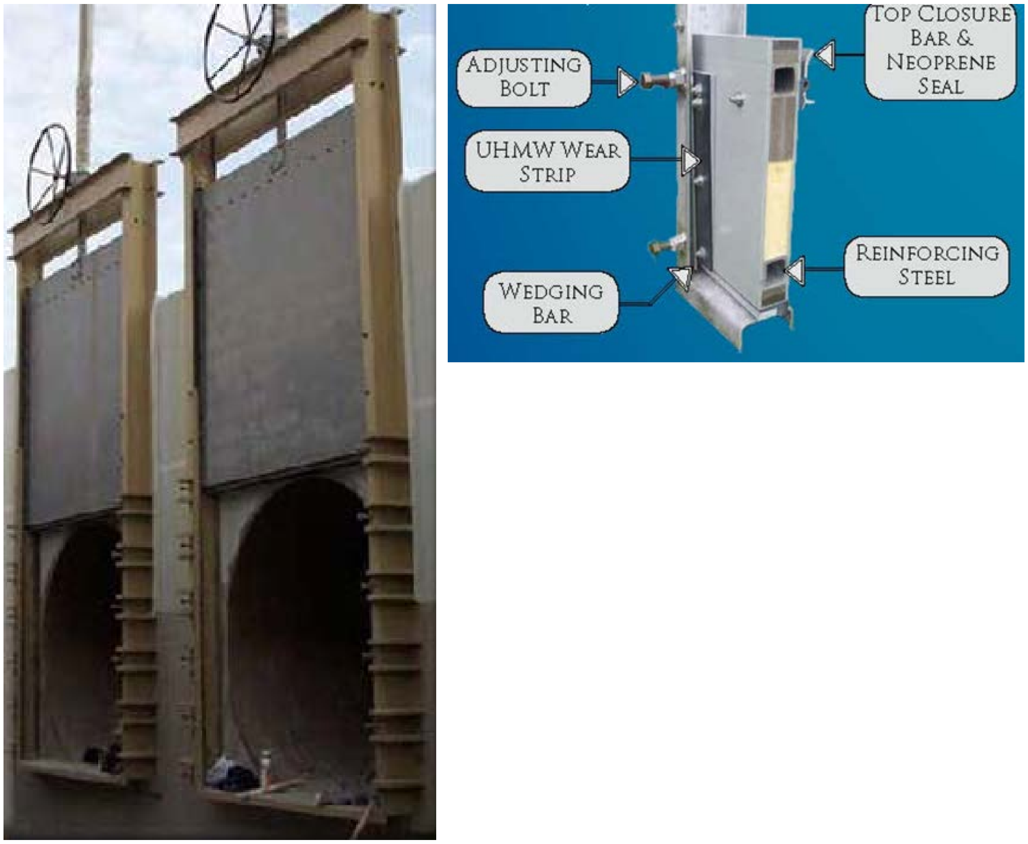


Figure 17. Vacuum infused fiberglass reinforced FRP slide gates for outlet works. Cross-section shows the various components of the gates including reinforcing steel as required for head pressures to surpass deflection criteria. [18]

Stoplogs

The fiberglass stoplogs shown in Figure 18 have been used for numerous applications over the last 18 years. Since they have no seams from mechanical construction, they do not allow seepage like steel stoplogs [**Error! Bookmark not defined.**]. Water absorption is lower for the composites compared to wooden stoplogs, decreasing the likelihood of poor sealing. They were produced using a vacuum infusion method using prepreg mats and pressure.

Figure 18. Fiberglass stoplogs used successfully over the past 18 years in numerous applications. [Error! Bookmark not defined.**]**

Specifications

Reclamation would need to write a performance specification for projects in which composite materials are an option for low-risk infrastructure (e.g., slide gates, bulkheads, and stoplogs). The specification would follow the general Reclamation guidelines for structures of that type. In particular, the specification should include information regarding:

- Materials- including type of composite and any restrictions on components; materials allowed for joints or anchors; special reinforcement, coatings, additives, coloring, or other treatments; standards that components should meet
- Manufacturing- is hand lay-up allowed or must process be automated; design standards that should be followed during manufacturing
- Dimension- size requirements including tolerances
- Performance Requirements- mechanical/load requirements; environmental performance criteria such as temperature tolerance, corrosion resistance, UV light exposure, fire retardancy, and chemical resistance; any applicable standards
- Quality Assurance/Quality Control- including samples and/or test results that must be submitted to Reclamation for verification; define what would be grounds for rejection of a part
- Installation- including instructions on joining or sealing composite parts
- Storage and Handling- typically per manufacturer's recommendations

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