GFRC

by Edwin A. McDougle

Comes *of* Age

The Cervantes Convention Center, St. Louis

New production methods and quality control systems, together with specifiers' increased understanding of its potential, are increasing demand for glass fiber reinforced concrete.

Glass fiber reinforced concrete (GFRC) is a portland cement-based composite with alkali-resistant glass fibers randomly dispersed throughout the product. The fibers function similarly to how steel bars function in reinforced concrete when placed primarily in areas subject to tensile stress. Because the glass fibers add flexural, tensile, and impact strength, GFRC is perfect for lightweight architectural cladding panels.

GFRC cladding panels can be cast as wall units, window wall units, spandrels, mullions, and column covers. They also can be used as fascia panels, soffits, sun screens, mansard roofs, cornices, and interior feature panels. GFRC is moldable enough to replicate many complicated forms, including intricate ornamental details.

The Cervantes Convention Center, St. Louis. All illustrations courtesy the author

How It's Made

The GFRC mix design calls for portland cement, aggregates (primarily sand), alkali-resistant glass fibers, water, and a high-range water reducer, or super-plasticizer. In most instances, an acrylic thermoplastic copolymer dispersion is used to minimize water loss during curing.

GFRC is applied to the mold one of three ways. The most common is the simultaneous spray method, in which the manufacturer simultaneously sprays glass fibers and a slurry mix of cement and sand into the molds. An air-powered chopper slices a continuous strand of glass fiber into pieces appromiately 40 mm (1½ in.) long. The chopper is attached to a slurry spray gun through which the slurry mix is pumped and simultaneously sprayed with the glass fiber into the molds.

A second method sprays a premixed material that contains glass strands that are about 13 mm (½ in.) long.

The third way is the hand lay-up method, which mixes, forms, and places the material into a mold by hand. This method is the most labor-intensive and is used only in small ornamental applications.

No matter how the material is applied to the molds, the glass fibers, to ensure proper strength, must constitute between 4 and 5 percent of the product's total weight.

The fibers consist of glass strands having approximately 200 individual filaments per strand. These joined glass strands provide extremely high initial properties: 68 950 kPa (10,000 psi) compression, 20 685 kPa (3,000 psi) flexural strength, 6895 kPa (1,000 psi) tensile strength, and 6895 kPa to 9650 kPa (1,000 psi to 1,400 psi) first-crack strength. Because maintaining the 4 to 5 percent of fibers is essential to the final product's quality, manufacturers should be certified for their quality control.

In the first and second methods, a producer should spray several layers of slurry and fibers onto the mold, much in the way fiberglass and resin are blended to create fiberglass-reinforced boat hulls. Each layer is then compacted using metal or plastic rollers and trowels as well as by hand to force out air pockets and ensure a smooth application between 13 mm and 20 mm (½ in. and ¾ in.) thick throughout the skin, particularly at stress points such as corners and reveals. After an initial overnight curing, the product is removed from the mold.

Unless the panel is relatively small (about 1 x 1 m [3 x 3 ft]) and has a shape that is functionally strong, stiffeners are usually necessary. These can be prefabricated steel studs or structural tubes attached to the GFRC skin using flex anchors welded to the frame and attached to the skin with bonding pads at the plant.

Other strengthening options include adding integral ribs to the back of the panel by overspraying (thus hiding rib formers such as expanded polystyrene strips) or adding an upstanding single skin rib to the back of the panel. These stiffeners also provide a location for attaching the panel to the supporting structure.

Advantages

GFRC can replicate almost any concrete material but at a much lighter weight. Typical GFRC units weigh between 0.6 kPa and 0.9 kPa (12 lb/ft² and 18 lb/ft²) of surface area and average 0.7 kPa (15 lb/ft²)—as much as 80 percent lighter than precast concrete. The advantages of this relative lightness include the following:

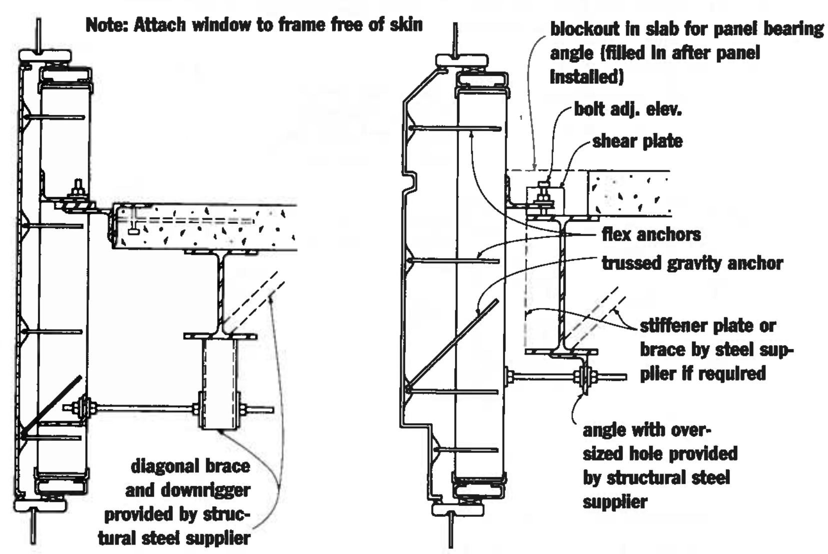
- Lighter framing. GFRC panels place a lighter load on the structural framing and foundation of buildings, offering potential savings in multistory construction and in construction on poor supporting soil. The light weight also can be exploited on low-rise buildings where heavier cladding systems would require larger framing members.
- Speedy erection. The lighter panels can be erected quickly and efficiently, even in hard-to-reach areas, allowing other trades to begin work on the shell's interior earlier in the construction cycle.
- Renovation advantages. On rehabilitation and renovation projects, replicated materials can minimize the weight added to an existing structure or foundation. That means fewer supporting members and a smoother transition from existing components. Working with lightweight material also makes it easier to maneuver among fragile historic components.
- Cost savings. All of the advantages listed above save money. Lighter structural members allow for smaller erection crews and equipment. Enclosing the building faster can reduce interim financing, and renovating faster reduces the time that a building is out of operation.

The GFRC manufacturing process permits a wide range of creative architectural design. Designers can choose from deep reveals or complex rectilinear and curvilinear shapes such as short radius curves, wide sweeping arcs, or 90-degree angles.

The amount or degree of complex shaping on panels has little effect on the cost of panels, because GFRC is an inherently flexible material. This moldability can pay off in a variety of ways, including the following:

- Energy savings. Shading devices that fit the design attributes of the building can lower energy costs without detracting from the building's look. This works particularly well for such elements as vertical and horizontal sunshades. Profiled window wall units make of GFRC can form deeply recessed window frames that shade the sun without reducing natural light and view.
- Restoration. GFRC can duplicate cornices, balustrades, porticoes, mullions, corbels, medallions, or even small sculptures at a far lower cost than sculpting each piece individually. A rubber mold, for example, can be formed from existing architectural elements, created from scratch, or based on old photos.

Figure A. These two options for spandrel connections provide ways to attach these elements to the GFRC. Window connections must be made to the frame and remain free of the skin, or the movement of the GFRC as it expands and contracts will cause cracking.



• Textures and colors. GFRC also is well suited to mimic textures. Renovators can match terra-cotta and other materials that are difficult to specify in a cost-effective manner. GFRC can be cast to match limestone, granite facings, and even metal panels.

and thus does not contain materials that will burn or produce noxious gases. Nor does it add to a building's fire load. GFRC products can provide up to two hours of fire resistance. In addition, because glass fibers are relatively large and strong, they cannot be inhaled or absorbed.

During restoration of One North State Street in Chicago, rubber molds were used to replicate existing elements and duplicate the terracotta coloring and texture.

A variety of aggregate colors can be formulated in the face mix. Panels produced with a face mix that is 3 mm to 13 mm (⅛ in. to ½ in.) thick can contain decorative aggregates as large as 10 mm (⅜ in.). Retarding, sand or abrasive blasting, acid etching, honing, or polishing can bring out a number of hues on panels.

Gray, white, or buff-colored portland cements and pigments further increase the range of colors available for panels. Coatings or stains can give deeper colors.

A smooth, off-the-form finish may be the most economical surface, but uniformity in gray, buff, or pigmented surfaces may be difficult to achieve. These aesthetic limitations can be disguised a number of ways: by fluted, sculptured, board, or other profiled finishes; by subdivided panels; by white cement; or by coatings.

GFRC is an inorganic concrete product

GFRC panels and components stand up to ultraviolet degradation, rot, weather, water erosion, and most chemicals.

The panel's acoustical control makes it a popular choice for everything from highway soundwalls to interior panels for auditoriums.

Panels can be cast in sizes up to approximately 4 x 9 m (12 x 30 ft), and that limitation arises not from structural restraints but from transportation logistics. On single large stud frames, the continuous GFRC skin should span no more than 6 m (20 ft) without including a control joint.

Because GFRC panels typically have steel studs or other stiffeners integrated into them, studs may not need to be added on-site and panels already have an interior surface ready for the finishing phase. (The window frames can be supported on the steel frame, but not on the skin itself.)

The studs also provide a cavity for installing insulation and for electrical, mechanical, and telephone conduits. This means less floor space is needed for these items and that electricians and others are less likely to have to overlap their work schedules or get in each others' way.

Because insulation is applied between the studs, U values as low as 0.04 are possible without making the walls thicker. Furthermore, the GFRC wall system is usually designed to hang outside the floor slab, which increases the usable floor space. This capability can appreciably raise the return on investment for a multistory project.

GFRC can withstand a variety of cleaning methods, a quality typical of any concrete product. It requires almost no maintenance—at most, some caulking every 15 to 20 years.

If a second barrier to protect a structure against water penetration is required, designers should make sure the panels can be double-caulked. Sealers can facilitate water runoff and remove surface dirt. Several coats of sealer applied one right after the other can improve water repellency dramatically.

Applications

GFRC was misused during its infancy in the 1970s, damaging its image. Since then, more study and new techniques have shown where GFRC works best and where other materials are preferable. New cementitious systems, standard practices, and quality control methods have greatly improved the product and expanded its range of application.

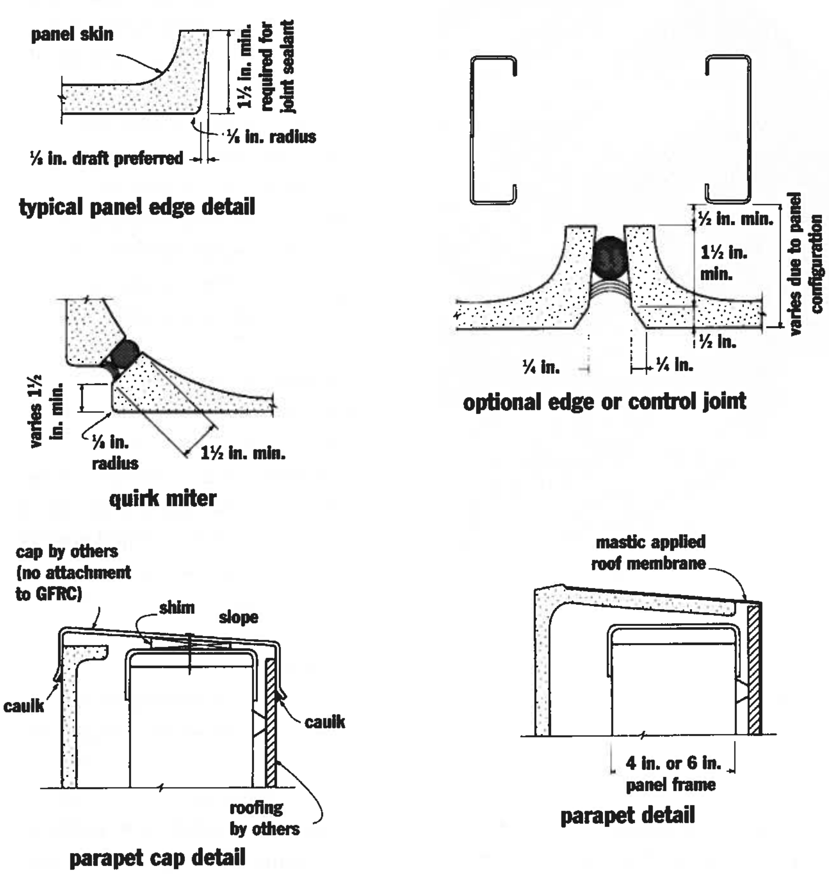
The most common problem arises when specifiers assume that precast concrete techniques can be universally applied to GFRC. GFRC shrinks considerably as it cures, and then it expands and contracts in response to changes in temperature and moisture. This recurring expansion and contraction has to be considered when trying to exploit GFRC's potential.

The shrinking and need for flexibility has caused the most problems when

GFRC has been used as a backing panel for thin brick tile or terra-cotta facing. The combination of shrinking and modulating GFRC and the inflexible face material causes GFRC panels to bow.

To address this phenomenon, remember the following key points:

Figure B. Typical architectural details showing some of the common situations encountered when designing with GFRC



• Allow the skin to shrink before erecting any panels in any GFRC project. This will ensure proper spacing of panels and uniform joint widths.

• Do not use GFRC as a backing for clay products.

• Use small aggregates only—10 mm at the most—in the face mix.

• Use sufficiently flexible anchors when attaching the skin to the frame to minimize stress on the GFRC skins.

• Place a bond breaker between stone veneers and the GFRC skin so the skin and veneer can move independently.

• Fasten window and door attachments to the panel frames, not to the panel skins. The connection must be steel to steel (or whatever framing material is used). The skin must be able to move freely. Caulking can be applied to the skin around the opening, but the window cannot bear directly on the skin.

• Develop samples, approximately 300 x 300 mm (12 x 12 in.) for initial color and texture approval. Use larger mockups of actual project shapes to ensure that design concepts can meet production requirements.

• Avoid thin projections whenever possible. Instead, use rounded (approximately 3 mm) corners and incorporate chamfers at the inside corners of molds.

• Consider the slope of the mold required to strip the unit from the mold and to achieve the desired finish before establishing the final shape. To ease stripping, make the draft or slope to vertical walls at least 25 mm (1 in.) in every 200 mm (8 in.), unless the side forms are removable.

• Use a demarcation feature when the surface of a GFRC panel has two or more different mixes or finishes.

• Calculate the total load (taking into account that exposed aggregate facings will increase the weight of panels).

• Give priority to skin alignment when panels are being erected. This will result in the interior stud face becoming slightly out of plane. The way a panel is designed often prevents the spacing for studs or tubes from being coordinated with interior drywall modules. If the studs are to receive interior treatments, drywall should be mounted on shimmed transverse furring channels rather than directly onto studs. An independent interior stud wall may be less expensive and thus more desirable than furring.

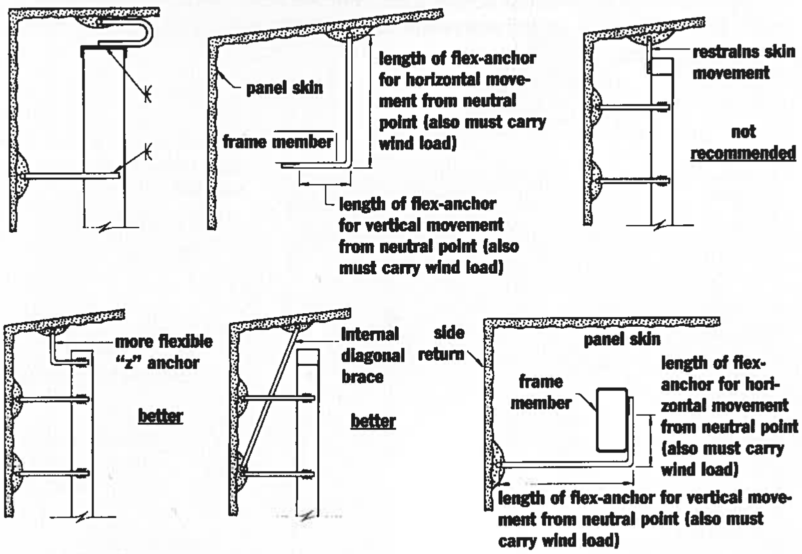
Loss of Ductility

Another concern arises from a loss of ductility in GFRC products as they age. Recent studies have shown that this phenomenon is not caused by alkali attack on cement fibers, as originally believed. Rather, it results from calcium hydroxide and calcium silicate hydrates forming around and within the bundles of glass filaments. This initial solution is drawn by capillary action into the fiber bundles and later crystallizes, filling the pores and locking the fiber into the cement matrix. This prevents the slippage that creates ductility in young GFRC. Loss of ductility is a known phenomenon and is accounted for in the product's design.

Possible solutions in maintaining GFRC ductility have included using pozzolanic materials such as silica fume and fly ash, but these materials have been shown to have drawbacks of their own. Research now has focused on metakaolin, a calcined china clay produced by the thermal activation of kaolin in air at approximately 800 °C (1,470 °F).

Metakaolin has yet to be used for extended periods, and, therefore, its long-term durability and performance standards must remain somewhat theoretical. Although metakaolin appears to offer great potential, more study and experimentation are needed before a specific solution to the problem of lost ductility can be endorsed.

Figure C. A variety of options for using flex anchors to reduce restraint in GFRC panels. Many problems have been traced to designers not allowing for enough movement in the skin or facing with a material that was not compatible with the GFRC backing.



The thermoplastic copolymer used as an internal curing additive has also been shown to reduce the long-term loss in ductility. This finding is based on testing samples which have undergone natural aging for over twelve years. Additional research is ongoing to correlate this finding with other results.

Quality Control is Crucial

The Precast/Prestressed Concrete Institute's (PCI) third edition of *Recommended Practice for Glass Fiber Reinforced Concrete Panels* discusses every aspect of GFRC design, production, and quality control and directly addresses concerns that arise from the interaction of the facing material and the GFRC backing. It also includes detailed guide specifications for GFRC panels. In addition, Masterspec offers a comprehensive GFRC specification.

In 1991, PCI's GFRC Quality Control Manual Subcommittee created *The Manual for Quality Control for Plants and Production of Glass Reinforced Concrete Products*. This 168-page manual discusses every aspect of controlling the quality of GFRC material, including testing the quality of the product and the properties of the material, determining the number and qualifications of personnel needed, assessing the number and type of inspections required, noting the various types of record keeping involved, and so on.

The manual focuses on quality control as an entity distinct from the production process. It also has a format intended to help specifiers and producers fully understand the ramifications of each standard. Each page is divided into two vertical columns. On the left side, the basic standards are outlined. On the right, a detailed commentary explains why the standard is set as it is and offers suggestions and amplifications for additional steps. This commentary has become a popular reference guide because it provides additional background information concerning the development and application of the standards. The side-by-side approach also ensures that the commentary parallels the specific standard being discussed.

Strict quality control over GFRC production is especially vital because GFRC skins are produced in relatively thin sections and restrictions on glass-fiber content in the mix are tight. Experienced eyes are needed to ensure that mixes meet requirements and that all air voids are eliminated. In what can be a labor-intensive procedure, there is little margin for error in producing a durable, top-quality GFRC component. Quality-certified plants can ensure that the specifier receives the best product on the market.

PCI certification is specific. It certifies only a plant's capabilities to produce specific products; it does not certify a plant and then automatically allow that certification to carry over to every product produced at the plant. PCI conducts random, two-day audits of each plant two to three times annually.

Plants can be certified in four distinct groups: Architectural Products (A1), GFRC (A2), Bridges (B), and Commercial Structures (C). Groups B and C are each divided into four categories based on the complexity of products. Plants must carry an A2 certification to qualify for producing GFRC under the tight procedures required by PCI standards. A complete list of these plants and the products they have been certified to produce is available from PCI. ◆

References

GFRC Recommended Practice for Glass Fiber Reinforced Concrete Panels. 3d ed. Chicago, Illinois: Precast/Prestressed Concrete Institute, 1993.

Manual for Quality Control for Plants and Production of Glass Fiber Reinforced Concrete Products. Chicago, Illinois: Precast/Prestressed Concrete Institute, 1991.

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