Manual for
QUALITY CONTROL
for Plants and Production of
GLASS FIBER REINFORCED
CONCRETE PRODUCTS

SECOND EDITION

MNL-130-09
This manual has been prepared as a guideline for the manufacture of glass fiber reinforced concrete (GFRC). GFRC is the term applied to products manufactured using a cement/aggregate slurry reinforced throughout with alkali-resistant glass fibers. The manufacture of glass fiber reinforced concrete products requires a greater degree of craftsmanship than other precast concrete construction products. In addition, many combinations of shape, size, color, and texture are demanded of this product. Therefore, it is important to implement the quality control procedures as given in this Standard.

Consultation with representatives of experienced manufacturers will be of great value in achieving high-quality products at a reasonable cost to the owner. Materials and performance requirements for glass fiber reinforced concrete should be clearly stated in the plans and specifications. They should be neither open to interpretation nor unnecessarily restrictive. All personnel in the manufacturer’s and erector’s organizations must be thoroughly trained and competent in order to achieve quality glass fiber reinforced concrete installations.

This second edition of the PCI Manual for Quality Control for Plants and Production of Glass Fiber Reinforced Concrete Products was prepared by the GFRC Quality Control Manual Subcommittee of the PCI Glass Fiber Reinforced Concrete Panels Committee. It represents the most current PCI recommendations and is the industry standard for quality control.

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INTRODUCTION
MNL-130, Second Edition

The Standard and Commentary portions of this manual are presented in a side-by-side column format, with the Standard placed in the left column and the corresponding Commentary aligned in the right column. The Standards have been printed in the same typeface as shown in this paragraph.

The Commentary is printed in the same typeface as shown in this paragraph. Additionally, a “C” precedes Commentary article numbers to help further distinguish the Commentary from the Standards.

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The information in this manual is intended to serve as standards for quality control for the manufacture of glass fiber reinforced concrete (GFRC) products and as a complete guide for the development of an internal manufacturing quality control program. The Standard portion is intended to serve as a specification reference document. It should be augmented as required for specific operations and products by specifier or producer. The Commentary provides amplification and explanation of the Standard.

The requirements of this Standard are intended to achieve optimum quality, which may be defined as that level of quality, in terms of appearance, strength and durability, that is appropriate for the specific product and its particular application. In other words, it is the level of quality that is both economical to achieve and suitable for the particular purpose it serves as a component in the overall building project.

While it may be interpreted that this Standard provides a minimum level of quality, there is no intent to place a ceiling on excellence. The degree of success in specifying and obtaining optimum quality for GFRC products will depend on the combined efforts of designers and GFRC manufacturers to define and coordinate their individual requirements, responsibilities, and expectations.

No manual of this type can be all-inclusive. The recommendations given herein are presented only as an outline of the more important factors governing the product quality of glass fiber reinforced concrete. Their value is dependent on rational application and a determination on the part of individual producers to establish a standard of quality that will be recognized and respected by the specifier.

Satisfactory conformance with the Standards in this manual is required for certification in the PCI Plant Certification Program for Product Group/Category G – GFRC products. For an explanation of these program requirements and procedures, see Appendix I, PCI Plant Certification Program.

This manual incorporates proven standards of practice. It contains requirements necessary to achieve an acceptable level of quality, but not the means or methods for doing so. The requirements of the manual are not intended to be applied in a manner that is restrictive to the development of individual plant techniques or innovation. As new materials and processes are developed, their application should be considered within the scope and intent of these Standards. The information contained in the Commentary is not to be considered as part of the Standard in judging quality control procedures. It does provide additional information on current practices, responsibilities, materials, and equipment on a portion of topics in the Standard. Plant and regional differences will determine the applicability of this information.

This manual mainly applies to thin-walled architectural cladding panels manufactured by the spray-up process using special alkali-resistant glass fibers that are chopped and sprayed onto a mold with an appropriate cement/aggregate slurry. The premix method of manufacturing concrete composites is not covered in the Standards and Commentary portion of this manual, but is added as Appendix M. This manual is not intended to preclude the use of alternate systems or methods.

GFRC does not consist of a single composition, but can be manufactured using different combinations of materials to meet the required properties. Mix composition, type of cement, and the proportion, length, and orientation of glass fibers may all be varied to produce a specific product. Typically, a GFRC panel consists of 5% by weight (of total mix) of alkali-resistant glass fibers randomly distributed throughout a portland cement/sand matrix. Methods of manufacture vary, but spraying either by hand equipment onto a mold of the desired shape and size, or mechanically on a production line are most common. Either a thermoplastic copolymer dispersion shall be used for curing purposes or the composite shall be suitably moist cured. It is not the intention of this manual to restrict individual plant techniques except for minimum raw-material-content requirements.
GFRC panels, through the application of finish, shape, color, or texture, contribute to the architectural form and finished effect of a structure's facade. Design flexibility in surface appearance is possible by incorporating various cements, coarse aggregates, sands, and pigments into the face mix. Natural stone products may be used as a veneer finish if special design requirements are met. Alternatively, panels may be painted or stained to achieve the required colors.

GFRC cladding panels can be custom designed as non-loadbearing wall units, window wall units, spandrels, mullions, and column covers in sizes to suit the modular planning of the building. GFRC is also suitable for use as fascia panels, soffits, sun screens, mansard roofs, and interior feature panels. GFRC is not considered as a vertical loadbearing component or as part of the lateral load–resisting system. GFRC can be designed to accept and transfer wind loads and self-weight (face mix/veneer finish and GFRC backing) and its own inertial seismic loads to the building's load-resisting system. GFRC panels are used primarily as cladding or fascia panels.

The architect/engineer is directed to Appendix B for a listing of the responsibilities that are to be considered in the preparation of plans and specifications for a glass fiber reinforced concrete project.

Note: The production of GFRC may involve hazardous materials, operations, and equipment. This manual does not address the safety issues associated with production. It is the responsibility of the producer to establish appropriate safety and health practices and determine the applicability of regulatory requirements.
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**Note:**
- The table above provides a structured outline of the contents of the document, indicating the page numbers for each section or subsection.
DEFINITIONS

A (Aged) – One of two general ages in life of GFRC composites. No specific time interval is intended (unless otherwise indicated). It is a general term associated with GFRC composite properties after the time-dependent changes discussed in Sections 4.2 and 5.2 (usually, but not always, modified by F or T and Y or U).

Admixture – A material added to modify the properties of mortar or cement slurry.

Air Permeability – The rate of air flow through a material; commonly expressed in perm-inches.

Alkali-Resistant (AR) Glass Fiber – Fiber made from glass having a high zirconia content (minimum 16%) formulated to improve resistance to attack by aqueous alkaline solutions.

Ambient Temperature – The temperature of the air surrounding an object.

Anchor – A device for the attachment of the skin to the panel framing system; includes the flex, gravity, and seismic anchors.

Artificial Aging – A condition to which test specimens are subjected in order to simulate their exposure to natural weathering; the intent is to accelerate any aging effects.

Attachments – A term that includes both anchors and connections.

Backfill – The GFRC mix deposited into the mold after the face mix or veneer has been placed and consolidated.

Bag and Bucket Test – A plant test for determining the rate of slurry output and fiber chopping rate to evaluate the glass fiber content before the start of spray-up.

Blocking – Materials used for keeping GFRC elements from touching each other or other materials during storage and transportation.

Bondbreaker – A substance placed on a material to prevent it from bonding to the GFRC, or between a face material such as natural stone and the GFRC backing.

Bonding Agent – A substance used to increase the bond between an existing piece of GFRC and a subsequent application of GFRC such as a patch.

Bonding Pad – A supplemental section of GFRC material that covers the foot of the flex, gravity, or seismic anchor.

Boss – A thickened section of backing mix into which an insert can be embedded.

BOP – Bend-over point (tensile) in some literature; replaced herein by TY, tensile yield.

Carbonation – A reaction between carbon dioxide and a hydroxide or oxide to form a carbonate, especially in cement paste or mortar; the reaction with calcium hydroxide to produce calcium carbonate.

Chopped Glass – Non-continuous multi-filament glass fiber strands; it is chopped from roving in the spray-up process.

Cladding Panel – A lightweight non-structural GFRC prefabricated building component produced by the spray-up process for use as an exterior panel.

Clearance – The interface space (distance) between two items.

Compaction – The process whereby the volume of the face mix or GFRC backing is reduced to the minimum practical volume by the reduction of voids, usually by vibrating, tamping, rolling, or some combination of these.

Composite – A material obtained by combining two or more materials, but so interconnected that the combined components act together as a single member and respond to load as a unit, e.g., GFRC.

Connector (Connection) – A device for the attachment of GFRC units to each other or to the building structure.

Coupon – A specimen for testing.

Crazing – A network of fine cracks in random directions breaking the surface of the panel into areas of 1/4 in. to 6 in. (6 mm to 152 mm) across.

Creep – The time-dependent change in dimension or shape caused by a sustained load.

Curing – The maintenance of appropriate moisture and temperature of freshly placed face mix and backing during some definite period following placing, spray-up, or finishing to assure satisfactory hydration of the cementitious materials and proper hardening of the skin. When the curing temperature remains in the normal environmental range [generally between 60 °F and 90 °F (16 °C and 41 °C)] it is considered normal curing; when the curing temperature is increased to a higher range [generally between 90 °F and 120 °F (41 °C and 50 °C)] it is considered accelerated curing.
Draft – The slope of the mold surface in relation to the direction in which the GFRC element is withdrawn from the mold to facilitate stripping.

Dry Density – The weight per unit volume of an oven-dry specimen; commonly expressed in pounds per cubic foot (pcf) (kg per m³).

Ductile-Appearing or Pseudo-Ductile – Large permanent deformation without apparent rupture but in fact having multiple microcracks; unaged GFRC has this characteristic.

Dunnage – See Blocking.

E (Early)* – One of two general ages in the life of GFRC composites. Often but not always associated with 28 days. Specifically an age prior to the time-dependent property changes (usually, but not always, modified by F or T and Y or U).

E-Glass Fiber – Borosilicate fiber widely used for the reinforcement of plastics, but not recommended for use with portland cement.

Efflorescence – A deposit of salts, usually white, formed on the surface of the skin. It is a substance that emerges in solution from within the GFRC backing or face mix and is deposited by evaporation.

Erection Drawings – A set of instructions in the form of diagrams and text. The instructions typically describe the location and assembly details of each GFRC element at the construction site.

F (Flexural)* – Flexural strength at either yield (Y) or ultimate (U). The apparent maximum stress when GFRC is subjected to flexural loading (Mc/I). This is the most commonly determined measure of strength (herein usually, but not always, modified by A or E and Y or U).

Face Mix – A proportioned mix of unreinforced mortar, concrete, and admixtures at the exposed face of a GFRC unit used for specific appearance reasons.

Facing Aggregate – An aggregate complying with ASTM C33, except for gradation, predominantly retained on the No. 20 (850 µm) sieve with a 1/4 in. (6 mm) maximum size.

Fiber – An individual glass filament with an average diameter of 13 to 20 microns and not less than 9 microns in diameter.

Fiber Content – The ratio, usually expressed as a percentage, of glass fiber to the total composite; can be by weight or by volume.

* The abbreviations A or E, F or T, and Y or U are used in this manual in appropriate combinations to describe particular conditions. For example, AFY indicates that state of material in the Aged Flexural Yield Conditions.

Flex Anchor – A rod or bar that connects with GFRC skin to the panel frame. See illustration for parts of anchor.

FRC – Fiber-reinforced concrete or fiber-reinforced cement; concrete containing dispersed, randomly oriented steel, plastic, natural, or other fiber is not by definition GFRC and is not intended to be synonymous with GFRC.

Form – See Mold.

Gap-Graded (Aggregate) Concrete – A face mix with one or a range of normal aggregate sizes eliminated, and/or with a heavier concentration of certain aggregate sizes over and above standard gradation limits; it is used to obtain a specific exposed-aggregate finish.

GFRC – Glass fiber reinforced concrete. In this Recommended Practice, GFRC is a sprayed composite with an absolute minimum of 4% by weight of AR glass fiber to total mix with a minimum backing design thickness of 1/2 in. (13 m) as produced by a PCI-Certified Plant – Group G.

GRC – Glass-reinforced concrete or glass fiber reinforced cement; intended to be synonymous with glass-fiber-reinforced concrete.

Gravity Anchor – Rods, bars, or plates that transfer the weight (gravity load) of the skin to the panel frame.

Hardware – A collective term applied to items used in connecting GFRC units or attaching or accommodating adjacent materials or equipment. Hardware is normally divided into three categories:

Contractor’s hardware – Items to be placed on or in the structure in order to receive the GFRC units—e.g., anchor bolts, angles, or plates with suitable anchors.

Plant hardware – Items to be part of the GFRC units themselves, either for connections and GFRC erector’s work, or for other trades, such as mechanical, plumbing, glaz-
ing, or miscellaneous iron, masonry, or roofing trades.

**Erection hardware** – All loose hardware necessary for the installation of the GFRC units.

**Insert** – A threaded connecting or handling device cast into a GFRC panel or the structure. Inserts are machine- or coil-threaded to receive a bolt or slotted to receive a bolt head, nut, strap anchor, or threaded rod.

**LOP** – Limit of proportionality (flexural) in some literature; replaced herein by FY, flexural yield.

**Matrix** – The cement paste into which various amounts of aggregate particles and/or glass fibers are incorporated.

**Mist Coat** – A thin [1/8 in. (3 mm) nominal] coat of portland cement/sand slurry of a composition similar to the GFRC backing mix but without glass fiber, applied to the surface of the mold to give a smooth, even surface and hide the glass fibers. It may be the exposed face of a GFRC unit used for specific appearance reasons.

**Modulus of Elasticity** – Ratio of normal stress to corresponding strain for tensile, flexural, or compressive stresses within the elastic limit of material.

**Moisture Migration** – The movement of moisture through the skin.

**Moisture-Induced Movement** – Volume change of the skin due to change in moisture content. Volume change may be contraction or expansion.

**Mold** – The container or surface against which fresh GFRC is deposited to give it a desired shape; sometimes used interchangeably with form.

**MOR** – Modulus of rupture (flexural in some literature); replaced herein by FU, flexural ultimate.

**Panel** – The entire prefabricated GFRC assembly.

**Panel Frame** – Plant-attached steel frame of cold-formed studs and track and/or structural shapes used to support and stiffen the skin and provides a means for connecting the skin to the building frame.

**PEL** – Proportional elastic limit in some literature and used to apply to either flexural or tensile values; replaced herein by FY, flexural yield, and TY, tensile yield.

**P-GFRC** – Polymer (modified)-glass fiber reinforced concrete with a polymer solids content 10% or greater by volume (not covered in this Recommended Practice).

**Plastic Cracking** – Short cracks, often varying in width along their length, that may occur in the surface of the fresh skin soon after it is placed and while it is still plastic.

**Polymer** – As used in this Recommended Practice, an emulsion of an alkali-resistant synthetic thermoplastic in water obtained by polymerization, used as a curing admixture and to improve long-term durability.

**Premix** – A process of mixing cement, sand, chopped AR glass fiber, and water together into a mortar and subsequently spraying or casting with vibration, press-molding, extruding, or slipforming the mortar into a product.

**Production Drawings** – A set of instructions in the form of diagrams and text. The instructions contain all the information necessary for the manufacturer to produce the unit.

**Quirk Miter** – A corner formed by two chamfered members to eliminate sharp corners and ease alignment.

**Retarder** – An admixture that delays the setting of cement paste.

**Retarder, surface** – A material used to retard or prevent the hardening of the cement paste on a GFRC surface within a time period and to a depth to facilitate removal of this paste after the GFRC element is otherwise cured (a method of producing an exposed-aggregate finish).

**Return** – A projection of like cross section that is 90 degrees to or splayed from the main face or plane of view.

**Reveal** – (1) A groove in a panel face generally used to create a desired architectural effect; (2) The depth of exposure of the facing aggregate of an exposed-aggregate finish.

**Rib** – (1) A stiffening member backing the skin; (2) A projection from the panel face.

**Roving** – A group of glass fiber strands gathered together and wound into a package.

**Rustication** – A groove in a panel face for architectural appearance; also reveal.

**Sand** – Washed and dried silica, complying with composition requirements of ASTM C144; passing No. 20 (850 µm) sieve with a maximum of 2% passing No. 100 (0.15 mm) sieve.

**Sandwich Panel** – A prefabricated panel that is a layered composite formed by attaching two skins separated by an insulated core.
Scrim – A manufactured fabric with open area construction (windows) of over 0.062 in.$^2$, (0.40 cm.$^2$) using AR glass fiber strands. It is laid up by hand to reinforce an area of the GFRC backing.

Sealant, joint – A material used to exclude water and solid foreign materials from joints between GFRC members and GFRC units and adjacent materials.

Sealer – A clear chemical compound applied to the surface of GFRC units for the purpose of reducing water absorption or improving weathering qualities.

Seismic Anchor – Rods, bars, or plates that transfer the seismic load of the skin to the panel frame.

Shop Drawings – (1) A collective term used for erection drawings, production drawings, and hardware details; (2) Diagrams of GFRC members and their connecting hardware, developed from information in the contract documents. They show information needed for both field assembly (erection) and manufacture (production) of the GFRC units.

Sizing – Coating materials applied to the glass fibers during manufacture to facilitate and/or improve the processing and performance of the fiber.

Skin – The thin exterior section of a panel, including the face mix/veneer finish and GFRC backing mix but excluding ribs, bosses, panel frame, etc.

Skin Segment – The discrete sections of skin within a panel separated by control joints.

Slump Test – A plant test for determining the apparent viscosity of a cement slurry.

Slurry – A mixture of water, portland cement, sand, and other additions or admixtures in suspension.

Spray-Up Process – The simultaneous depositing of glass fibers and slurry by spraying onto a mold followed by appropriate compaction.

Strand – A number of individual continuous fibers bound together by sizing. Typical AR glass fiber strands contain 102, 204, or 408 fibers.

Stripping – The process of removing a GFRC element from the mold in which it was sprayed.

Stud Frame – See Panel Frame.

Superplasticizer – A high-range water-reducing (HRWR) admixture producing a cement slurry of significantly higher slump without additional water.

T (Ultimate)* – The ultimate strength or failure point at which a material is no longer capable of carrying load (herein usually, but not always, modified by A or E and F or T).

UTS – Ultimate tensile strength in some literature; replaced herein by TU, tensile ultimate.

Vapor Permeance – The rate of water vapor transmission per unit of vapor pressure differential; commonly expressing in perms.

Volume Change – An increase or decrease in volume of the skin. It includes initial drying shrinkage, moisture-induced movement, thermal movement, and creep.

Wythe – Each continuous vertical section of a wall.

Wythe Equivalent Thickness – The thickness of a solid flat wythe having the same volume as the wythe in question. For a wythe having a non-uniform cross section throughout its length, the equivalent thickness is equal to the cross-sectional area divided by the length of the cross section.

Y (Yield)* – Yield point or strength; point on a stress-strain curve at which strain ceases to be proportional to stress (herein usually, but not always, modified by A or E and F or T).
Standard

1.1 Objective

Quality control shall be an accepted and functioning part of the plant operation. Overall product quality results from individual as well as corporate efforts. Management must make a commitment to quality before quality programs can be effectively adopted or implemented at the operational level. Management shall establish a corporate standard of quality based on uniform practices in all stages of production, and shall require strict observance of such practices by all levels of personnel.

The general objective of this manual is to define the required minimum practices for the production of GFRC units and for a program of quality control.

Construction project specifications and manuals can prescribe and explain proper quality control criteria for all phases of production consistent with producing products of the highest quality. However, to ensure that such criteria are followed, inspection personnel and a regular program of auditing all aspects of production should be provided.

The individuals in control of operations should have the commitment to produce products of proper quality, and should delegate authority for assignment of the responsibilities necessary to achieve the desired results. Consistent quality can only be achieved if proper procedures are established and then carried out.

While the guidelines in this division address the quality control function, it is recognized that the primary responsibility for quality rests with production personnel. Accordingly, the production personnel should understand the role of quality control and work to ensure effective monitoring, timely responses, corrective actions, and improvement.

Although production personnel are responsible for the quality of products, it is necessary to have a system of checks and balances. Quality control inspections provide this check-and-balance system and consequently are a vital tool for management. The number of persons required to effectively perform the quality control functions will vary with the size and extent of plant operations.

Supervisory personnel are an integral part of the process and should be committed to the quality standards. The production of quality products requires uniformity of management’s expectations for all areas of operations and types of products.

Commentary

C1.1 Objective

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Supervisory personnel are an integral part of the process and should be committed to the quality standards. The production of quality products requires uniformity of management’s expectations for all areas of operations and types of products.
2. Organizational structure and relationships, responsibilities, and qualifications of key personnel.

3. Management review of the quality assurance program at regular intervals, not to exceed one year, to ensure its continuing suitability and effectiveness. This review will include handling of nonconformances, corrective actions, and response to customer complaints.

4. Plant facilities in the form of a plant layout that notes allocation of areas, services, machinery, and equipment.

5. Purchasing procedures for quality control compliance that include project specification review for specific requirements.

6. Identification of training needs and provisions for training personnel in quality assurance requirements.

7. Control, calibration, and maintenance of necessary inspection, measuring, and test apparatus.

8. Uniform methods of reporting, including sample forms, reviewing, and maintaining records. Each GFRC unit shall be uniquely identified to a specific set of applicable quality control records.

9. Standards for shop (erection and production) drawings to ensure accuracy and uniform interpretation of instructions for manufacturing and handling.

10. Procedures for review and dissemination of project-specific requirements to production and quality control personnel.

1.2.2 Documented Procedures

Control of documented procedures and data, relative to the effective functioning of the quality assurance program, shall cover as a minimum:

1. Inspecting and verifying purchased materials for conformance with specification requirements. Vendors shall be required to submit proof of compliance for both materials and workmanship.

2. Sampling methods and frequency of tests.

3. Checking and approval of shop drawings.

4. Inspecting and verifying the accuracy of dimensions.

5. Procedures for and inspection of batching, mixing, placing, consolidating, curing, and finishing GFRC.

6. Procedures for and inspection of repairs, handling, storing, and loading of finished products.

The best possible design and use of the highest quality materials do not ensure product quality. Quality is established through adherence to proven production procedures. When possible, procedures with a high degree of variability and that are subject to human error should be eliminated.

The most important aspects of a quality assurance program are:

1. Adequate inspection personnel to ensure review of all materials and processes.

2. Clearly defined responsibilities and required functions for each inspector.

3. Management commitment to supporting the quality assurance program and establishing a uniform standard of quality in the plant.

4. Clear and complete records of inspection and testing.

5. Updating and calibration of testing equipment in a timely manner.

Information gained through quality control inspections should be reviewed on a weekly basis with production personnel. This review may be useful in identifying areas that require additional training in proper production procedures, procedures that require modifications, or equipment that needs repair or replacement.

C1.2.2 Documented Procedures

A complete and accurate record of operations and inspection activities is beneficial to a producer if questions are raised during the use of plant-produced products. For additional information, see Division 2, Product Control.
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7. Inspection of the placement and quality of panel frames, cast-in appurtenances, ribs, and block-outs.
8. Mix design preparation and evaluation.
10. Sampling and testing of materials and fresh slurry.
11. Inspection of stripping procedures.
12. Inspection of finished products for conformance with the shop drawing, and other project requirements, such as approved samples when stipulated.
13. Repair procedures for noncompliant conditions.
14. Preparing and maintaining complete quality control records.
15. Maintenance and calibration requirements (items and frequency) of plant equipment that may affect product quality.

1.2.3 Management Responsibilities

Plant management shall establish and support fundamental quality control requirements. These include, but are not limited to:

1. A corporate standard of quality.
2. A written plant quality system manual, which establishes a uniform order or practice for all manufacturing operations.
3. Personnel, whose primary function is quality control, with direct responsibility to the general manager or chief engineer.
4. An acceptance program for finished products prior to shipping.
5. Uniform methods for reporting, reviewing, and keeping records. Each GFRC unit produced shall be traceable to a specific set of applicable quality control records.
6. Engineering operations to ensure compliance with the required codes, standards, specifications, and in-plant performance requirements.

Commentary

C1.2.3 Management Responsibilities

Plant management should be committed to quality, and this commitment should be demonstrated to all personnel. Quality control inspection functions cannot overcome a lack of dedication to quality by management. Those responsible for producing the product should understand that management supports the production of quality products.

1.3 Personnel

1.3.1 General

Each plant shall have personnel qualified to perform the functions of the various positions outlined in this section. Personnel responsibilities, and the relationship between quality control, engineering, and production, shall be established and clearly defined.
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At least one individual in the plant organization shall be certified as a GFRC Technician/Inspector in the PCI Quality Control Personnel Certification Program.

**Commentary**

Proper and responsible performance of persons involved in manufacturing GFRC products requires specialized technical knowledge and experience. The plant should have appropriate contingency plans in place to provide for the absence of regularly assigned quality control staff.

Although production personnel are responsible for the quality of products, it is necessary to have a system of checks and balances. Quality control inspections provide this check-and-balance system and consequently are a vital tool for management. The number of persons required to effectively perform the quality control functions will vary with the size and extent of plant operations.

1.3.2 Engineering

Plants shall have available the services of a registered professional engineer experienced in the design of GFRC. The GFRC engineer shall prescribe design policies for GFRC design and be competent to review designs prepared by others.

The GFRC design engineer shall be responsible for evaluating preproduction strength tests for skins and anchors (see Division 2) and shall determine allowable design values accordingly.

1.3.3 Drafting

Plants shall use experienced personnel competent to prepare shop (production and erection) drawings in general accordance with the *PCI Drafting Handbook – Precast and Prestressed Concrete*, MNL-119.

1.3.4 Production

Production personnel shall be qualified to produce units in accordance with the production drawings, the plant's quality control requirements, and other project requirements, such as approved samples, when stipulated.

1.3.5 Quality Control

This function shall have lines of communication to engineering, production, and management; however, direct responsibility shall only be to management. Quality control personnel shall not report to production personnel.

C1.3.3 Drafting

Shop drawings should clearly and completely detail the requirements of the contract documents in a manner that minimizes the possibility of errors during the manufacturing and erection process.

C1.3.4 Production

Production personnel have the immediate responsibility of supervising all plant operations involved in the manufacture of products to ensure compliance with production drawings, specifications, and established plant standards.

C1.3.5 Quality Control

Quality assurance is the primary responsibility of the quality control staff. Production personnel should be involved in assuring quality and communicate closely with the quality control staff; however, the delineation of responsibility between production and quality control personnel should be recognized and respected.

The qualifications of personnel conducting inspections and tests are critical to providing adequate assurance that the GFRC products will satisfy the desired level of quality.
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Quality control personnel shall be responsible for ensuring that the following activities are performed at a frequency adequate to meet plant-specific quality objectives or as addressed in this manual:

1. Inspecting and verifying the accuracy of dimensions and conditions of molds.
2. Verifying procedures for batching, mixing, placing, consolidating, curing, and finishing GFRC.
3. Verifying procedures for repair, handling, storing, and loading of finished product.
4. Verifying the proper fabrication and placement of panel frames and internal items.
5. Inspecting and preparing test boards.
6. Preparing or evaluating mix designs.
7. Preparing representative test samples and performing all required testing.
8. Inspecting finished products for conformance with the shop drawings and other project requirements, such as approved samples.
9. Preparing and maintaining complete quality control records.

Commentary

Quality control personnel should observe and report any changes in plant equipment, working conditions, weather, and other items that have the potential for affecting the quality of products.

1.4 Design Responsibilities

C1.4 Design Responsibilities

1.4.1 General

The responsibilities of the architect/engineer and the GFRC manufacturer are subject to a contractual relationship with the owner. The manufacturer shall be responsible for translating the project specifications into samples (as required), shop drawings, tooling, manufacturing procedures, and installation procedures in accordance with the appropriate provisions of the contract documents.

Local practices regarding responsibility for the design of GFRC units vary widely. Similarly, but to a lesser extent, relevant codes or statutes governing professional design and the responsibility of manufacturers can also vary widely. Accordingly, the information provided in this section should be evaluated for conditions applicable to the particular location or to individual projects. For additional information, refer to the Code of Standard Practice for Precast Concrete – PCI Design Handbook, MNL-120.

In the interest of both the GFRC producer and architect/engineer, the design responsibilities of each party should be clearly defined. It is recommended that this be done in the contract documents.

When conditions are known, the manufacturer shall analyze all GFRC units for handling stresses and temporary loadings imposed on the units prior to and during final incorporation into the structure.

The engineer of record should recommend the sequence of erection when the sequence may affect the structural stability of the supporting elements. In situations where the engineer of record or others provide product design for in-place loading conditions, the GFRC manufacturer should determine any additional requirements imposed by manufacturing and handling procedures.

The GFRC engineer shall be responsible for the design of all products for production, handling, and known erection stresses.
1.4.2 Shop Drawings

The manufacturer shall prepare and submit drawings for approval, as required, in general accordance with the PCI Drafting Handbook – Precast and Prestressed Concrete, MNL-119, and the project specifications. Production drawings shall be prepared to convey all pertinent information necessary for fabrication and inspection of the GFRC products.

1.5 Project Samples

1.5.1 General

After award of the contract, and before producing any units, the GFRC manufacturer shall prepare and submit for approval a representative sample or samples of the required color and texture. Any changes in the source of materials or in mix proportions to facilitate production shall require new reference samples and approval review. If specified, or if the color or appearance of the cement or the aggregates is likely to vary significantly, samples showing the expected range of variations shall be supplied.

The GFRC mixing, placement, and consolidation method used to make the sample shall be representative of the intended production methods.

1.5.2 Size and Shape

Samples shall be provided as required by the project documents.

The size of the sample shall reflect the relationship between materials (maximum size of aggregate to be used), finishes, shapes, and casting or spraying techniques, such as mold types, orientation of exposed surfaces, and consolidation procedures.

1.5.3 Identification

Samples shall be supplied for each of the different finishes for a project and all submitted samples shall be clearly identified.

C1.4.2 Shop Drawings

The primary function of GFRC shop (erection and production) drawings is the translation of contract documents into usable information for accurate and efficient manufacturing, handling, and erection of the units. The erection drawings provide the architect/engineer with a means for checking the interface between adjacent materials and the GFRC producer’s interpretation of the contract drawings. Production drawings should provide effective communications between the engineering/drafting and the production/erection departments of a GFRC plant.

C1.5 Project Samples

C1.5.1 General

All project samples should be submitted promptly for early acceptance to provide sufficient lead time for procurement of materials and production of units for the project.

Sample approval should be in writing with reference to the correct sample code number and written on the sample itself. Approval of the sample by the architect/engineer should indicate authorization to proceed with production, unless such authorization is expressly withheld.

If small samples are used to select the aggregate color, the architect should be made aware that the general appearance of large areas of a building wall may vary from the samples.

Color selection should be made under lighting conditions similar to those under which the GFRC will be used, such as the strong light and shadows of natural daylight.

C1.5.2 Size and Shape

For nonplanar, curved, or other complex shapes, a flat sample may not represent the anticipated appearance of the final product. Select sample shapes that will offer a reasonable comparison to the GFRC units represented.
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1.5.4 Visual Samples and Initial Production Approval of Architectural Finishes

Projects that use new shapes, shape combinations, finishes, or aggregates shall use a sample consisting of a full-scale portion of a unit for initial production approval. When approved, these samples shall form the basis of judgment for the purpose of accepting the appearance of finishes. These samples shall establish the range of acceptability with respect to color and texture variations, surface defects, and overall appearance. Samples shall be viewed at a distance consistent with their viewing distance on the structure but not less than 20 ft (6 m). Samples shall also serve as testing areas for remedial work. Approved samples shall be kept at the manufacturing facility and shall be used to monitor the acceptability of the production panels.

Mock-ups should be produced using production equipment and techniques. Special details, such as reveal patterns and intersections, corner joinery, drip sections, patterns, color and texture, and other visual panel characteristics should be demonstrated in large production samples for approval.

Small 12 in. (300 mm) square samples do not generally reflect the relationship between materials, finishes, shapes, placement techniques, mold types, thickness of section, orientation of exposed surfaces during production, and consolidation procedures. Previously completed projects, mock-ups, or samples may be used for initial production approval of products that are similar. Where mock-up units are not used, the manufacturer should request the architect/engineer and/or owner to inspect and approve (sign and date) initial production units. Larger production samples will remove uncertainties in the minds of the architect/engineer and owner alike.

At least three range samples of a size sufficient to demonstrate actual planned production conditions should be used to establish a range of acceptability with respect to color and texture variations, uniformity of returns, frequency, size and uniformity of air voids, distribution, surface blemishes, and overall appearance.

When specified, the acceptability of repair techniques for chips, spalls, or other surface blemishes should also be established on these samples.

See Appendix D, Finish Samples, for additional information.
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DIVISION 2 – PRODUCTION PRACTICES

Standard

2.1 General Objectives and Safety

2.1.1 General

The plant facility shall be adequate for production, finish processing, handling, and storage of product in accordance with this manual.

2.1.2 Plant Safety

Each operation shall establish and maintain a written program that encourages workers' safety and health. It shall be patterned after the OSHA Safety and Health Standard-29CFR 1910 and/or other jurisdictional safety and health standards.

Commentary

C2.1 General Objectives and Safety

C2.1.1 General

Plant facilities are the tools of the industry and should be maintained in good operating condition. Facilities suitable for the production of GRFC units will vary from plant to plant. These facilities will be affected by size, weight, volume of units produced, variety of surface finishes offered, and climate.

C2.1.2 Plant Safety

A safety program is an important element of any production operation. PCI encourages safety and loss prevention programs. The PCI Safety and Loss Prevention Manual, SLP-100, can be used to start a program. Such programs should outline general safety practices as related to the GFRC industry and existing federal regulations.

A safety program should include the following basic elements:

1. Policy. A written statement of plant or company policy for safety that establishes clear lines of authority.
2. Rules. Safety rules designed to help employees avoid injury.
3. Training. A training program to ensure that employees are instructed in safe operating procedures.
4. Accident Investigation. An accident investigation procedure to identify causes or areas needing improvement, better supervision, or employee training.

The details of a safety program are not specified in this manual, but are left to the individual plants to customize for their facilities, products, and operations.

2.2 Production and Curing Facilities

2.2.1 Area Requirements

The production and curing area(s) shall be designed for controlled production of GFRC units. The area(s) shall be of adequate size in relation to the volume and complexity of the products manufactured for a well-organized, continuous operation.

C2.2 Production and Curing Facilities

C2.2.1 Area Requirements

In design of the areas, consideration of production flexibility, flow patterns, health, and safety should be made. The production area should provide flexibility in planning and spacing of the forms. This area should facilitate efficient movement of workers, materials, and equipment. Provisions should be made to control the temperature with reasonable accuracy, as form release agents and other chemicals may react differently under varying temperature and humidity ranges. Adequate lighting should be provided for all operations.
All material shall be stored in a manner that will prevent contamination or deterioration and in accordance with applicable manufacturer's recommendations.

2.2.2 Mold Fabrication

Mold fabrication facilities shall be tooled to provide for the building of molds at a sufficient level of accuracy to produce the product within required tolerances.

Molds shall be stored in a manner that protects them from damage that could result in dimensional change or general surface or structural deterioration.

2.2.3 Storage of Release Agents and Retarders

Release agents and retarders shall be stored in accordance with manufacturer's recommendations, particularly with regard to temperature extremes. Before use, release agents and retarders shall be checked for sediment. If solids have settled out, uniformity and original consistency shall be maintained by periodic mechanical mixing or stirring in accordance with manufacturer's recommendations.

Release agents and retarders containing volatile solvents shall be stored in airtight containers to prevent a change in concentration. Release agents shall not be diluted unless specifically permitted by the manufacturer.

2.2.4 Steel Fabrication and Storage

Steel hardware shall be stored in bins or in areas that are clearly marked. All hardware shall be identifiable as to the size and source.

Panel frame facilities shall provide sufficient area for raw material storage, frame assembly, and frame storage prior to use. Materials shall be stored on a flat surface. Steel without corrosion protection shall be stored on blocks or racks.

Parts that require primer paint shall be stored in a manner that prevents loose rust from forming and prevents contamination. Stainless steel hardware shall be pro-
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tected from contamination with other metals during storage and fabrication.

Adequate space and equipment shall be provided for the construction of the panel frame. A weather-protected area shall be provided for welding operations.

Work benches or jigs where welding is performed shall be arranged so that the workers are protected from welding flashes. The area shall be ventilated to avoid the buildup of excessive welding fumes. If primer painting of panel frame is performed, it shall be done in an area with proper ventilation.

Electrodes used for welding operations shall be bought in hermetically sealed containers. Low-hydrogen SMAW electrodes shall be stored either in their original airtight containers or at the recommended elevated temperature in a suitable oven. Once containers are opened, welding electrodes shall be kept in drying ovens.

If hardware is fabricated by an outside supplier, that supplier shall furnish records of compliance to specification requirements and mill certificates for material used.

Periodic review of hardware fabrication shall be performed by quality control personnel at the fabrication area.

2.2.5 Production Area and Equipment

The production area shall provide adequate space for molds, materials, and equipment involved in placing the face mix, spraying the backing mix, initial curing, and stripping of products. All production areas shall be protected from wind, dust, and direct sunlight. Extremes of high and low temperatures that dry the sprayed material or delay the cure shall be avoided. Air currents that cause rapid moisture loss resulting in plastic shrinkage cracks shall be avoided.

Handling equipment for the face mix shall be such that it will convey the face mix from the mixer to the mold:

1. Without undue delay.
2. Without segregation of aggregates and paste.
3. In sufficient quantities to avoid undue delays in consolidation.
4. With uniform consistency.
5. With ease of discharge into molds.
6. With equipment capable of being easily cleaned and maintained.

Commentary

Light-gauge steel framing components may be ordered cut to length; however, some cutting will probably be necessary for most projects. Cutting may be accomplished with a saw or shear.

It is necessary to store some electrodes in a controlled environment to prevent moisture absorption into the flux from ambient humidity.

C2.2.5 Production Area and Equipment

Molds should be arranged for good aisle space, storage for parts of the mold, and cleanup of overspray such that good housekeeping is not difficult.
The slurry-handling equipment shall convey slurry from the mixer to the mold:

1. Without blockages that disrupt the spray-up process. The slurry hopper shall have a screen with openings of approximately 1/8 in. (3 mm) square to filter out lumps.
2. With uniform consistency of the GFRC mix.
3. With a well-atomized spray.
4. In sufficient quantities to avoid undue delays in placement.

Careful attention shall be given to the proper operation of the chopper gun and the spray head assembly. The equipment used in the spray-up process shall be in good operating condition. Air compressors shall be capable of supplying a minimum of 80 cfm (2270 l/min) of air at 100 psi (0.7 MPa) for each spray unit. Pump output shall be variable to allow optimization of slurry flow rates according to production demands and slurry flow parameters.

Spray guns and nozzle systems for GFRC slurries shall be capable of providing a well-atomized spray.

The function of the glass fiber chopper is to cut the AR glass fibers into desired lengths and to propel them into the slurry spray. This is accomplished by cutting blades mounted on a drum running against a rubber-covered wheel. The AR glass fiber roving is fed between the drum (cutter head) and the rubber-covered wheel (cot) and the fibers are actually broken by being bent by the blades. After being chopped, the fibers are propelled into the slurry where the slurry and fiber are mixed and carried to the mold surface.

Two types of pumps are generally used to convey the face mix and slurry to the nozzle or chopper gun: the peristaltic pump is used to pump face mixes and the rotor and stator type is used to pump slurries.

The concentric spray gun has the slurry spray head and roving chopper mounted together with the axes of their spray pattern in line. The fiber is sprayed through the center tube while the slurry is sprayed through the ring-shaped orifice around the center tube, Fig C2.2.5. It gives a much more uniform fiber distribution than the dual-head gun. Adjustment of air pressures for the fiber air-mover and the slurry atomizer modifies the spray pattern.
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The proper finishing tools shall be available to compact the GFRC composite in the mold.

2.2.6 Curing and Finishing Areas

The curing area shall provide sufficient protection and storage space until the product meets the curing requirements of Article 4.3.1. When an acrylic thermoplastic copolymer dispersion is used as a curing admixture, the plant shall be capable of maintaining a minimum panel temperature of 60 °F (16 °C) during initial cure (prior to stripping).

When moist curing is used, facilities shall provide a well-drained area with adequate covering to maintain the required relative humidity and temperature.

The finishing areas shall provide for the varying types of finishes to be produced by the plant (see Article 2.3).

Sand or Abrasive Blast (See Article 2.8.3). Large air compressor capacity, ample abrasive supply, adequate ventilation, and proper safety protection for the operator shall be provided. If blasting is done in an enclosure,

Lighting is extremely important in the finishing area and at the point where final inspection is made before transport to the storage area. This is where comparison to the approved samples is made for color and texture. Where possible, indoor lighting should compare to daylight as closely as possible.

Figure C2.2.5 Concentric spray gun.

Rollers are typically made of either plastic or aluminum. They should accept extension handles for use on large flat areas. A selection of trowels is useful for pushing material into edges, corners, and other fine details. Knives with replacement blades can be used to trim units after initial setting of cement.

Rollers should be cleaned immediately after each use to prevent buildup of slurry.

C2.2.6 Curing and Finishing Areas

Configuration of curing facilities will depend on the components being made and the method of curing.

Provisions should be made to control the temperature with reasonable accuracy, because chemical retarders and form release agents may react differently under varying temperature and humidity ranges. To meet the provisions of Division 5, it may be necessary to provide heating and/or proper ventilation for the spray area and the molds, depending on the geographic location of the plant.
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it shall be ventilated in such a way that a continuous inward flow of air will be maintained at all openings of the enclosure during the blasting operation.

Retarded Finish (See Article 2.8.4). Ventilation, removal of retarded cement paste, and rinse washing with proper disposal of the solids and solutions shall be provided.

Acid-Etched Finish (See Article 2.8.6). When performing acid etching or acid washing of panels, ventilation and protection for equipment and workers shall be provided. Special safety and disposal methods shall be observed.

In the case where units are to receive no further finish treatment prior to storage and delivery, they shall be protected from damage or staining that cannot be readily removed by cleaning.

Provision shall be made for an area to patch flawed or damaged products.

2.2.7 Handling Equipment

The production facilities shall include adequate product-handling equipment that is maintained in good working condition. Handling equipment shall be capable of stripping, moving, stacking, retrieving, and loading units without marking the finished surfaces or causing excessive stress in the units.

All lifting equipment shall be clearly marked with its appropriate safe load capacity. If mobile equipment is to be used, the ground shall be stable and firm for it to operate properly.

2.2.8 Storage Area for Finished Products

The storage area shall be of adequate size to allow safe storage and easy access to the products by the handling equipment. The area shall be clean, well drained, and stabilized to minimize differential settlement under all weather conditions, soiling, and damage of the product. Refer to Article 2.7.3 for dunnage requirements.

Storage racks shall be designed to safely store product to prevent units from tipping over and damaging adjacent units. Storage racks shall be well constructed to minimize warping, bowing, chipping, or cracking of the products.

Commentary

A high-pressure, low-volume water pump is normally used.

Dip tanks, brushing, or high-pressure, low-volume hot water pumps are normally used.

C2.2.7 Handling Equipment

The type and capacity of handling equipment used for handling materials and products will depend on size, configuration, and the operating conditions.

C2.2.8 Storage Area for Finished Products

Access should be provided in the storage area to allow for production inspection.

The subgrade in the storage area should be stabilized to avoid soft spots where one end of a member can settle. This settlement creates twisting or tensile stresses that can cause cracking and damage. For example, units should not be stored on frozen ground without proper safeguards to prevent settlement when the ground thaws. The storage area should be inspected after hard rains or large snowmelts for washouts and other damage.
Where necessary, such storage equipment shall be protectively coated to avoid staining or discoloration of the finished products.

Overhead wiring and other overhead obstructions in the storage area shall be clearly marked.

### 2.3 Panel Frame

#### 2.3.1 Fabrication

The production facilities shall include adequate area for fabricating panel frames and other items of hardware.

The panel frame shall be fabricated in accordance with approved shop drawings.

Fixtures used to fabricate panel frames shall be rigid enough to maintain dimensional control and squareness of frames. All weld areas shall be accessible to the welder. All welds shall be performed in accordance with written Welding Procedure Specifications (WPS) by certified welders qualified in accordance with AWS D1.1 and D1.3.* Allowances for welding of flex, gravity, and seismic anchors to accurate dimensions shall be designed into the fixtures. All flex anchors shall be oriented and installed as shown on the approved shop drawings.

When light-gauge steel is welded, it shall be a minimum of 16 gauge \[0.0598 \text{ in. (1.52 mm) nominal, 0.0566 in. (1.44 mm) design, 0.0538 in. (1.37 mm) minimum uncoated thickness}\] material. Care shall be taken when welding plates and angles to the light-gauge steel to prevent burn-through, because burn-through can significantly alter the section properties of the member and the strength of the welded connection.

* Titles for all standards and other documents referred to in the manual are given in Appendix J.
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**Standard**

Galvanized steel shall be welded in accordance with AWS D1.1 and D1.3.

**Commentary**

Removal of zinc coating is the preferred approach for welding galvanized steel. If removed, the welding procedures will be the same as for uncoated steel. Zinc can be removed by burning with an oxygen-fuel gas torch, shot blasting with portable equipment, or grinding with an abrasive disc. In general, metal arc welding procedures for galvanizing steel are similar to procedures for welding uncoated steel. However, welding of galvanized steel requires a welding procedure qualified in accordance with AWS D1.1 and D1.3.

The prefabricated panel frame will be moved several times both before and after skin attachment; therefore, welded rather than screw connections are recommended.

The size, length, type, and location of all welds shall conform to those shown on the shop drawings, and no unspecified welds shall be added without approval of the design engineer. Surfaces to be welded, and surfaces adjacent to a weld, shall be uniform, free from fins, tears, cracks, and other discontinuities, and free from loose or thick scale, slag, rust, moisture, grease, and other foreign material that would prevent proper welding or produce objectionable fumes. Mill scale that can withstand vigorous wire brushing, a thin rust-inhibitive coating, or antispatter compound may remain.

Slag from each pass shall be completely removed before depositing the next pass to avoid porosity and slag entrapment. Slag shall be removed from all completed welds, and the weld and adjacent base metal shall be cleaned by brushing or other suitable means. Tightly adherent spatter remaining after the cleaning operation is acceptable. Accessible welds of corrosion protected material (galvanized or painted) shall be slagged and touched up after welding. Zinc-rich paint shall be brush- or spray-applied to a thickness of approximately 0.004 in. (100 µm) over the welded areas to replace the removed or damaged galvanizing or in conformance with ASTM A780.

For welding in cold temperatures, preheat guidelines as specified in AWS D1.1 and D1.3 shall be followed.

**2.3.2 Verification**

Panel frames shall be fabricated with sufficient lead time to allow for proper inspection. The components, dimensional accuracy, and welding of each frame shall be inspected and recorded.

Panel frame inspection shall include the following:

1. Review of welding drawings, Welding Procedure Specifications (WPS), and welders’ certification.
2. Assurance that welding materials and consumables are in accordance with WPS.
3. Checking and identifying materials as they are received against WPS.

C2.3.2 Verification

Welds should be inspected on all light-gauge members for burn-through conditions, because burn-through can significantly alter the section properties of the member and the strength of the welded connection.
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4. Checking storage of filler material.
5. Checking equipment to be used.
7. Verifying the application of the approved welding procedure.
8. Verifying size, length, soundness, and corrosion protection of welds.
9. Verifying size, length, and location of screws.
10. Maintaining records.

Each frame assembly shall be marked and traceable to a welding operator or operators. Inspected and approved frames shall be marked by the inspector.

All defects found during inspection of panel frames shall be corrected.

#### Commentary

2.4 Molds

2.4.1 Materials and Construction

All molds, regardless of material, shall conform to the profiles, dimensions, and tolerances indicated by the contract documents and the approved shop drawings.

Molds shall be dimensionally stable to produce the required finish and tolerance. Repeated use of molds shall not affect the dimensions or planes of the molds beyond allowable tolerances. The mold fabrication and setup tolerances shall be sufficient to produce units within specified tolerances. Mold materials shall not warp or buckle due to temperature change or moisture, which can cause unsightly depressions and uneven swells in the finished surface. The mold materials shall be nonabsorbent or sealed to prevent excessive moisture absorption in order to minimize variations in finish due to differential moisture movements resulting from varying degrees of absorbency. The manufacturer shall evaluate the effect of different materials on the color of the finished surface when they are combined in the same mold.

Ideally, all corners should have a radius or have fillets. Chamfers, rounded corners with a minimum 1/8 in. (3 mm) radius, draft or slope to vertical walls (minimum 5 degrees), built-in air connections, and/or jacking points help to increase mold life by making stripping easier. In instances where vertical faces are required, molds should be designed so that the vertical portion of the mold is removable or collapsible.

Collapsible cores or blockouts are advisable for openings within panels to accommodate drying shrinkage. It may also be necessary to make molds oversized to allow for this shrinkage.

In general, the mold fabrication and set-up tolerances should be one-half of the tolerances of the units they are to produce, or a maximum of ±1/8 in. (±3 mm). Window openings require that a high degree of accuracy be maintained for sealing...
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Molds shall be coated with release agents that will permit release without damaging or staining the GFRC and without affecting subsequent coating, painting, or caulking operations. Release agents shall be applied in accordance with manufacturer’s directions. Just prior to applying a release agent, the surface of the mold shall be clean and free of water, dust, dirt, or residues that could be transferred to the surface of the GFRC or affect the ability of the release agent to function properly. Excess release agent shall be removed from the mold surface prior to spraying or casting.

The selection of a release agent should include investigation of the following factors:

1. Compatibility of the agent with the mold material, form sealer, or admixture in the GFRC mix.
2. Possible interference with the later application of sealants, sealers, or paints to the mold contact area.
3. Discoloration and staining of the GFRC face.
4. Amount of time allowed between application of spraying and the minimum and maximum time limits for molds to stay in place before stripping. The release agent may require a curing period before being used. If too fresh, some of the release agent will become embedded in the GFRC.
5. Effect of weather and curing conditions on ease of stripping.
7. Meeting current local environmental regulations regarding the use of volatile organic compound (VOC) compliant form release agent.

Applying too much of the release agent can cause excessive surface dusting on the finished surface.

Mineral oil, oil-solvent-based release agents, or paraffin wax should not be used on rubber or elastomeric liners as the hydrocarbon solvent will soften the rubber. The rubber or elastomeric supplier’s recommendations should be carefully followed.

Molds shall be built sufficiently rigid to provide dimensional stability during handling. The assembled mold shall not allow leakage of water or cement paste. Joints in the mold material shall be made so that they will not be reflected in the surface and mar the appearance of the product.

Molds shall be capable of supporting their own weight and the weight of the applied GFRC without deflection or deformation. Molds shall be sufficiently rigid to withstand the forces necessary for consolidating a face mix and if required, should be capable of transmitting the vibration over a sufficient area in a relatively uniform manner.

The spray gun should be able to gain access to all parts of the mold. Hand-placing GFRC into inaccessible mold features is more difficult. Special attention should be given when hand-placing GFRC to achieve a well-compacted, high-quality product with the required thickness.

Panel skin size limitations require molds that allow for skin control joints in large units that will use one continuous panel frame.
Mold design shall take into account the special requirements of GFRC products. Sharp angles and thin projections shall be avoided whenever possible and chamfers or radii at inside corners of the mold shall be incorporated due to the possibility of fiber bridging at the corner. Mold parts shall allow for stripping panels without damage.

Whenever possible, molds should have sufficient draft to facilitate stripping with a minimum of mold breakdown. Generally, the minimum draft that will enable a unit to be stripped easily from a mold is 1 in. in 12 in. (25 mm in 300 mm) (5 degrees). This draft should be increased for narrower sections or delicate units as the suction between the unit and the mold then becomes a major factor in both design and stripping. The draft should be increased to 1:6 (10 degrees) for screen units with many openings, or for ribbed panels. Drafts for ribbed panels should be related to the depth and spacings of the ribs. The drafts selected for finish consideration will vary due to shapes and techniques proposed for production.

Molds shall permit controlled, fixed positioning or jigging of hardware and allow for the suspension or placement of the panel frame. Supports for molds shall prevent undesirable movement. Blockouts shall be of the size, shape, and location as shown on the shop drawings. Blockouts shall be held rigidly in place within tolerance. Mold parts shall allow for stripping without damage to the units.

Molds shall be designed to prevent damage to the GFRC from: (1) restraint as the GFRC shrinks; and (2) the stripping operation.

Wood molds shall be sealed with suitable materials to prevent absorption. The sealer manufacturer's instructions regarding application shall be followed. Sealing molds minimizes nonuniformity in the surface finish and will stabilize the mold dimensions. For some sealers, there are minimum temperatures stated, below which they must not be applied. An appropriate drying or curing time should be allowed.

Concrete molds shall be treated with a coating that renders the concrete nonabsorbent to reduce mold damage and to improve the release of the product during the stripping operations.

GFRC mold skin shall be sufficiently thick to hold up during the required number of reuses. The backing frame shall be sufficiently stiff to assure mold rigidity. The surface shall be treated with a coating to enhance its release characteristics.

Producing a GFRC mold is similar to producing a GFRC panel. As a forming material, GFRC has similar characteristics to concrete. Particular effort should be made to provide adequate draft on all mold surfaces in the direction of the release, so that the product may be easily removed without damage to either the panel or the mold. Molds should be made with dense surfaces, typically a mix with a polymer, and be well compacted. Even very fine hairline cracks in the mold will be visible in the finished products.

Plastic molds shall not be used when curing temperatures above 140 °F (60 °C) are anticipated. The susceptibility of the plastic mold to attack by the proposed release agent shall be determined prior to use. Surface maintenance of the resin cover is mandatory for surface uniformity and can be accomplished by careful cleaning, use of a release agent, or occasional touch-up of the surface.
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conditions, joints, and gel coat material shall be visually inspected prior to each use.

Steel molds shall be visually inspected prior to each use for rust, welding distortion, and tightness of steel sheet joints.

Care shall be taken to use mold release agents that are compatible with elastomeric mold liners.

2.4.2 Verification and Maintenance

The mold surfaces and dimensions shall be checked in detail after construction and before the first unit is made and after any modifications. A complete check of the first product from the mold shall be performed. Molds shall be thoroughly cleaned and inspected before each use for defects that will affect performance or appearance.

Steel molds should be well braced and frequently examined for bulging or buckling. Dimpling, twisting, or bending may occur if they are not properly stacked for storage. When joining two or more steel sheets by welding, care is required to avoid distortion from the heat of the welding operation. If joining is required, the welds should be ground smooth and coated with an epoxy or similar material to hide the joint. It is recommended that a test section be produced at the joint to determine that the joined area produces an acceptable product.

C2.4.2 Verification and Maintenance

When a new mold is placed into production, a complete dimensional check should be made, taking into account main dimensions, warping, squareness, flatness, reveals, blockouts, and quality of the surface finish. Fixtures and/or templates can aid in checking. The report of this check should be kept on file.

The molds should be reassembled within the dimensional limitations specified for the product on the shop drawings. The overall length, width, thickness, and other basic dimensions should be checked on all sides of the mold. The squareness of the mold should be checked by comparing diagonal measurements to the corners of the mold. Any discrepancy noted in mold dimensional accuracy should be transmitted to production personnel for correction.

A basic assessment of the mold should be made by the spray team in advance of spraying. Assessment should ensure that:

1. The molds have been assembled correctly within specified tolerances.
2. The release agent has been properly applied without excessive ponding.
3. Overspray, dust, and the like have not contaminated the mold surface.

Bulkheads, templates, and similar equipment shall be regularly inspected and maintained as necessary. All anchorage locations on the mold for holding any set-in materials to a given position shall be checked. If more than one mold is used to produce a given unit, a comparative dimensional check shall be made.
2.5 Anchors, Inserts, and Hardware

2.5.1 Installation

The placement of flex, gravity, and seismic anchors, handling and lifting devices, and connection hardware on the frame shall be checked prior to the frame installation on the panel skin to verify that they are accounted for, are of the proper size and type, and are accurately located as detailed on the shop drawings.

Inserts and embedments shall be firmly held in the correct position during production by jigs, beams, templates, or mold brackets. They shall be properly embedded in built-up homogeneous GFRC bosses or bonding pads that shall be monolithically integrated into the GFRC backing. Installation shall take place while both the pad and the skin are in a fresh state to prevent "cold joints" from occurring. Boss installation shall be in accordance with dimensions determined from insert tests conducted for panel-design purposes. Encapsulated inserts shall protrude slightly above the surface of the GFRC and the depth of thread shall be constant for the same-size insert throughout a particular project.

Encapsulating wood in GFRC panels, even if the wood is sealed, shall be avoided because the tendency of wood to swell under moist conditions can cause cracking of the GFRC.

C2.5 Anchors, Inserts, and Hardware

C2.5.1 Installation

Location of lifting hooks and inserts should be determined carefully to avoid excessive stresses in the units during handling. Lifting points should be located relative to the center of gravity of the unit.

All lifting devices, temporary bracing, and other hardware are usually attached to the panel frame. Anchors and inserts embedded in GFRC should have fully compacted, fresh GFRC material surrounding them in order to develop design strength (Fig. C2.5.1). Excess GFRC from trimming operations is not to be used.

![Figure C2.5.1 Insert Connection Details for Panels without Panel Frame](image)

Insert attachments should bear directly upon the insert, not the GFRC surface, to prevent pullout of the insert when the bolt is tightened.

A typical size and thread depth for inserts on projects will minimize the possibility of erection crews using the incorrect size and length of bolts.

Rigid embedded items that are bonded to the panel skin, such as steel more than 6 to 12 in. (152 to 305 mm) long, may create undesirable restraint due to volume changes and may cause overstressing of the GFRC. Isolation of embedded items, use of a bondbreaker, discontinuity of a rigid item, or an increased section of material may be used to minimize the risk of overstressing.
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2.6 Product Identification

GFRC units shall be clearly marked with a unique identification as shown on the shop drawings. Identification shall be sufficient to distinguish the date of spraying and trace the GFRC unit to associated quality control records.

2.7 Product Handling

2.7.1 Stripping

Stripping shall not be performed until all removable parts of the mold are released or removed. Lifting equipment shall be in good operating condition and properly secured to the unit.

Care shall be exercised in removing the GFRC panel from the mold to prevent damage to the unit from overstressing or chipping. Panels shall only be stripped at points indicated on approved shop drawings or as approved by the plant engineering department. Initial lifting shall be made cautiously and gradually.

Immediately after stripping, bonding pads and bosses in the vicinity of lifting points shall be examined for cracking. Cracked bonding pads shall be marked on the panel for repair.

Commentary

C2.6 Product Identification

Product identification may be made in the wet GFRC painted on the units or with tags, provided the tags are securely fastened to the units. Product identification should remain legible while in storage.

C2.7 Product Handling

C2.7.1 Stripping

Significant panel stresses are often produced during demolding. Proper care should be taken to minimize demolding stresses and keep them within acceptable limits.

The panel will not have achieved its fully cured properties at the time of stripping. Therefore, panel and mold design should allow sufficient lifting points and easy release from the mold without overstressing.

Stresses imposed on the panel skin during stripping of the panel from the mold, handling, transporting, or erecting should remain below the flexural yield strength at the specific time of that operation. The stresses due to stripping depend on the shape of the element, the location of the handling points, and the type of mold and release agent used. Handling stresses that are created as a result of the panel being manufactured in an orientation different from that of its service life and the low strength at stripping of the GFRC should be taken into account in the design of the panel. Panels should be checked for cracks while under load during stripping.

Prying with screwdrivers, knives, or other tools between the unit and the mold surfaces to loosen a unit should be discouraged, as it will invariably lead to unit and/or mold damage.

If difficulty is encountered in stripping the panel, some or all of the following items should be investigated:

1. Inadequate or improper use of mold release.
2. Insufficient curing.
3. Failure to clean overspray from edges of mold.
4. Improper mold or panel details, inadequate draft angles, sharp corners, panel shrinkage inadequately allowed for, and lack of stripping or handling lugs and fittings.

The center of gravity should be shown on all panel production drawings and used by the stripping crew to determine proper rigging requirements or the lifting points should be shown on the production drawings.
2.7.2 Handling

All GFRC panels shall be handled in a position consistent with their shape, size, and design. The number and location of lifting points for handling of elements and details of lifting devices shall be considered integral parts of the design of GFRC units and shall be shown on the shop drawings.

Panels shall be handled to avoid structural damage, cracking, architectural impairment, or permanent distortion.

During handling, the units shall not be subjected to excessive stresses (limit stresses to values compatible with the strength of the GFRC) caused by vibration, impact, or lateral forces.

All means of fastening and rigging shall comply with governing safety practices. Proper attention to safety and prevention of damage to units shall be a prime consideration in all operations.

2.7.3 Yard Storage

The storage area shall be laid out in a manner to help ensure delivery and storage of the units without damage. GFRC panels shall be supported by the panel frame and stored on unyielding supports at designed locations. Units shall be stored on a firm, level, and well-drained surface with identification marks visible. Dunnage and storage racks, such as A-frames and vertical racks, shall be well constructed and aligned to minimize warping, bowing, chipping, or cracking of the GFRC panels and stabilized against potential lateral loads. Protective material shall be provided at points of contact with exposed surfaces. All blocking, packing, and protective materials shall be of a type that will not cause damage, staining, or objectionable disfigurement of the panels. Staggered or irregular blocking shall be avoided. When setting one panel against another, nonstaining protective blocks shall be placed immediately in line with the supports of the first panel.

When long panels are stored vertically, horizontal support shall be provided at each end.
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The GFRC panels shall be protected from contact with earth, oil, gas, tar, or smoke. Any soiling or weathering of units, which would result in a pattern different from the normal weathering as finally installed, shall be avoided by storing in a manner similar to their final position, or by suitable protection from such soiling or weathering. Embedded items shall be protected from penetration of water or snow during cold weather.

2.7.4 Cleaning

All surfaces of the GFRC units to be exposed to view shall be cleaned, as necessary, prior to shipping to remove dirt and stains that may be on the units. The cleaning procedures shall not detrimentally affect the surface finish.

Commentary

To prevent rust staining on finished surfaces, all exposed metal inserts, anchorages, and other hardware should be coated with a rust-preventive material.

Panels stored leaning on one another may induce high stress loads in long storage lanes. The “domino effect” (cumulative loading) should be considered. Panel units should be stacked against both sides of the supports to equalize loading and to avoid potential overturning.

Two-point support is recommended because if support is continuous across three or more points, the panel may bridge over one of the supports (because of differential support movement) and result in bowing and cracking.

Often the manner of storing depends on how the panel is to be shipped and what limitations the panel’s cross sections impose on handling. Where practical, the panel should be stored in the same manner in which it will be shipped.

Exposed (finished) surfaces should be carefully spaced using a molded plastic bubble spacer suitably positioned to minimize the contact area in order to prevent differential curing or drying of the surface, which will produce permanent color variations. Stacking some units so air circulation and sunshine cannot reach the faces, leaving some units indoors, or having variations in curing technique can affect the uniformity of the color of the finished units for the project. It may be desirable to face the skin toward the north to minimize color variation.

C2.7.4 Cleaning

A small area should be cleaned and appraised to be certain there is no adverse effect on the surface finish before proceeding with the work.

For information on removing specific stains from GFRC, reference should be made to “Removing Stains and Cleaning Concrete Surfaces,” IS 214, published by the Portland Cement Association, Skokie, IL.

It may be necessary to remove efflorescence that may occur to various degrees on panel surfaces. Efflorescence is a crystalline deposit of salts, usually white, caused by soluble alkalies that migrate to the panel surface with evaporating water. Discoloration may occur, but is usually temporary. Efflorescence is most apparent on dark surfaces and might not be seen on a light or white surface. Efflorescence occurs most frequently when a slower rate of evaporation due to low temperature and high relative humidities allow excessive migration of the salts to the surface.
2.7.5 Loading

Units shall be loaded as necessary:

1. To permit their removal for erection from the load in proper sequence to minimize handling.
2. With proper supports, blocking, cushioning, and tie-downs to prevent or minimize in-transit damage.
3. With proper padding between GFRC and chains or straps to preclude chipping of the GFRC edges or damage to returns.
4. To support the panels in a manner that minimizes relative movement between the panel frame and the skin.

The blocking points and orientation of the units on the shipping equipment shall be as designated on the shop drawings or established plant procedures. Care shall be taken to ensure that the unit is supported by the panel frame during transport, or that special blocking between the skin and the frame at support points is provided to transfer the loads to the panel frame.

Blocking, packing, and other protective materials shall not cause damage, staining, or other disfigurement of the units.

2.8 Face Mix/Veneer Finishes

2.8.1 General

Each plant shall develop quality requirements for all architectural finishes prior to undertaking actual production of such finishes. Such requirements shall include samples and production procedures. A finishing process shall produce an acceptable uniform appearance without detriment to required material properties.

All finishes of GFRC units shall be stated on shop drawings. Reference samples or mock-up units shall be available in the plant so that all concerned can be sure that standards of finish and exposure are being maintained. These samples shall be protected during the course of the project to prevent any unwanted changes in appearance with time.

C2.8 Face Mix/Veneer Finishes

C2.8.1 General

White cement is recommended to be used in all face mixes.

Returns can be accomplished by spraying when the aggregate is small enough to be pumped and sprayed. The mix will have to be adjusted to stick on the return without slumping. There can be uniformity differences in face mix finishes sprayed on the down face in the mold versus returns. The preferred method for large returns is to spray returns separately and joint the panels with a caulked joint. This enables all faces to be cast with the same orientation.

The fine particle size of the cement-sand slurry matrix allows it to closely follow the surface texture or pattern of the mold. However, the extent to which the glass fibers are able to penetrate surface detail depends on the scale of the detail.

It should be recognized that some blemishes or variations in color occur in GFRC. For example, units containing aggregates and matrices of contrasting colors will appear less
Whether the surface finish material is a face mix or a veneer material, the volume-change characteristics shall be compatible with those of the GFRC backing.

The extent to which aggregates are exposed or “revealed” is largely determined by their size. Reveals shall be no greater than one-third the average diameter of the coarse aggregate particles and not more than one-half the diameter of the smallest-sized coarse aggregate.

GFRC backing mixes have a much higher cement content than conventional concrete. Consequently, integral face mixes that have historically been used with conventional concrete may not be compatible with GFRC backing mixes for the following reasons:

1. Differences in initial shrinkage.
2. Differences in thermal-induced volume changes.
3. Differences in moisture-induced volume changes.

In cases of volume-change differentials of the mixes in conjunction with panel frame restraint, high stresses are developed as a result of the bowing being restrained by the panel frame and anchors. Therefore, only compatible face mixes should be used so that stresses resulting from restrained bowing are minimized. Comprehensive testing is necessary to develop compatible integral face mixes, considering aged properties of the GFRC.

When an integral face mix is used, the moisture and thermal-induced volume changes of the face mix may cause overstressing and/or bowing in the panel because the GFRC backing mix is shielded from the elements and, consequently, the associated volume changes. Compatibility of the face mix and backing mix will minimize this potential. Introducing skin joints to keep panel segments smaller in size may also alleviate this problem.

Clay-product veneers, which are rigidly bonded to the GFRC backing, are discouraged due to volume-change considerations. With stone, current practice is to use mechanical anchors and prevent bond to the GFRC backing.

When using an unbonded, mechanically attached veneer finish material, an attachment system must be designed to accommodate the incompatibility of that material with the GFRC backing.
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A demarcation feature, a skin joint, or change of plane shall be incorporated into the surface of a GFRC panel having two or more different mixes or finishes. The different face mixes shall have reasonably similar behavior with respect to shrinkage in order to avoid cracking at the demarcation feature due to differential shrinkage.

The appearance, color, and texture of the surface finish of all units shall match within the acceptance range of the color, texture, and general appearance of the approved sample panels.

2.8.2 Smooth

The molds shall be carefully made and finished so as to present a smooth, unmarked surface. If air voids are anticipated on return surfaces, the sample shall be used to establish acceptability of such voids with respect to frequency, size, and uniformity of distribution of the voids.

As a general rule, a textured surface is aesthetically more satisfactory than a smooth surface because the texture of the surface, to a very large extent, camouflages subtle differences in texture and color of the GFRC.

C2.8.2 Smooth

Even with good quality control, smooth finished GFRC will exhibit some negative aesthetic features such as shadowing, ghosting, and blotchiness, especially on nonprofiled flat panels.

When air voids of a reasonable size, ¼ to ⅛ in. (3 to 6 mm) are encountered on return surfaces, it may be desirable to retain them rather than filling and sack rubbing them in. Color variations can occur when sacking is performed.

A mist coat is often applied directly to the surface of the mold prior to spray-up, especially where the surface of the panel will not be post-coated or painted. When applied correctly, the mist coat will pick up all the details of the mold surface but will not result in too thick a cement-rich layer on the surface of the unit.

A smooth, off-the-form finish is not recommended as it may be one of the most difficult to produce, and color uniformity may be difficult to achieve. The cement exerts the primary color influence on a smooth finish because it coats the exposed GFRC surface. Many of the aesthetic limitations of smooth GFRC may be minimized by the shading and depth provided by profiled surfaces (fluted, sculptured, board finishes, etc.), subdividing the panel into smaller surface areas, or using white cement.

The smooth cement film on the GFRC may be susceptible to surface crazing, such as fine and random hairline cracks, when exposed to wetting and drying cycles. This is, in most cases, a surface phenomenon and will not affect structural properties or durability. In some environments, crazing will be accentuated by dirt collecting in these minute cracks. This will be more apparent in white than gray finishes and in horizontal more than in vertical surfaces. The use of polymer curing admixtures in the mist coat or face mix may minimize crazing.
Standard

2.8.3 Sand or Abrasive Blast Finish

The type and grading of abrasives affect the surface finish and shall remain the same throughout the entire project.

Commentary

C2.8.3 Sand or Abrasive Blast Finish

Sand or abrasive blasting of surfaces is suitable for exposure of large and small aggregates. Uniformity of depth and exposure is essential for achieving an acceptable finish. Skill and experience of the operator plays a significant role in achieving a uniform finish. Consequently, the same blasting crew and equipment should be used for the duration of the project when possible.

Differences in shading and, to some extent, color will vary with the degree of aggregate exposure. The age of the unit at the time of blasting will also affect the rate of material removal and depth of aggregate exposure. The age and strength of the concrete at the time of blasting should be consistent throughout the project to help achieve the desired finish.

The degree of uniformity obtainable in a blasted finish is generally in direct proportion to the depth of removal. A light blasting may look acceptable on a small sample, but uniformity is difficult to achieve in a full-size unit. A light blast will emphasize visual defects and reveal imperfections previously hidden. The lighter the blast, the more critical the skill of the operator becomes. This is particularly true in sculptured units.

Sculptured units generally will have air voids on the returns, which may be accentuated by a light blast. Due to the difficulty of obtaining such a finish, small air voids up to 1/4 in. (6 mm) should be considered acceptable, as sack rubbing may cause an undesirable color variation.

Brush blasting, which is little more than uniform scour cleaning, is used to remove minor surface variations. A brush-blast surface seldom appears uniform at close inspection. Consequently, it should be viewed at a distance for determining acceptability. This finish is normally used on features such as reveals for accentuating an area. It is also commonly used to help improve the bond of applied coatings.

“Bank” or “river” sand should not be used as a blasting abrasive.

2.8.4 Retarded Finish

Surface retarders that are to be used to expose the aggregate shall be thoroughly evaluated prior to use. A sample panel shall be made to determine the effects created by the mold and GFRC materials. This involves using the cement, aggregate, and specific mix selected for the product.

C2.8.4 Retarded Finish

Retardation involves the application of a specialized chemical to the face mix surface (normally the mold surface) that delays the surface cement paste from hardening for a time period and to a depth depending upon the type or concentration of retarder used.
When using a retarder, the manufacturer’s recommendations shall be followed. Surface retarders shall be uniformly applied by roller, brush, or spray.

Chemical retarders are available for the face-down or face-up methods of casting, and for horizontal as well as vertical surfaces. Retarders are available for light, medium, and deep exposures. The degree of uniformity normally improves with an increased depth of exposure.

The effectiveness of the retarder will vary as it is extremely sensitive to changes in the rate of hydration due to different temperatures, humidity, or water content of the face mix. The depth of reveal or retardation will be deeper:

1. The wetter the mix
2. The slower the time of set
3. The more aggregate in the mix
4. The closer together the coarse aggregate
5. Depending on the type and concentration of the retarder

Retarders function by delaying, not preventing, cement hydration. This concept will help in analyzing various mix designs for depth of retardation. For example, as the sand or coarse aggregate in the mix increases, there will be less cement paste per volume of material at the surface. This change in the mix proportions will result in a deeper exposure for similar retarder concentrations. It should be noted that some retarders are effective for long periods of time while others are only active for a few hours.

Water shall not contact the retarder on the mold surface before the GFRC is placed. Water activates the retarder.

The retarded surface shall be exposed by removing the cement paste to a level that matches the approved sample. The retarded cement paste should be removed the same day that the units are stripped. Delays in removing the paste will result in a lighter, less uniform etch. Preliminary tests should be performed before planning the casting for a large project to determine the most effective finishing time. The timing of surface-finishing operations should be consistent from day to day.

Formliner panels shall be secured in molds by methods that will not permit impressions of nail heads, screw heads, rivets, or the like to be imparted to the surface of the GFRC unless this feature is desired. Steps shall be taken to camouflage anomalies to within the pattern of the texture.

Formliners may be incorporated in or attached to the surface of a mold to produce the desired pattern, shape, or texture in the surface of the finished units. The method of attaching the formliner should be studied for resulting visual effect.

A formliner texture can be of considerable influence in assisting as-cast surfaces to appear more uniform. Formliner material selection depends on the amount of usage and whether or not the pattern has undercut (negative) drafts. Matching joints between liners is very difficult. Liners should either be limited to widths less than the available width of the liner or liner joints should be at mold edges or be detailed as an architectural feather in the form of a groove, recess, or rib.
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2.8.6 Acid-Etched Finish

In cases where aggregate is to be exposed to a considerable depth, acid-resistant siliceous aggregate shall be used.

To provide a uniform finish, the acid shall be applied at consistent face-mix temperatures and strength levels.

The GFRC unit shall be well wetted with clean water prior to acid treatment to help control the rate and depth of penetration. Acid shall not be allowed to remain on the surface longer than 15 minutes. Deep etching shall be achieved by multiple treatments. After completion of acid etching, the unit shall be thoroughly flushed with water.

Prewetting the GFRC with water fills the pores and capillaries and prevents the acid from etching too deeply, and also allows all acid to be flushed after etching. Failure to completely rinse the acid solution off the surface may result in efflorescence or other damaging effects.

C2.8.6 Acid-Etched Finish

Acid etching may be accomplished by: (1) brushing the surface with a stiff-bristled brush that has been immersed in the acid solution; or (2) spraying acid and hot water onto the panel surface using specially designed pumps, tanks, and nozzles.

Acid etching is most commonly used for light or medium aggregate exposure. Acid etching of GFRC surfaces will result in a fine, sandy texture if the face mix is uniform and properly consolidated. Nonuniform GFRC mixtures, aggregate color, and acid application techniques may cause appearance problems. The potential for appearance problems increases with large planar surfaces and light acid-etching techniques. Carbonate aggregate, such as limestone, dolomite, and marble, may discolor or react with the acid due to high calcium content.

With light textures, the color compatibility of the cement and the aggregate is more important. White or light colors are more forgiving to the eye and increase the likelihood of a better color match between units. There is a minimum depth of etch that is required to obtain a uniform surface. To attempt a lighter texture may result in a blotchy finish. A light depth of reveal only exposes sand and the very tips of the coarse aggregate.

It is difficult to achieve a light exposure that is uniform on highly sculptured panels. This is due to the acid concentrating in areas such as inside corners. This may, however, be acceptable if the sculpturing creates differential shadowing.
Prior to acid etching, all exposed metal surfaces, particularly galvanized metal, shall be protected. Metal surfaces damaged by acid shall be treated with a compatible protective coating.

Effective coatings include vinyl chlorides, chlorinated rubber, styrene butadiene rubber (not latex), bituminous paints, enamels, and polyester coatings.

Galvanized metals may be repaired with a minimum 3 mil (0.08 mm) thickness of a single component, zinc-rich compound with 95% pure zinc in the dried film.

If parts of the GFRC surface are not to be acid etched they may be coated with an acrylic lacquer.

Quality requirements for design and production procedures with attached veneer facing materials shall be established on the basis of prior experience or test samples.

Color control or blending for uniformity of stone should be done by the stone plant, as the desirable characteristics are easier to see during the finishing stages. A qualified representative of the owner who understands the aesthetic appearance required by the owner or architect should perform this color control. Acceptable color of the stone should be judged for an entire building elevation rather than for individual panels.

All testing to determine the physical properties of the stone veneer with the same thickness and finish as will be used on the structure should be conducted by the owner prior to the award of the contract. This will reduce the need for potentially costly repairs or replacement should deficiencies in the stone veneer be found after start of fabrication.

Cut stones that are easily stained by oils and rust shall be protected by lining the forms with polyethylene sheet or other nonstaining materials.

A complete bond breaker between the natural stone veneer and GFRC shall be used. Bond breakers shall be one of the following: (1) a minimum of 4 mil (0.1 mm) polyethylene sheet; (2) a 1/8 in. (3 mm) polyethylene foam pad or sheet; or (3) a liquid bond breaker applied to the back surface of the veneer prior to spraying the GFRC. The bond breaker shall prevent GFRC from entering the spaces between the pieces of veneer. The veneer shall be connected to the GFRC with mechanical anchors that can accommodate the expected magnitude of relative movement due to differential volume change. Preformed anchors fabricated from Type 302 or 304 stainless steel shall be used unless otherwise specified. Close supervision is required during the insertion and setting of the anchors. Anchors placed in epoxy shall not be disturbed until the epoxy has cured. Care shall be taken to ensure compaction of the GFRC around the anchors.

Care should be taken so that differential stone thickness does not constrain the GFRC skin.
When using epoxy in anchor holes, 1/2-in.-long (12 mm) compressible rubber or elastomeric grommets or sleeves shall be used on the anchor at the back surface of the stone. The epoxy manufacturer’s recommendations for mixing and curing temperature limitations shall be followed. The strength of the stone anchorage system shall be determined to ensure adequate strength for handling, transportation, erection, and service conditions.

Veneer joints within a GFRC element shall allow for differential movement between materials in the mold. Veneer joints within a GFRC element shall be a minimum of 3/8 in. (10 mm) wide. The veneer pieces shall be temporarily spaced with a nonstaining compressible gasket that will not adversely affect application of the sealant. Shore A harness of the gasket shall be less than 20 durometer.

The gasket shall be of an adequate size and configuration to provide a pocket for the sealant. It shall prevent the GFRC backing mix from entering the joints between the veneer units. Gaskets shall be removed after the panel has been stripped from the form unless a resilient sealant backup is used.

When stone veneer is used as an accent or feature strip on GFRC panels, a space shall be left between the edge of the stone and the GFRC to allow for differential movements of the materials. This space shall be caulked as if it were a conventional joint.

**Clay products.** When considering clay products bonded directly to GFRC (including thin brick, structural facing tile, and architectural terra cotta), adequate testing and design analysis shall be made to determine moisture and thermal movement compatibility of the clay-product veneer and the GFRC backing or measures shall be taken to address the incompatibility. Terra cotta shall have a bond breaker between it and the GFRC and be attached with mechanical anchors.

**2.8.8 Applied Coatings**

When GFRC is to be painted or stained, mold release agents compatible with the coating shall be used. All types of release agents shall be permitted if surface preparation for the purpose of assuring adhesion between the coating and the GFRC is required.

**Clay products.** Clay-product veneers, which are rigidly bonded to the GFRC backing, are not recommended due to volume-change considerations. To date, laboratory results show that differential movements with mix designs using currently available cements are greater than existing recommendations for compatibility. The testing does show that some cements have extremely favorable characteristics for this application as they have almost no shrinkage during their curing process. These cements, however, are currently not available mainly due to low demand. The physical properties of the clay products should be compared with the properties of the concrete backup. These properties include the coefficient of the thermal expansion, modulus of elasticity, and volume change due to moisture.

**C2.8.8 Applied Coatings**

Light sandblasting or scarifying that is performed to help ensure proper bond of applied coatings will eliminate possible detrimental effects of the mold release agent.
Coatings applied to exterior surfaces shall be of the breathable type (permeable to water vapor but impermeable to liquid), or wall cavities shall be well vented when a non-breathable coating is used. The coating manufacturer’s instructions regarding mixing, thinning, tinting, and application shall be strictly followed.

Whenever GFRC is so smooth that it makes adhesion of some coatings difficult to obtain, such surfaces shall be lightly sandblasted, acid etched, or ground with silicon carbon stones to provide a slightly roughened, more bondable surface.

2.9 Repairs

When noncompliant defects occur, immediate action shall be taken to determine the cause of the defect and establish appropriate mitigating measures for preventing further occurrence. Repairs shall be performed in accordance with detailed written repair procedures. Major repairs shall not be attempted until an engineering evaluation by the panel design engineer is made to determine whether the unit will be structurally sound.

Repairs shall be properly cured to ensure that the repair does not dry out too quickly and cause it to shrink away from the existing GFRC.

Repairs shall be inspected for acceptability by quality control personnel. The inspection shall ensure that proper repair and curing procedures have been followed and that the results are acceptable. Repairs shall be evaluated after having been properly cured and the finished surface is dry.
2.10 Acceptability of Appearance

The finished face surface shall have no obvious imperfections or evidence of repair other than minimal color and texture variations. The acceptability of appearance shall be made in comparison with the approved sample in good daylight conditions. The unit and approved sample should be viewed with the unaided eye at an appropriate distance of 20 ft (6 m) or greater. Appearance of the surface shall not be evaluated when light is illuminating the surface from an extreme angle.

Unless approved otherwise in the sample/mock-up process (see Article 1.5.4), the following is a list of finished defects that shall be properly repaired if readily visible when viewed from a distance of 20 ft (6 m).

1. Ragged or irregular edges.

2. Excessive air voids (commonly called bug holes) evident on exposed surfaces.

C2.10 Acceptability of Appearance

Uniformity of appearance is generally a matter of subjective individual judgment. Therefore, it is beyond the scope of this Standard to establish definitive rules for product acceptability on the basis of appearance.

Angled lighting will accentuate minor surface irregularities due to shadowing.

1. It is strongly recommended that all edges of GFRC units be detailed with a reasonable radius or chamfer, rather than leaving them as sharp corners. Sharp corners chip easily during handling and during service in the building. Mitered corners are difficult to manufacture and erect within tolerances that are acceptable from either an appearance or jointing standpoint. It can be difficult to place a face mix at a 45-degree point because of the size of the aggregate. Therefore, this edge should have a cutoff or quirk. The size of the quirk return should never be less than 3/8 in. (10 mm), nor less than 1.5 times the maximum aggregate size used in the face mix.

2. Sculptured panels, channel panels, and panels with deep returns may have visible air voids on the returns. The air voids (bug/blow holes) become accentuated when the surface is smooth, acid etched, or lightly sandblasted. If the air holes are of a reasonable size, 1/8 to 1/4 in. (3 to 6 mm), repair is not recommended. Filling and sack rubbing could be used to eliminate the voids. However, this procedure is costly and may cause color differences. Samples or the mock-up
3. Adjacent flat and return surfaces with greater texture and/or color differences than the approved samples or mock-ups.

4. Spraying and/or aggregate segregation lines caused by improper spraying of the face mix.

5. Visible mold joints or irregular surfaces in excess of, or larger than, those accepted in the approved samples or mock-ups.

6. Rust stains on exposed surfaces.

7. Units with excessive variation of texture and/or color from the approved sample, within the unit or compared with adjacent units.

Standard panels should be used to establish acceptable air void frequency, size, and distribution.

3. Returns in some finishes will not appear exactly like the front face (down-face) due to a number of factors such as mix proportions and differences in consolidation techniques, particularly in the case of intricate shapes. Consequently, the down-face in the mold will nearly always be more uniform and denser than the returns or upper radius.

6. Rust stains caused by reactive iron pyrites or other contaminants will occur where such contaminants are found as part of the aggregates. Rust stains may also be caused by particles of steel burned off in welding and accidentally left in the mold. These stains (and steel particles) should be removed from the surface as soon as they are observed.

7. It should be recognized that some blemishes or variations in color occur in GFRC panels. Uniformity in color is directly related to ingredients supplying the color.

Panels containing aggregates and matrices of contrasting colors will appear less uniform than those containing materials of similar color (as the size of the coarse aggregate decreases, less matrix is seen and the more uniform the color of the panel will appear). It is advisable to match the color or tone of the matrix to that of the coarse aggregate so minor segregation of the aggregate will not be noticeable.

Color uniformity is difficult to achieve on gray, buff, and pigmented GFRC surfaces. The use of white cement will give better color uniformity than gray cement. Allowable color variation in the gray cement is enough to cause noticeable color differences in GFRC units. In climates with intermittent dry and wet conditions, drying-out periods often produce blotchy appearances in all-gray cement face mix units. This is particularly true of fine-textured surfaces. The slightest change of color is readily apparent on the uninterrupted surfaces of smooth off-the-mold GFRC and any variation is likely to be regarded as a surface blemish. As a general rule, a textured surface and natural variations in aggregate will, to a large extent, camouflage subtle differences in texture and
<table>
<thead>
<tr>
<th>Standard</th>
<th>Commentary</th>
</tr>
</thead>
<tbody>
<tr>
<td>color of the GFRC. The degree of uniformity (different shadings, and to some extent, depth of color) between panels and within panels in a sandblasted finish, as in all exposed-aggregate processes, is generally in direct proportion to the depth of exposure. For example, a light sandblasting may look acceptable on a small sample, but uniformity is difficult to achieve in reality. Sunlight and exposure to the elements may even out the variation to a great extent.</td>
<td></td>
</tr>
<tr>
<td>8. Blocking stains evident on the exposed surface.</td>
<td>8. Blocking used to separate production units in the storage yard or during shipments should be made with nonstaining materials. Blocking should not trap moisture or prevent air circulation that may disrupt uniform curing conditions. Plastic bubble-type pads are well suited for this purpose. Lumber or padding wrapped with plastic should not be used for blocking for extended periods, unless in an area that is not visible in the final structure.</td>
</tr>
<tr>
<td>9. Areas of GFRC backing, exposed glass fibers, or exposed anchors or embedments showing through the face mix.</td>
<td></td>
</tr>
<tr>
<td>10. Foreign material embedded in the face.</td>
<td></td>
</tr>
<tr>
<td>11. Repairs visible from a viewing distance of 20 ft (6 m).</td>
<td></td>
</tr>
<tr>
<td>12. Shadow lines.</td>
<td>12. Shadow lines can appear at the face of a GFRC panel for several reasons. Integral ribs can create shadowing due to differential curing. Moisture migration through the panel is affected by the rib and may result in further shadowing. Areas of higher density are more likely to show through to the face. An example of this is a flex anchor or a portion of the panel frame pressed into the face. If the building insulation rests against the GFRC backing, the face of the panel will not dry evenly. Over a period of time, this differential drying can lead to shadow lines. Restraining straps, wires, or rods should be installed between the panel frame and the GFRC skin to prevent the insulation from resting against the GFRC backing.</td>
</tr>
<tr>
<td>13. Cracks visible at 20 feet (3m) viewing distance.</td>
<td>13. It should be recognized that a certain amount of crazing or cracking may occur in GFRC without being detrimental. The cement film on the face may develop fine and random hairline cracks. A hairline crack is defined as a surface crack of minute width, visible to the naked eye but not measurable by ordinary means. The primary causes of these cracks are the shrinkage of the surface with respect to the mass of the face mix or GFRC backing, due to the cement-rich mix.</td>
</tr>
</tbody>
</table>
Another cause may be stripping of the panel too early (inadequate strength and curing), although this type of crack may be structural. Crazing has no structural or durability significance but may become visually accentuated when dirt settles in these minute cracks. This is more true with white cement than with gray or a dark color, but the effect will depend on the character of the cement film. Face mix placement techniques can have a large impact on the amount of crazing. Where crazing occurs, a horizontal face-up surface will be affected more than a vertical surface due to the settlement of dirt. Crazing generally will not appear where the outer cement skin has been removed. Such cracks are of little importance and should not be a cause for rejection.

2.11 Sealers or Clear Surface Coatings

Sealers or clear surface coatings are specified, they shall be tested on reasonably sized samples of varying age, and their performance verified over a suitable period of exposure or be based on prior experience under similar exposure conditions. Sealers shall be applied in accordance with manufacturer’s written recommendations.

The clear sealer shall not cause joint sealants to stain the panel surface or affect the bond of the joint sealant. The manufacturers of both the joint sealant and the sealer shall be consulted regarding compatibility prior to application or the material shall be pretested.

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Sealers or clear surface coatings may be considered for the possible improvement of weathering characteristics. The quality of GFRC, even with minimum practical thickness, does not require sealers for waterproofing. It is important that the coating be water vapor permeable to allow the panel to “breathe.”

It may be well to omit the use of sealers on panels in locations having little or no air pollution or in dry climates, in view of the additional cost, the bother of possible recurring periodic applications, and uncertain results of the application of sealers to GFRC panels.

The type of solvent used in sealers, as well as the solids content, can affect the resulting color of the panel surface. Thus, neither the type nor the source of sealer should be changed during the project. Generally, sealers having higher solid contents tend to darken the panel surface. The amount of color change depends primarily on the type of material in the sealer and the concentration, as well as the porosity of the surface. The active ingredient of the sealer must be chemically resistant to the alkaline environment of the GFRC. Also, sealers should be evaluated on how well they penetrate panel surfaces that vary in absorption and texture. The penetrating sealers, generally silanes or siloxanes, develop their water-repellent ability by penetrating the surface to depths of 1/4 in. (6 mm), reacting with the cementitious materials in the GFRC and making the GFRC hydrophobic. The penetrating ability of the sealer system depends on the molecular size of the active ingredient, the viscosity of the system, and the solvent-carrying system.

In most cases, except for the silane or siloxane sealers, it may be necessary to adequately roughen the surface in order to obtain good adhesion of the coating. One way is to lightly sandblast the surface to be coated.
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**DIVISION 3 – RAW MATERIALS AND ACCESSORIES**

### Standard

#### 3.1 Face Mix and GFRC Backing Matrix Materials

##### 3.1.1 General

Frequent inspections shall be performed to check and evaluate test results and the finished product to identify changes that may adversely affect the properties of the mix or the surface appearance.

##### 3.1.2 Cement

Unless otherwise specified, the producer shall have the choice of type and kind of cement to use to achieve the specified properties. Cements shall be selected to provide predictable strength and durability as well as proper color. Cement shall conform to ASTM C150.

Each shipment of cement shall be referenced to a certified mill test report that indicates compliance with the specified type of cement and requirements of ASTM C150. The producer shall maintain the test reports on file.

To minimize the color variation of the surfaces exposed to view in the finished structure, cement of the same type, brand, and color from the same mill shall be used.

### Commentary

#### C3.1 Face Mix and GFRC Backing Matrix Materials

##### C3.1.1 General

With GFRC, any change in face mix materials or proportions will affect the surface appearance. A change in aggregate proportions, color, or gradation will affect the uniformity of the finish, particularly when the aggregate is exposed.

##### C3.1.2 Cement

Cement hydration can be influenced by atmospheric conditions, and cement has an influence on finishing techniques, mix-design requirements, and spray-up procedures. Normal production variables, such as changes in water content, curing cycles, temperature, humidity, and exposure to climatic conditions at varying strength levels all tend to cause color variation. Color variation in a gray cement matrix is generally greater than those matrices made with white cement with a black pigment or a blend of white and gray cement. Uniformity normally increases with increasing percentage of white, but the gray color is dominant.

Different cements have different color characteristics that affect the desired GFRC face mix. The cement color exerts a considerable influence on the color of the finished product.

Type I portland cement, conforming to ASTM C150, is recommended for use in GFRC. Type III may be used under certain conditions when variations in the sprayability of the cement slurry and those properties of the composite affected by the cement fineness are accommodated.

If production problems indicate that a particular batch of cement is causing a false set, or perhaps a flash set, the stockpile should be sampled and a check made on the setting time using the Vicat Needle Test (ASTM C191). Questionable stocks of cement should be put to one side. Lumpy cement should be investigated with reference to the post-mixing state. If high shear mixers are employed, it may be possible to process lumpy cement, but with forced pan mixers, blockages in the mortar spray head can occur.

If lumpy cement must be used, it should be screened to remove the lumps prior to mixing. Screening of the mixed slurry as it enters the pump should then remove any remaining lumps. The presence of lumps in the slurry at the nozzle invariably causes blockages that result in greatly reduced productivity and considerable operator frustration.
3.1.3 Facing Materials

C3.1.3 Facing Materials

The choice of fine and coarse aggregates to be used for face mixes should be based on a visual inspection of GFRC samples prepared by the manufacturer.

Selection of aggregates should be governed by the following:

1. Aggregates should have proper durability and be free of staining or deleterious materials. They should be nonreactive with cement and available in particle shapes required for good GFRC and appearance.
2. Final judgment of colors should be made from GFRC samples that have the proper matrix and are finished in the same manner as planned for production. Some finishing processes change the appearance of the aggregates. If small GFRC samples are used to select the aggregate color, the architect should be aware that the general appearance of large areas after installation tends to be different from the appearance indicated by the trial samples.
3. Aggregates with a dull appearance may appear brighter in a white matrix than a gray matrix.
4. Weathering may influence newly crushed aggregate when first crushed. Many aggregates are bright but will dull slightly with time. Similarly, some of the sparkle caused by acid etching may not survive more than a few weeks. The architect/engineer should recognize that samples maintained indoors may not retain their exact appearance after exposed to weather for a few weeks.
5. The method used to expose the aggregate in the finished product may influence the final appearance.

3.1.3.1 Fine Aggregate

Fine aggregate for face mixes shall consist of high-quality natural sand or sand manufactured from coarse aggregate. Fine aggregates shall comply with ASTM C33, except for gradation, which can deviate to achieve the texture mutually agreed upon by the architect and GFRC manufacturer. The gradations shall be consistent. Variations in fineness modulus shall not exceed ±0.20 from the average value used in the mix design. Material finer than the No. 200 (75 µm) sieve (ASTM C117) shall be limited to 3%. The percentage of fine aggregates passing the No. 100 (150 µm) sieve shall be limited to a maximum of 5%. Variations in these percentages shall be limited to 1% of the amount es-

C3.1.3.1 Fine Aggregate

Fine aggregate can have a major effect on the color of white or light-colored concrete and can be used to add color tones. When the color depends mainly on the fine aggregate, maintaining a consistent gradation is important. This is particularly true for the fractions of the fine aggregate.

Excessive quantities of minus No. 200 (75 µm) fines may act as an unwanted coloring agent, decrease strength, increase the mixing water requirements, and increase the rate of slump loss and drying shrinkage. Excessive fines may require double washing of aggregates.
Fine aggregates shall be obtained from sources from which representative samples have been subjected to all tests prescribed in the governing specification and the slurry-making properties of the aggregates have been demonstrated by trial mixes. Once the soundness and slurry-making properties of the aggregates are established, only annual tests for these properties are required so long as the source and type of aggregates remain unchanged.

Once a sample panel has been approved by the architect/engineer, no other source of exposed aggregate or facing material shall be used for the project unless shown to be equivalent in quality, gradation, and color to the approved sample.

The GFRC manufacturer shall verify that an adequate supply from one source (pit or quarry) for each type of aggregate for the entire project will be readily available and, if possible, shall obtain the entire aggregate supply prior to starting the project or have the aggregate supply held by the supplier.

3.1.3.2 Coarse Aggregate

Coarse aggregate for face mixes shall conform to the requirements of ASTM C33, except for gradation, and shall be of the size, shape, gradation, and color required for architectural effect. The nominal maximum size of aggregate in the face mix shall not be larger than 1/4 in. (6 mm). Flat and/or elongated pieces of aggregate (slivers) shall be limited to a maximum of 15% by weight of aggregate. Material finer than the No. 200 (75 µm) sieve (ASTM C117) shall be limited to 1%.

Coarse aggregate may be selected on the basis of color, hardness, size, shape, gradation, method of surface exposure, cost, and availability provided levels of strength, durability, and workability are met. Colors of natural aggregates may vary considerably according to their geological classification and even among rocks of one type.

Aggregate sizes larger than 1/4 in. (6 mm) may cause difficulties in production and could make panels particularly prone to bowing or cracking unless the shrinkage of the face mix and GFRC backing are similar.

Flat and/or elongated pieces of aggregate will produce irregular and nonuniform finishes when exposed and may be dislodged from the face mix.

Coarse aggregate shall be obtained from sources from which representative samples have been subjected to all tests prescribed in the governing specifications and the concrete-making properties have been demonstrated. Aggregates to be exposed or other materials used to face GFRC units shall be evaluated or proven in the anticipated service environment before their use on a project. When an aggregate source is specified that does not meet the requirements of this Standard, the GFRC manufacturer shall notify the architect/engineer in writing before the start of production.
Standard

Coarse aggregates that may contain particles with an iron oxide content shall be tested by ASTM C641 and shall show a stain index less than 20. Deleterious substances in aggregates shall be limited to the allowances given in ASTM C33 for exposed architectural concrete located in severe weathering regions, with one exception. Fine aggregates shall not exhibit a color darker than Organic Plate 1 when tested for organic impurities in accordance with ASTM C40.

Once a sample panel has been approved by the architect/engineer, no other source of exposed aggregate or facing material shall be used for the project unless shown to be equivalent in quality, gradation, and color to the approved sample.

The GFRC manufacturer shall verify that an adequate supply from one source (pit or quarry) for each type of aggregate for the entire job will be readily available and, if possible, should obtain the entire aggregate supply prior to starting the project or have the aggregate supply held by the supplier.

When natural stone is used as a facing material. A flexible bond layer or a bond-breaker with flexible mechanical anchors shall be used to minimize bowing or high stresses.

3.1.4 Sand for GFRC Backing

Sand used in the GFRC slurry shall be washed and dried, be free of contaminants and lumps, and meet the compositional requirements of ASTM C144. In order to increase the uniformity of the slurry, all sand shall come from one source of supply throughout GFRC panel production. A recommended silica sand composition is:

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
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<tbody>
<tr>
<td>Silica</td>
<td>96% to 98%</td>
</tr>
<tr>
<td>Soluble Salts (Sulfates, Chlorides, and Alkalies such as Na₂O, K₂O, CaO)</td>
<td>1% Maximum</td>
</tr>
<tr>
<td>Loss on Ignition</td>
<td>0.5% Maximum</td>
</tr>
<tr>
<td>Clay &amp; Organic Matter</td>
<td>0.5% Maximum</td>
</tr>
</tbody>
</table>

To minimize clogging of the spray nozzle, all of the particles shall pass a U.S. No. 20 (850 µm) sieve. Fines shall be limited to a maximum of 2% passing a U.S. No. 100 (150 µm) sieve.

Dry sand is usually employed, but when it is intended that wet sand be used, the free water content shall be

Commentary

Stockpiling of a sufficient amount of aggregate for an entire project will help minimize color variation and maximize color uniformity. The stockpile may be stored at any convenient location that provides for proper separation from other materials.

C3.1.4 Sand for GFRC Backing

The use of a properly graded sand in the GFRC backing can reduce drying shrinkage as much as 20% and can increase flexural strength, thereby reducing the possibility of cracking and bowing due to shrinkage. A reasonable sand gradation can generally be obtained by combining two or three sands. The optimum gradation depends on the sands available and the cement–sand ratio.
3.1.5 Mixing Water

Water shall be free from deleterious matter that may interfere with color, setting, or strength of the GFRC backing or face mix. Water, either potable or nonpotable, shall be free from injurious amounts of oils, acids, alkalies, salts, organic materials, chloride ions, or other substances that may be deleterious to cement paste or the panel frame. The water shall not contain iron or iron oxides, which will cause staining. Water from a source other than a municipal water supply shall be tested on an annual basis as required in Article 5.1.2. The water shall not exceed the maximum concentration limits given in Table 3.1.5.

Excessive impurities may cause efflorescence, staining, increased volume change, and reduced durability. Accordingly, limits should be set on deleterious substances contained in the mix water. Some impurities have little effect on strength and setting time; however, they can adversely affect durability and other properties. In particular, the chloride ion content should be limited to a level well below the recommended maximum, when practical. Chloride ions contained in the aggregate and in admixtures should be considered in evaluating the acceptability of the total chloride ion content of mix water.

Table 3.1.5 identifies some of the more common substances and concentration limits that are known to be deleterious to concrete. Also provided in Table 3.1.5 are associated ASTM test methods for identifying and quantifying such substances. Other recognized methods, such as the Environmental Protection Agency (EPA) test methods, may be used when applicable.
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Table 3.1.5 Chemical Limits for Nonpotable Mixing Water\(^a\)

<table>
<thead>
<tr>
<th>Substances</th>
<th>Maximum Concentration (ppm)</th>
<th>ASTM Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soluble carbon dioxide</td>
<td>600</td>
<td>D513(^b)</td>
</tr>
<tr>
<td>Calcium plus magnesium</td>
<td>400</td>
<td>D511</td>
</tr>
<tr>
<td>Chloride, as Cl(^-)</td>
<td>500</td>
<td>D512</td>
</tr>
<tr>
<td>Iron</td>
<td>20</td>
<td>c</td>
</tr>
<tr>
<td>Phosphate</td>
<td>100</td>
<td>D4327</td>
</tr>
<tr>
<td>Boron &amp; borates</td>
<td>100</td>
<td>D3082</td>
</tr>
<tr>
<td>Alkalies (Na(_2)O + 0.658K(_2)O)</td>
<td>600</td>
<td>D4191 &amp; D4192</td>
</tr>
<tr>
<td>Silt or suspended particles</td>
<td>2000</td>
<td>D1888</td>
</tr>
<tr>
<td>pH</td>
<td>6.0 to 8.0</td>
<td>D1067</td>
</tr>
<tr>
<td>Dissolved solids</td>
<td>2000</td>
<td>C1603</td>
</tr>
<tr>
<td>Sugars and oils</td>
<td>Not detectable</td>
<td>c</td>
</tr>
</tbody>
</table>

\(^a\) Other methods as used by EPA or water-analysis companies are generally satisfactory.

\(^b\) Alternatively, soluble carbonate and bicarbonate may be determined by appropriate methods (e.g., Hach Chemical Company procedures and calculated as CO\(_2\)).

\(^c\) No ASTM method available.

3.1.6 Admixtures

Admixtures used shall be of the same brand, type, and source of supply throughout the GFRC panel production. The admixture supplier’s recommendations shall be observed subject to plant checking and experience. The effect of variations in dosage and the sequence of charging the admixtures into the mixer shall be determined from the recommendations of the admixture supplier or by trial mixes.

The polymer curing admixture used to replace the moist cure shall conform to the curing admixture specification in Appendix C. Only polymers shown to eliminate the need for moist curing through published independent laboratory test data shall be used. The curing admixture shall be a homogeneous dispersion and free from lumps.

Air-entraining admixtures shall conform to the requirements of ASTM C260. Water-reducing, retarding, or accelerating admixtures shall conform to the requirements of ASTM C494. High-range water-reducing admixtures (HRWR), also referred to as superplasticizers,

C3.1.6 Admixtures

Admixtures should be materials of standard manufacturing that have established records of tests to confirm acceptable properties and performance. Expected performance of a given brand, class, or type of admixture may be obtained from one or more of the following sources:

1. Results from jobs that have used the admixture under good technical control, and preferably using the same materials, under similar service conditions.
2. Technical literature and information from the manufacturer of the admixture.
3. Laboratory tests made to evaluate the admixture.

The polymer curing admixture reduces the added water of the mix because it contains water.

The use of air entrainment is recommended to enhance durability when the face mix will be subjected to freezing and thawing in wet conditions, except when a curing admixture is used in the face mix. Curing admixtures contain a defoamer, which negates the effect of air entrainment.
shall conform to the requirements of ASTM C494, Type F or G. Set accelerators containing calcium chloride may cause severe shrinkage in the cement-rich GFRC mixes and corrosion of embedded items and shall not be used.

Water-reducing admixtures can be used in a variety of ways to potentially enhance the spray characteristics and performance of GFRC. The following are several examples:

1. A reduction in the water content while maintaining the same level of consistency. GFRC water-cement ratios are lower than those normally used for precast concrete.
2. Increasing the workability without increasing the water content.
3. Increasing or maintaining strength while maintaining or lowering the cementitious-material content, respectively.

The reduction in w/cm achieved by reducing the mix water may produce a greater strength improvement than a similar reduction in the w/cm obtained by adding cement.

Retarding admixtures are used primarily to offset the accelerating effect of high temperature on the set characteristics of the concrete.

High-range water reducers (superplasticizers) will allow very high (up to 30%) reductions in water-cement ratios while maintaining proper mix consistency. However, at the high dosage levels necessary to achieve very low water-cement ratios, the flow and spray characteristics of the slurry are adversely affected. Also, a sprayed-up mix may not stay in place on inclined mold surfaces. Lower dosages are recommended to prevent improper slurry flow or atomization of the slurry at the spray nozzle. The use of thixotropic agents, such as carboxyl methyl cellulose, may be required when spraying vertical sides to reduce slump and hold sand in suspension.

Mineral admixtures or pozzolans meeting ASTM C618 or C1240 may be added for additional durability, increased strength, reduced permeability, and reduced efflorescence. If an HRWR is used with silica fume, the admixture shall be compatible with any admixture in the silica fume. The amount of metakaolin used in GFRC shall not exceed 25% by weight of the portland cement unless it is demonstrated that the GFRC will satisfy strength, durability, and volume-stability requirements.

Generally, fly ash or silica fume modification of GFRC matrices is effective only at high cement-replacement levels (e.g., 20%). This degree of cement substitution substantially lowers the physical properties of the composite material during that period when most products are called upon to withstand their highest stresses caused by fabrication, handling, shipping, and installation loads. Fly ash or silica fume modification of GFRC mixes is therefore not generally recommended.

The use of fly ash or silica fume (microsilica) in a concrete mixture will darken the concrete color and may make it difficult to achieve color uniformity. The color of silica fume depends on carbon content and several other variables. Silica fume from one source may be nearly white in color, while from another it may be black. Metakaolin is a white, dry powder and does not darken white or gray concrete.
Coloring admixtures or pigments shall conform to the requirements of ASTM C979. Coloring pigments shall be finely ground materials with a proven history of satisfactory color stability when used in concrete. Pigments shall be insoluble in water, free of soluble salts and acids, colorfast in sunlight, resistant to alkalies and weak acids, and virtually free of calcium sulfate. The amount and type of pigment shall not affect backing mix and face mix setting time or strength. All coloring agents required for a project shall be ordered in one lot. The amounts of pigment to be used shall not exceed 10% by weight of cement.

Pigments are often added to the mix to obtain colors that cannot be obtained through combinations of cement and fine aggregate. Variable amounts of a pigment, expressed as a percentage of the cement content by weight, produce various shades of color. High percentages of pigment reduce concrete strength due to the high percentage of noncementitious fines introduced to the mix. For this reason, the amount of pigment should be controlled within the prescribed limits to avoid degrading strength and absorption parameters. Different shades of color can be obtained by varying the amount of coloring material or by combining two or more pigments. Brilliant colors cannot be achieved with natural or synthetic pigments. This is due to the low allowable addition rate and the masking effect that the cement and aggregate can create. White portland cement will produce cleaner, brighter colors and should generally be used in preference to gray cement.

When using pigment dosages of less than 1% by weight of cement, the sensitivity of color intensity to minor pigment quantity variations is very high, causing potential color variation. When using dosages from 1% to 5%, the color sensitivity is reduced and more easily controlled. Addition of synthetic iron oxide pigments above 5% will not increase color intensity. The saturation point for natural pigments is closer to 10%.

Coloring pigments of iron oxides are generally preferred because of better performance. However, such pigments may react chemically with other products, such as surface retarders or muriatic acid, and should be tested prior to use.

Green pigment is permanent, except in light shades. Some blues are not uniform or permanent. Cobalt blue pigment should be used to reduce uniformity and fading problems. Dark colors accentuate the efflorescence that forms on all concrete surfaces. If the fading of the color over time due to efflorescence becomes objectionable, the color can be restored by washing the unit with diluted hydrochloric acid and rinsing thoroughly. Carbon black is not recommended due to its extremely fine particle size and tendency to wash out of the concrete matrix. Synthetic black iron oxide will produce a more stable charcoal color.

Architects can best specify the desired color by referring to a swatch or color card. A cement color card is preferable but one published by a paint manufacturer is acceptable. An excellent color reference is the Federal Color Standard 595 B, published by the U.S. Government Printing Office.

Efflorescence deposited on the surface may mask the true color and give the appearance of fading, even though the cement paste itself has not undergone a color change. In addition, weathering of the pigmented cement paste exposes more of the aggregate. If the color of the aggregate is in contrast...
Whenever more than one admixture is used in a GFRC mix, it shall be determined that each material will perform as required without affecting the performance of the other.

**3.2 Reinforcement**

**3.2.1 Alkali-Resistant Glass Fibers**

Only high zirconia (minimum 16%) alkali-resistant glass fibers specifically designed for use with portland cement and conforming to the requirements of ASTM C1666/C1666M and Appendix F shall be used. Unprotected “E” glass, the type designed for use in reinforced plastic, shall not be used.

Glass fiber lengths of 1 to 2 in. (25 to 50 mm) are most common in GFRC production. Lengths less than 1 in. are used for special situations where ease of placement is more important than optimum properties.

Alkali-resistant glass fiber reinforcement is available in roving, chopped strand, and scrim forms. Roving is used for spray-up, with scrim being used for selective reinforcement in areas of high stress concentrations. Typical properties of the glass are shown below.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>170 pcf (2.7 g/cm³)</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>$145–246 \times 10^3$ psi (1.0–1.7 GPa)</td>
</tr>
<tr>
<td>Young's Modulus</td>
<td>$11,400 \times 10^3$ psi (78 GPa)</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>2 ±0.5%</td>
</tr>
</tbody>
</table>

**3.3 Panel Frame and Hardware**

**3.3.1 Panel Frame**

The panel frame for a GFRC panel shall be fabricated from light-gauge steel and/or structural steel shapes. Light-gauge steel materials shall be either painted or galvanized to inhibit corrosion.

Light gauge steel shall conform to ASTM A1011 or A1008, Grades A, B, C, or D, of Section A3.1 of the AISI Specifications and shall be prime-painted with a rust-inhibitive paint conforming to MPI 79 or SSCP Paint 25 or galvanized in accordance with ASTM A653 or A924 with a minimum G-60 coating. Gauge, yield strength, size of studs, tubes, and tracks shall be as shown on the approved shop drawings.

Structural steel tubes shall conform to ASTM A500, Grade B, or ASTM A513. Other structural shapes shall conform to ASTM A36. Member size and yield strength shall be as shown on the approved shop drawings.
DIVISION 3 – RAW MATERIALS AND ACCESSORIES

3.3.2 Anchors and Inserts

Steel for anchors shall conform to the appropriate requirements of ASTM A29 or A108. Yield strength shall conform with design minimum and maximum steel yield strength.

Anchors incorporated into the GFRC skin shall be corrosion resistant. Materials that are galvanized shall conform to the requirements of ASTM A153. Materials that are cadmium plated shall conform to the requirements of ASTM B766. Materials that are zinc plated shall conform to the requirements of ASTM B633. Inserts shall be compatible with or isolated from the other materials with which they will come in contact in order to avoid unwanted chemical or electrochemical reactions. Ductile materials shall be used.

C3.3.2 Anchors and Inserts

Hardware that is specified to be protected with paint, galvanizing, or plating may require touch-up prior to final installation. When connections requiring protection are not readily accessible for the application of zinc-rich paint or metalizing after erection, they should be metalized, galvanized, or plated prior to erection and connections bolted where possible. If welding is required as part of the field assembly, the welded area should be cleaned and touched up with zinc-rich paint.

Care should be taken to avoid embrittlement of the anchors induced by cold working or hydrogen embrittlement during the galvanizing process; refer to ASTM A143/A143M. Also, excessive roughness of the galvanized anchor surface may create undesirable restraint to movement of the flex anchor within the bonding pad.

The allowable load on an anchor or insert molded into the GFRC skin should be determined by the results of controlled tests duplicating the loading condition in which it is used. Many inserts used in GFRC panels have been designed and tested by the insert manufacturer for use in precast or cast-in-place concrete. Adapting these inserts for use in GFRC requires further testing to determine their suitability.

3.3.3 Handling and Lifting Devices

Handling and lifting devices shall be fabricated from ductile material. They shall be designed to lift and transport the GFRC panel with an appropriate factor of safety, which anticipates the various positions of the panel during handling, including special loadings such as wind or impact.

C3.3.3 Handling and Lifting Devices

In determining safe loads for lifting inserts and devices, the inclination of the lifting force should be considered, although this may vary in the case of separate handling operations. Lifting devices are subject to dynamic loads; therefore, the ductility of the material should be a part of the design requirements.

When permanent connection hardware is used for handling, it should be properly designed for such additional service without any danger of subsequent damage to such connections or their performance. Impact loads associated with the handling and setting of GFRC panels may double or, in extreme cases, may triple the dead load used in the design of a connection. This depends on the methods and controls of hoisting and the vulnerability of the connection or its anchorage to impact loads.
### 3.3.4 Connection Hardware

Miscellaneous structural shapes used to support or attach GFRC panels to the structure shall be fabricated from steel conforming to ASTM A36 or A500. Light-gauge shapes shall conform to ASTM A1011 or A1008 and A653, A924, with MPI 79 or SSPC Paint 25. Under normal circumstances, connection hardware equal to or greater than \( \frac{3}{16} \) in. (5 mm) thick will not require corrosion protection except in aggressive environments.

### 3.4 Integral Rib Formers

#### 3.4.1 Rib Former Materials

Care shall be exercised when expanded polystyrene and polyurethane foam are used where ambient service temperatures are greater than 140 °F (60 °C). If GFRC forms are to be incorporated into a panel, they shall be prevented from drying prior to their incorporation to minimize restraints due to differential drying shrinkage.

If integral ribs are used to provide structural rigidity, they shall be manufactured in accordance with the geometry and thickness shown on shop drawings.

### 3.5 Welding

#### 3.5.1 Materials

The welding of panel frame members shall be in accordance with AWS D1.1 for structural steel and AWS D1.3 for sheet steel.

The welding of panel frame members shall be by shielded metal arc welding (SMAW), flux cored arc welding (FCAW), or gas metal arc welding (MIG).

Electrodes for shielded metal arc welding (SMAW) shall conform to the requirements of the latest edition of AWS D1.1, Section 4, and AWS D1.3, Section 5 (AWS A5.1 or A5.5). Electrodes (wires) and shielding gases for gas metal arc welding shall conform to the requirements of AWS D1.1, Section 4, and AWS D1.1, Section 5 (AWS A5.18). The type and grade of electrode shall be as recommended by AWS for the grade of material being welded.

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<table>
<thead>
<tr>
<th><strong>Standard</strong></th>
<th><strong>Commentary</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Shop drawings shall clearly define dimensions and locations for fabrication and placement of handling and lifting devices or refer to standard details.</td>
<td></td>
</tr>
</tbody>
</table>

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**C3.4 Integral Rib Formers**

Rib formers may be used to produce ribs, which provide strength and stiffness for the GFRC panels. Expanded polystyrene and polyurethane foams are the most common materials used. Hollow sections can be made by using GFRC or cardboard shapes to form the void and then overspraying with GFRC backing mix.

The use of integral ribs in GFRC panels may create shadowing on the surface due to differential curing. Moisture migration through the panel is affected by the rib and may result in further shadowing. This should be considered in the design of ribbed panels.
4.1 Face Mix

4.1.1 Mix Proportioning

In proportioning face mixes, attention shall be given to ensure sufficient compatibility with the GFRC backing. Face mixes shall be proportioned to achieve the required aesthetic quality.

The following factors shall be considered in preparing the mix design:

1. Volume-change compatibility with GFRC backing mix.
2. 28-day compressive strength, $f'_c > 4000$ psi (28 MPa).
3. Absorption < 10% by weight.
4. Entrained air (non-polymer containing mixes) in freeze/thaw areas = 3% to 7.5%.
5. Maximum aggregate size = $\frac{1}{4}$ in. (6 mm).
6. Water-cementitious ratio, maximum = 0.35.

When facing materials are bonded to GFRC, tests should be performed on these materials to determine shrinkage and other moisture-induced movement characteristics.

4.1.2 Batching and Mixing

Mix designs shall be recorded and kept at the batching plant. All materials shall be accurately weighed or metered into the mixer. Consistency from batch to batch shall be maintained in accordance with the tolerances below. Slump shall be controlled by use of an admixture rather than additional water. Separate containers for water and each type of admixture shall be used to avoid contamination.

Components shall be measured within the following tolerances. Cement shall not be batched by volume.

1. Water: $± 1\%$ of the required volume of material being batched.
2. Aggregates: $± 1\%$ of the required volume of material being batched.

C4.1 Face Mix

C4.1.1 Mix Proportioning

In proportioning face mixes, attention should be given to ensure sufficient compatibility with the GFRC backing—reasonably similar cement, aggregate, and water contents should be used. Large differences in physical properties such as shrinkage and thermal coefficient of expansion of the face mix and GFRC backing mix may cause cracking and/or delamination as well as bowing.

GFRC backing mixes have a much higher cement content than conventional concrete. Consequently, integral face mixes should be compatible with GFRC backing mixes in the following areas:

1. Initial shrinkage.
2. Moisture-induced volume changes.
3. Thermal-induced volume changes.

GFRC water–cementitious ratios are lower than those normally used for precast concrete. Conventional water-reducing agents or high-range water reducers (superplasticizers) are often used. The use of an acrylic thermoplastic copolymer dispersion as a curing admixture may reduce the water requirement of the mix.

Maximum aggregate size of sprayed mixes is limited by spraying equipment.
DIVISION 4 – PRODUCTION

Standard

3. Admixtures: ± 3% of the required volume of material being batched, but not less than ± 1 ounce (30 gm) or ± the minimum recommended dosage rate per 94 lb (43 kg) bag of cement, whichever is greater.

When the components are batched by weight, the following tolerances shall be followed:

1. Cement and other cementitious materials: ± 1% of the required weight of material being weighed, or ± 0.3% of scale capacity, whichever is greater.

2. Aggregates: ± 2% of the required weight of material being weighed, or ± 0.3% of scale capacity, whichever is greater.

3. Water: ± 1% of the required weight of material being weighed, ± 0.3% of scale capacity.

4. Admixtures: ± 3% of the required weight of material being weighed, or ± 0.3% of scale capacity, or ± the minimum dosage rate for one 94 lb (43 kg) bag of cement, whichever is greater.

Pigments shall be weighed to the nearest gram, when weight of the added pigment is less than 500 g per 94 lb (43 kg) bag of cement. For larger weights, pigments shall be weighed to the nearest 5 g.

For ingredients batched by weight, the accuracy tolerance required for the batching equipment shall be applicable for batch quantities between 10% and 100% of scale capacity.

All scales shall be maintained to provide accuracy within ± 1% of the loads weighed under operating conditions or ± 0.20% of scale capacity throughout the range of use. Scales shall register loads at all stages of the weighing operations from zero to full capacity.

For calibration of scales, standard test weights aggregated to at least 500 lb (227 kg) (each accurate to within ± 0.01% of indicated values) shall be used. Calibration of scales shall be performed at intervals not greater than six months and whenever there is reason to question accuracy. Scale calibration certificates and charts shall be prominently displayed at the batch control location.

Commentary

Many admixtures are time sensitive and may cause the water demand to vary, which may cause inconsistent finish and color. For some combinations, varying the time at which admixtures are added during mixing may result in varying degrees of retardation or acceleration, or it may significantly affect the water requirement of the mixture.

Admixtures may be measured volumetrically using 50 ml to 350 ml graduated cylinders with 1 ml or 2 ml increments, and kept in small containers until required.

Accurate measurements of the admixture are often difficult in small dosage amounts. The minimum recommended dosage rate is 1 fl oz (30 ml) for liquid admixtures or 1 oz (30 g) for dry admixture per 94 lb (43 kg) bag of cement. For dosage rates lower than this, admixtures should be reconstituted until the rate is at least 1 fl oz (30 ml) per 94 lb (43 kg) bag of cement. Testing to ensure proper mix properties may be necessary.

Natural and synthetic pigments are used to achieve color in face mixes. When using pigment dosages of less than 1% by weight of cement, the sensitivity of color intensity is very high, causing potential panel-to-panel color variation. When using dosages from 1% to 5%, this sensitivity is much lower, and color variation will be more easily controlled. Addition of pigment above 5% may not increase color intensity.

Confirmation of accurate scale performance can only be determined by proper calibration checks. This is an important aspect of overall quality control.
DIVISION 4 – PRODUCTION

Standard

Buckets in which mix materials are weighed shall be clean and dry and shall not be used for other purposes. Weight scales shall likewise be kept clean. Tare adjustments shall be checked daily against the containers being used.

Fine aggregate batch weights shall include an allowance for free moisture.

In addition to accurate measurement of materials, correct mixing procedures shall be used to maintain batch-to-batch uniformity. Care shall be taken to ensure that the weighed materials are properly sequenced and blended during charging of the mixers. Admixtures shall be added to the mixer at the same point in the mixing sequence in each batch, in accordance with the admixture manufacturer’s recommendations.

Commentary

Varying the mixing time from batch to batch may cause different degrees of dispersion of coloring pigment and, therefore, different shades of color. Both undermixing and overmixing should be avoided. Water content, dispersion of color and cement, and slump are all controlled through uniform batching and mixing.

Consistency in all phases of batching and mixing is key to a quality finished product. Each mix should be batched in the same sequence and then mixed for the same length of time. Mix temperatures at the mixer should be maintained within the range of 60 to 75 °F (16 to 24 °C).

A typical mixer is shown in Figure C4.1.2.

Figure C4.1.2 Typical mixer

The necessary time for mixing will depend on many factors including batch size, workability of the batch, size and grading of the aggregate, type of mixer, condition of blades, and the ability of the mixer to produce uniform face mixes from batch to batch.

4.1.3 Placing and Consolidating

After application of a form release agent, a mist coat shall be applied directly to the surface of the mold prior to spray-up, when the surface of the unit will not have a face mix. The mist coat shall pick up all the detail of the mold surface without resulting in a cement-rich layer on the unit’s surface. The spray used to apply the mist coat shall be well atomized to provide a spray of

Discoloration may be caused by excessive use or uneven application of the release agent. Release agents of high viscosity or that are applied in thick applications tend to hold air and water bubbles, and should be avoided. Any excess release agent should be wiped off with a clean, lint-free cloth. Generally, the more thinly the coating is applied, the better the surface finish, although the film must be complete. Great
fine particles. Care shall be taken to keep atomization pressure as low as possible so as not to “bounce” sand grains out of the slurry as it impacts on the mold. Maximum thickness of the mist coat shall not exceed $\frac{1}{8}$ in. (3 mm). The initial GFRC spray-up coat shall be applied before the mist coat can dry.

**Commentary**

Care should be taken to see that the equipment used to apply the coating is clean.

The mist coat is a fine coat of cement/sand slurry applied to the surface of the mold. It should be just thick enough to cover mold details and surfaces. The mist coat should not be too thin, as fibers might be exposed, nor be too thick, as crazing might occur and excess weight will be added. Mixes that contain a curing admixture help reduce crazing of the surface. The spray should be well atomized to a fine mist without blobbing. Care should be taken to control mist coat placement. Overly thick, unreinforced surfaces may easily craze or chip. Mist coating with standard concentric guns may also be a problem due to the guns’ high atomizing pressures. Either the spray nozzle from a dual head gun or the more specialized mist coat gun (shown in Figure C4.1.3) with its own hopper available from GFRC machinery manufactures may be used to eliminate this problem.

Figure C4.1.3 Mist coat gun

The same face mix applied with or consolidated by different methods may result in varying colors and textures on the finished product. Therefore, the methods of applying or consolidating the face mix should remain the same throughout the project. Consolidation may be by tamping, rolling, brushing, or vibration.
DIVISION 4 – PRODUCTION

Standard

prevent bleeding through of the sprayed-up glass fiber backing mix.

Commentary

The primary concern with the face mix is uniformity and thickness. Thickness control of this first unreinforced layer is important to ensure that sufficient material is available for sandblasting or other surface treatments. However, it is critically important that the facing thickness be controlled and uniform since the thickness of the GFRC backing, to be subsequently applied on top of the facing, will be determined based on a measurement of the total thickness of the skin. Face mixes are generally applied \( \frac{1}{8} \) in. (3 mm) thicker than the largest aggregate size. It is desirable to saw-cut samples or unused panels to review the thickness variation of production methods.

4.2 GFRC Backing

4.2.1 Mix Proportioning

Records shall be kept of actual mixes used to enable comparison of cured products to the specified requirements. New mix designs shall have trial batches run and physical property tests evaluated prior to use.

The following factors shall be considered in preparing the mix design in order to achieve the desired physical properties:

1. Fiber content, absolute minimum = 4% by weight of total mix.
2. Fiber length, maximum = 2 in. (50 mm).
4. Water–cementitious ratio, maximum = 0.35.
5. Polymer content, minimum = 6% polymer solids by weight of cement.
6. Admixtures.

C4.2 GFRC Backing

C4.2.1 Mix Proportioning

In general, a fiber content of 5% by weight of total mix using 1 in. (25 mm) to 2 in. (50 mm) fiber lengths, cement–sand ratios of approximately 1:1, and typical 6% to 7% by weight of polymer solids to dry cement of an acrylic thermoplastic copolymer dispersion used as a curing admixture provide a blend of acceptable composite properties and processability. Fiber lengths less than 1 in. (25 mm) are used for special situations where ease of placement is more important than optimum properties.

Fiber content, length, and orientation primarily affect early flexural ultimate (EFU) strength and impact strength. Fiber content has little effect on the modulus of elasticity. A glass fiber content of 5% by weight is the optimum for GFRC mix designs.

Fiber contents greater than 6% tend to entrap air in the composite and reduce density. A minimum fiber content of 4.0% by weight is recommended to ensure adequate ultimate strengths.

Fiber length also affects composite ultimate strengths and compaction and consolidation. For GFRC spray-up, the optimum fiber length is 1 to 2 in. (25 to 50 mm). Shorter lengths, although easier to spray, will not provide maximum reinforcement efficiency. Longer fiber lengths may cause problems with fiber and slurry laydown as well as compaction and consolidation during rolling.

The impact resistance of GFRC is influenced strongly by the reinforcing fibers. Increasing fiber length from, for example, 1 to 2 in. (25 to 50 mm) increases impact strength. Impact properties relate to the area under the flexural stress-strain curve—as these curves change with time, impact properties are reduced.
Manufacturers should be aware of the potential variations in the physical properties of GFRC resulting from changes or modifications in mix composition.

Cement–sand ratios ranging from 1:1 to 3:1 have been used within the industry. The particle size and shape of an available sand determines pumping and spray characteristics.

Higher sand contents reduce the amount of shrinkage; however, shrinkage is still greater than that exhibited by precast concrete because of the higher cement content.

Experience has shown that cement–sand ratios of 1:1 can be accommodated without appreciable deterioration of the strength of the composite. Larger proportions of sand in the GFRC matrix may lead to a reduction in strength and other changes in mechanical properties. Although the addition of glass fiber to the cementitious matrix does not materially reduce its drying shrinkage, it does increase strength and reduce the risk of propagating shrinkage cracking.

The spray process requires a mix that is fluid enough for continuous pumping and spraying without blockages. A fluid mix also permits proper compaction of the composite. However, the mix should have a minimum and maximum water content. Low water contents give high cured strength and simplify the spraying of near-vertical mold surfaces. A mix that is too stiff may cause equipment blockages.

Other admixtures to the mix may be used to give certain properties or assist in spraying, such as air-entraining agents or thixotropic agents. The mix for any particular application should be designed before starting the job, and it should be carefully followed for each batch. Careful control of water content is particularly important since small changes in the water–cementitious ratio in the mix can have marked effects on the properties of the GFRC backing. The acrylic thermoplastic copolymer dispersions contain water that has to be considered.

The actual water content for a given mix should be determined and consistently maintained. The water–cementitious ratio should not exceed 0.35.

Many GFRC manufacturers establish a mix design and use it continually. It is important to statistically graph strength tests to continually monitor the performance of the mix design. The trend of consistency will point out problem areas. Material suppliers sometimes make minor changes that may affect the mix. The trends in the graph will pick up any corresponding changes in strength.

Several different polymer curing admixtures are currently available and in use. Therefore, composite mix proportions,
DIVISION 4 – PRODUCTION

Standard

4.2.2 Batching and Mixing

All materials shall be accurately batched by weight or volume. (See Article 4.1.2 for Tolerances). Mixing equipment shall be capable of thoroughly blending the materials. Mixes shall be free of lumps to avoid spray blockages. Care shall be taken to avoid overmixing the cement/sand slurry, which can reduce the density of the composite. Considerations shall be given to the time and temperature factors necessary to maintain pumpability.

Whenever practical, the use of admixtures in liquid form shall be used to obtain a more even distribution throughout the matrix within the time allotted to adequately and properly mix the slurry. The liquid portion shall be considered part of the mixing water. Regardless of the form of the admixture, provisions shall be made for control and uniform introduction with other matrix components to ensure good distribution within the mix in strict accordance with the admixture manufacturer’s recommendations.

If batching by bag, the weight of full bags of cement shall be checked for conformity to stated weight once for every 10 bags used and to determine that tolerances are being met. Fractional bags shall not be used unless they are weighed.

Mixing procedures shall be established to ensure that the weighed materials are properly sequenced and blended during charging of the mixer.

The minimum mixing time shall be established to ensure that the necessary level of uniformity and consistency is obtained.

Commentary

constituents, and physical properties can vary from one manufacturer’s plant to another.

Admixtures can be used in the hand-spray process for special purposes.

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Type of Admixture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing slump on vertical surface</td>
<td>Thixotropic</td>
</tr>
<tr>
<td>Increasing mix flowability</td>
<td>Water-reducing admixture</td>
</tr>
<tr>
<td></td>
<td>High-range water reducers</td>
</tr>
</tbody>
</table>

C4.2.2 Batching and Mixing

Solid ingredients should be weighed in clean, dry containers. If cement is added in whole bags, then the bag weight should be checked. It is generally not sufficient to rely on the nominal weight printed on the bag because actual weight may vary. Solid admixtures should be weighed and kept in small containers. Liquid additives should be measured in graduated cylinders. Scales should be kept clean, and if a tare device is used, this should be reset for each container. The amount of slurry mixed at one time will depend on the type of mixer and the rate of slurry usage. It is much better to use a small batch geared to the output of the pump than to fill the hopper and let the ingredients stand idle for long periods before being used.

Slurries for GFRC spray-up contain 40% to 50% portland cement and are prone to develop changes in mix consistency caused by the cement and its hydration processes. Assuming that other contributing factors (choice of cement, choice of admixtures, water and mixing temperatures) have been accounted for, the two problems that can be avoided or alleviated by proper mixing are false setting and slump loss. The remixing of false-set slurry will mechanically crack the false set and provide a usable mix. Slump loss (gradual stiffening or increasing viscosity of the slurry over time) can be alleviated by making mixes small enough to be used completely within 25 minutes of the time the cement first came in contact with the water. Certain combinations of high-range water-reducer brands and polymers may also cause slump loss.

Mix temperature should be maintained within a range of 60 to 75 °F (16 to 24 °C). Regulating mix water temperature will help improve the consistency of the slurry as well as maintain the desired mix temperature.
DIVISION 4 – PRODUCTION

4.2.3 Spraying

The pump shall be set to give the desired slurry flow rate. A small amount of slurry shall be run through the lines to remove excess water. The flow rate shall be checked using Appendix H, Test 2. The pump shall be adjusted as required to give the desired rate.

The flow-rate setting shall be checked shortly after beginning spray-up operations by spraying a test board and determining the actual glass fiber content by using Appendix H, Test 4. After determining the weight percentage of glass fiber in the freshly sprayed composite, GFRC manufactured by a spray process, either manual or automated, is a demanding operation requiring trained operators using recommended equipment. The proper spray-up of GFRC will provide a strong and durable product.

In the simplest form of spray processing, simultaneous sprays of cement-sand-water slurry and chopped glass fibers are deposited from a hand-held spray gun into or onto a suitable mold. Slurry is fed to the spray gun from a metering pump unit and atomized by compressed air. The glass fiber roving is fed to a chopper/feeder and mounted on the slurry gun, which

The mix material should be used immediately in production to prevent setting in the pump or hoses.

The consistency and quality of the mix can be affected by:

1. Cement age, type, and brand or changes in cement characteristics
2. Sand grading and moisture content
3. High-range water reducers
4. Polymer
5. Water temperature
6. Mixer type
7. Batch quantity or incorrect batch weights
8. Mix design
9. Mixing time

Any change in the mix consistency during spraying should be reported immediately to supervisory personnel and a check made on the slurry flow rate.

To ensure proper proportioning and mixing, the polymer should be a homogeneous dispersion free from lumps.

Care should be taken to avoid overmixing the cement-sand slurry as this can reduce the density of the composite or cause it to heat up and flash-set in the pump. Considerations should be given to the pot life and mix temperature to avoid blockage of the spray equipment. It is important to maintain proper cleanliness of the equipment.

Good record keeping will allow slurry flow rates and chopper output rates to be set accurately at the beginning of the day’s operation.
it shall be compared to the required level. If adjustments are required, the new chopper output or slurry flow rate shall be determined by multiplying the old rate by the ratio between the required level and the level determined by test.

Spray operators shall be trained personnel with a record of satisfactory performance based on results of wash-out and flexural tests. Spray-up of GFRC shall begin before any face mix or mist coat has set. Slurry and fibers shall be sprayed approximately perpendicular (90 ± 20 degrees) to the mold surface in straight lines, always holding the gun the same distance from the mold surface. The gun/chopper shall not be swung from side to side, spraying material in an arc of varying distance from the mold. The spray gun/chopper shall be moved back and forth covering the entire mold surface with reversing passes.

Each layer shall be compacted in accordance with Article 4.2.4. Additional layers shall be sprayed while the composite is still wet and plastic (before initial set) until the desired thickness is achieved.

Thickness checks are required to ensure minimum backing thickness is \( \frac{1}{2} \) in. (13 mm) or design thickness, whichever is greater.

**4.2.4 Compaction**

Each layer of the sprayed material shall be compacted. Fibers that bridge corners and false joints shall be pushed into the matrix to achieve proper compaction. Rollers and other compaction tools shall be kept clean by washing with water to avoid picking up the slurry. Hand or brush compaction shall be used in areas not accessible to rollers. Thickness shall be checked with a penetration gauge. Gauge holes shall be recom pacted after the thickness check. Final thickness tests shall be performed in accordance with Article 5.2.4. Care shall be taken not to leave a permanent mark on the face.

Each layer should be approximately \( \frac{1}{8} \) in. (3 mm) thick with uniform distribution of glass fiber and cement matrix. If one layer of GFRC is allowed to set before the application of the next, a plane of weakness will be formed in the GFRC, which will cause delamination.

**C4.2.4 Compaction**

Compaction is necessary to coat all glass fibers with cement, remove entrapped air, consolidate the composite, and ensure good reproduction of mold detail.

Composite density affects matrix-dependent properties; flexural and tensile strength and modulus of elasticity vary directly with density. Low density reduces strength because at lower densities entrapped air reduces the bond between the fibers and the matrix. Therefore, proper compaction of the composite is very important.

The GFRC backing mix is typically applied in layers. The thickness of each GFRC layer has a lot to do with the effectiveness of the compaction procedure. The thickness of individual GFRC layers should not exceed \( \frac{1}{4} \) in. (6 mm). Layers that are thicker than \( \frac{3}{8} \) in (10 mm) can be difficult to compact without using excessive pressure. Excessive rolling pressure causes material to be displaced (pushed away), resulting in potentially substandard GFRC thickness. Special care must be taken at the location of returns, reveals, and false joints to prevent displacement of sprayed GFRC material during compaction. Vertical returns (as oriented in the mold) should always be rolled with an upward motion to oppose the tendency of the sprayed material to slide down.
under its own weight. Vibrating trowels can be effective and eliminate the need for compacting at ¼-in.-thick (3 mm) intervals. This compaction method is only suitable for large flat areas of spraying.

The rollers should be ribbed either longitudinally or circumferentially so that they press the fibers into the cement matrix. Rollers with flat surfaces cannot achieve this objective and should not be used. Rollers may be made of plastic, steel, or aluminum.

Aluminum rollers corrode under alkali attack from the cement and tend to pick up more sprayed material as the surface roughens. Aluminum rollers usually need more frequent washing and cleaning.

A selection of trowels is also used for pushing material into edges, corners, and other fine details. However, the trowel does not give the same degree of compaction as a roller.

It is good practice to make special tools to help compact highly repetitive details such as surface ribs. Also, it is good practice to keep rollers and trowels in a water bucket during production. This stops the slurry from drying on their surfaces, which would reduce the effectiveness of the rollers.

Compacting GFRC at corners and over reveals requires special attention and care. Uniform thickness must be maintained. These areas are susceptible to over-rolling, which results in thin sections, as shown in Fig. C4.2.4(a). Thin sections at reveals and corners produce stress risers and locations for potential cracks. Special templates and gauges should be made to check the thickness of these areas during production. A second check can be made randomly, after curing and stripping, by core drilling a ½-in.-to 1-in.-diameter (13 to 25 mm) hole through these areas to measure the actual finished thickness, as shown in Fig. C4.2.4(b). Patching may be avoided by stopping the core at the face mix and removing the core. The production crew responsible for thickness and compaction should view the quality control coring tests to emphasize the importance of obtaining uniform thickness. The cored holes should be hand-packed with fresh GFRC after results of thickness checks are documented.

Since GFRC is a relatively thin material to begin with, even small thickness variations may affect skin stresses. Therefore, GFRC thicknesses should always be within specified thickness tolerances. In production, GFRC backing is often manufactured with a target thickness ¼ in. (3 mm) greater than the design thickness in order to meet the specified thickness tolerances.
DIVISION 4 – PRODUCTION

Standard

Commentary

Figure C4.2.4(a) Compaction of GFRC backing at corners and over reveals

Figure C4.2.4(b) Thickness check by core drilling
DIVISION 4 – PRODUCTION

4.2.5 Installation of Panel Frame

The panel frame shall be firmly held in position over the skin by jigs or brackets using adequate stops or supports to prevent deflection. The panel frame shall be installed before the GFRC backing reaches initial set.

The support of the panel frame should be accomplished through the use of rigid prepositioned stops rather than shims or temporary supports. The overall dimension from front face to back of frame should be maintained within tolerance.

The flex anchors should not protrude into the fresh GFRC. The pressure of the anchor compresses the GFRC and changes its density and water–cement ratio in that area and may cause a blemish or shadow mark on the exterior finished face. For production convenience, the flex anchors are usually set from 1/8 to 3/8 in. (3 to 10 mm) away from the surface of the GFRC backing. With some finishes, they may touch the surface of the GFRC backing. Damage that occurs to the GFRC backing during frame placement should be repaired immediately.

When inspecting the panel frame, make sure that the frame does not contact the skin at any point. Contact between the panel skin and the panel frame will impose restraint to movements of the skin that will occur due to normal and expected moisture or temperature changes. Excessive restraint imposed on the panel skin could result in stresses of sufficient magnitude to cause cracking; therefore, it is important that this situation be corrected. The clearance between the skin and the panel frame at all locations should be a minimum of 1/2 in. (13 mm) (See Fig C4.2.5) or extra care should be employed during manufacturing to ensure an unrestrained skin.

4.2.6 Application of Bonding Pads

Bonding pads shall be placed over each flex, gravity, and seismic anchor, and rolled and/or handworked onto the fresh GFRC backing. Bonding pads shall be

Immediately following placement of the frame, GFRC bonding pads are placed over the foot of each anchor and integrated into the GFRC backing. The GFRC used for bonding pads

Figure C4.2.5 Clearance between GFRC backing and panel frame

It is important that the quality control inspector has a clear understanding of the various conditions that affect the required anchor length and orientation.

C4.2.6 Application of Bonding Pads
applied by trained personnel. Bonding-pad size and thickness shall conform to the design criteria.

GFRC backing shall be in the plastic state (before initial set) during bonding-pad application in order to achieve an adequate bond of the pad to the backing.

Bonding pads shall cover the entire foot, and build-up on the heel of the flex anchors shall be avoided unless allowed by engineering analysis.

Bonding-pad installation procedures shall remain the same as were used in tests to determine design values.

should be the same as that used for the backing. Thickness of the bonding pad over the top of the flex anchor should be a minimum of $\frac{1}{2}$ in. (13 mm). The effective area of the bonding pad (effective length $\times$ effective width) should be a minimum of 24 in.$^2$ (155 cm$^2$) (See Fig. C4.2.6(a)). Care should be taken to achieve a good bond without overworking and creating thin areas over the anchors. Care should be exercised when placing bonding pads to allow for movement in the flex anchor.

It is recommended that bonding-pad test boards be manufactured and tested for newly trained personnel.

Figure 4.2.6(a) Bonding pad details

Time delay between the final roller compaction of GFRC backing and the placement of the frame and the bonding pad should be kept to a minimum. This is necessary to ensure monolithic bonding of the bonding pad. If there is a significant delay, initial set of the backing could prevent the bonding pad from achieving monolithic bonding to the backing and there could be a possible delamination problem.

Bonding pads should be inspected during demolding for cracking as well as for overall quality. Bonding pad cracking can take on several different forms, as shown in Fig. C4.2.6(b). However, there are several factors that could cause other failure modes to occur.
4.2.7 Integral Ribs

The position and size of the ribs shall be checked and the thickness shall be confirmed.

4.2.8 Inserts and Embedments

Encapsulated inserts shall be set with jigs to protrude slightly above the surface of the GFRC to prevent them from becoming recessed. Inserts and embedments shall be properly embedded in built-up, homogeneous GFRC bosses or bonding pads to develop their strength and distribute the load.

Quality GFRC shall be used around the embedments. Waste material, such as over-spray, is not acceptable.

Figure C4.2.6(b) Modes of failure on bonding pads

C4.2.7 Integral Ribs

GFRC rib formers should be saturated to minimize differential shrinkage between the rib former and the GFRC backing mix.

C4.2.8 Inserts and Embedments

Rigid embedded items that are bonded to the GFRC, such as steel more than 6 to 12 in. (150 to 300 mm) long, may create undesirable restraint to volume change and cause overstressing of the GFRC. With adequate precautions, overstressing can be avoided. These precautions include isolation of embedded items, use of bond-breaker, discontinuity of a rigid item, or an increased section of GFRC.

Corrosion-resistant inserts and embedments are recommended. Dissimilar metals that could lead to galvanic corrosion should be avoided.
4.3 Curing

Curing procedures shall be established and properly controlled to develop the required GFRC quality and strength.

*Mixes with Polymer Curing Admixtures*—Moisture shall not be allowed to contact the surface of the backing during the first three hours of curing. GFRC backing temperature shall be maintained between 60 and 120 °F (16 and 50 °C) to allow proper curing to take place.

Panel shall be protected from excessive air movement for the first 12 to 16 hours.

**Moist Curing**—Immediately after spray-up operations are complete or the panel frame is installed, the mold shall be covered. The mold shall remain covered overnight to avoid drying and to achieve adequate strength for stripping. During this period, the temperature of the GFRC shall be maintained above 60 °F (16 °C) to aid early strength development.

After initial overnight curing, the panel shall be removed from the mold and placed in a controlled curing environment. Panels shall be kept in a surface-damp condition at a temperature above 60 °F (16 °C) in a minimum of 95% relative humidity for a period of seven days. Consistent and uniform curing condition shall be provided from day to day.

**Mixes and Polymer Curing Admixtures**—The polymer curing admixture in the mix creates a film on the backing that holds the moisture in the panel to provide hydration of the cement. This eliminates the need for seven days’ moist curing. The film forms during the first three hours after placing at a temperature above 60 °F (16 °C). Moisture (hose spray, condensation drip, rain, steam) should not be allowed on the panel during this time as it causes loss of film-forming ability. Covering the panel after film formation will improve properties of the GFRC backing.

When polymer is used, the sprayed GFRC surface is initially glossy or it glistens. When the surface develops a matte or dull surface appearance, the film is forming. When the surface is glossy or glistens again, the film-formation process is complete.

All polymer curing admixtures have a minimum film-formation temperature (MFT) below which the polymer spheres will not coalesce to form a tough, durable film. Initial curing temperatures should be maintained above the MFT until the film-formation process is complete. The recommended minimum panel curing temperature of 60 °F (16 °C) should be maintained for 12 to 16 hours. At higher panel temperatures, film formation will be accelerated. Upon initial drying, the polymer particles form a film that retains moisture for curing and also inhibits early microcracking and surface crazing.

**Moist Curing**—After spray-up operations, including trimming and finishing, have been completed, the mold should be covered with a polyethylene sheet or tarpaulin to prevent any evaporation of moisture from the fresh unit, and set aside for an initial setting and curing period of 16 to 24 hours. During this period, the temperature of the unit should be maintained above 60 °F (16 °C) to aid early strength development.

Proper curing of fresh GFRC without polymer curing admixtures requires a moist atmosphere so that moisture is retained to ensure adequate hydration of cement and to prevent formation of cracks due to rapid loss of water.

**Accelerated curing systems with temperatures over 120°F (50°C) are not recommended and may be detrimental to strength.**

Adequate curing requires sufficient water to result in substantial hydration of the cement. This leads to good bond between fibers and the matrix that improves both fiber- and matrix-dependent properties.

**Moist Curing**—Immediately after spray-up operations are complete or the panel frame is installed, the mold shall be covered. The mold shall remain covered overnight to avoid drying and to achieve adequate strength for stripping. During this period, the temperature of the GFRC shall be maintained above 60 °F (16 °C) to aid early strength development.

After initial overnight curing, the panel shall be removed from the mold and placed in a controlled curing environment. Panels shall be kept in a surface-damp condition at a temperature above 60 °F (16 °C) in a minimum of 95% relative humidity for a period of seven days. Consistent and uniform curing condition shall be provided from day to day.
**DIVISION 4 – PRODUCTION**

**Standard**

4.4 **Batching and Mixing Facilities**

4.4.1 **General Requirements for Batching and Mixing Plants**

Batch systems shall be of a volumetric or weight type. Mixing equipment shall be of a capacity and type to produce a slurry or face mix of uniform consistency.

Batching and mixing facilities shall be capable of producing face mixes and/or slurry of the quality required for GFRC panels. They shall be properly equipped, maintained, and operated, and they shall have provisions for mixing face mixes and/or slurry at extreme hot or cold ambient temperatures.

Care should be taken when using overhead heaters in cold-climate production. Excessive heat or hot molds coupled with low relative humidity can subject the panels to rapid moisture loss, which can lead to drying-shrinkage cracks.

**Commentary**

C4.4 **Batching and Mixing Facilities**

C4.4.1 **General Requirements for Batching and Mixing Plants**

A volumetric system uses premeasured containers to determine the correct volume of material to be batched. When batching by weight, the material is charged onto the scales with the batch weights preset or dial scales used.

Care should be taken in hot climates to protect batch-material-storage bins and water lines from direct sun.

Mixers are of three general types:

1. **High-Shear Mixers**—The slurry is mixed completely in a high-speed (1000–1200 rpm) stationary mixer and transported to the spray pump by means of a bucket or mixing drum.
2. **Continuous-Feed Mixers**—The slurry is mixed in a stationary mixer and discharged directly into the spray pump, providing an uninterrupted supply of the slurry mix to the pump.
3. **Conventional Mixers**—Face mixes can be mixed in low-slump mixers of the vertical or horizontal shaft type. Face mixes can also be mixed in truck mixers.

A high-shear mixer is recommended for making slurries for GFRC spray-up. Conventional mortar and concrete mixers do not give complete mixing at low water–cement ratios and should not be used. The preferred mixer is a high-speed, shaft-type mixer with a sawtooth disc blade that can break up lumps and blend the mix ingredients to a smooth, flowing consistency. The most effective mixing of cement pastes and mortars is done using dispersion-type mixers.

Mixers shall be examined daily for changes in condition due to accumulation of hardened concrete or mortar, or wear of blades. Accumulations of hardened concrete shall be removed.

Mixer blades shall be replaced or repaired in accordance with the manufacturer’s recommendations regarding blade wear or damage.

C4.4.2 **Storage of AR Glass**

The storage area for alkali-resistant (AR) glass fibers shall be clean, dry, and sheltered. Packages of AR glass fibers shall be stored, raised off the floor on pallets or shelving, and remain sealed at all times in storage.

The exposure of AR glass fiber to water and dirt may impair its performance. It should not be stored where it is exposed to the weather or on the floor where it could be exposed to standing water.
**DIVISION 4 – PRODUCTION**

**Standard**

Boxes containing roving shall be stacked so that the axis of the roving package is vertical. Pallets of roving shall not be stored more than two high.

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**Commentary**

AR glass fiber should be protected from direct sunlight, as this could degrade the packaging, which could affect handling and run-out performance of the roving. Also, direct sunlight exposure for an extended period could affect the size of the fibers, which could affect the performance of the AR glass fiber product. Manufacturers of GFRC products should establish appropriate areas for storage and train all pertinent personnel in the procedures for the storage of AR glass fiber.

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### 4.4.3 Storage and Handling of Aggregates

Bagged aggregates shall be stored by individual sizes. Bagged sand shall be stored under dry conditions.

Aggregates in bulk shall be stored on a hard, clean, and well-drained base where chance of contamination is slight.

Aggregates should be handled and stored in a way that minimizes segregation and degradation and that prevents contamination by deleterious substances.

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### 4.4.4 Storage of Cement

Bulk cement shall be stored in weather-tight bins or silos that exclude moisture and contaminants. Each type of cement shall be stored in a separate bin.

Cement in bags shall be stacked on pallets or similar platforms to avoid contact with moisture and to permit

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Cement in bags shall be stacked on pallets or similar platforms to avoid contact with moisture and to permit

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Cement in bags shall be stacked on pallets or similar platforms to avoid contact with moisture and to permit
proper air circulation. Bags shall be stored clear of wall areas where condensation may occur. To avoid “pack set,” cement shall not be stacked in piles higher than 14 bags for more than 60 days. For longer storage periods, the stack shall not be higher than seven bags. Cement stored for more than 90 days shall be tested for conformity with ASTM C150 prior to use*. Bags shall be stacked so that the first in are the first out.

Cement that develops hard lumps (due to partial hydration or dampness) that cannot be reduced by light finger pressure shall not be used unless tested for strength and loss on ignition.

Portland cement has great affinity for water and, if left exposed to the atmosphere, will gradually absorb water from the air and thereby become “set” into small lumps. For this reason, only fresh portland cement should be used, and it should be kept sealed in its original bags and well protected from water or humidity until use. Mixes should be sized to use full bags of cement whenever possible. If it is necessary to store partially used bags of cement, they should be folded closed and then enclosed in a polyethylene bag. Old cement creates problems in spraying and reduces the strength of the GFRC.

4.4.5 Storage of Admixtures, Pigments, and Curing Admixtures

The storage, handling, and batching of admixtures shall be in accordance with the manufacturer’s recommendations. Adequate storage facilities shall be provided to ensure uninterrupted supplies of admixtures during batching operations.

Various admixtures shall be stored separately in weather-tight containers or tanks that are clearly labeled by the type, brand, and manufacturer of the admixture. They shall be protected from freezing and contamination. Polymer curing admixtures shall not be stored in direct sunlight or close to a high heat source. The temperature in the storage area for the polymer curing admixture shall be maintained above 40 °F (5 °C) and below 120 °F (49 °C).

Pigments shall be packaged in bags (dry powder pigments) or in drums (liquid pigments). In both cases, the storage area shall be clean and dry. The pigment shall remain in sealed containers until used. Opened packages shall be protected from contamination.

4.4.6 Measuring Equipment

Measuring equipment shall be capable of measuring components within the tolerances specified in Article 4.1.2.

Separate containers for water and each type of admixture shall be used to avoid contamination.

Admixture manufacturers usually furnish either complete storage and dispensing systems or at least information regarding the degree of agitation or recirculation required for their admixtures. Timing devices are commonly used to control recirculation of the contents of storage tanks to avoid settlement or, with some products, polymerization.

* Titles for all standards and other documents referred to in the manual are given in Appendix J.
Standard

Cement and aggregates shall be weighed in separate containers or weigh hoppers to avoid contamination.

Due to inconsistencies among suppliers, full bags of cement and aggregate shall be weighed to make sure each contains its stated weight and to determine that tolerances are being met. This shall be done once for every 30 bags.

Commentary

It is common practice to use careful manual weighing when small batches are required so that, with care, 0.1% of scale capacity (one scale division) can be obtained. With most batching equipment, some degree of more accurate control is possible but is usually accompanied by a slowdown in the normal time required to batch.

With manual batching, the signal to terminate the material flow depends on the human element to anticipate the unregistered material passing the cut-off device. Thus, the accuracy obtainable is dependent on the skill of the operator and the desire to do a good job.

With automation, the controls anticipate the various batching conditions. Although they often require more time to perform batching, automated controls can perform multiple functions at the same time, and are not subject to human error.

Manufacturers often provide a means to adjust the full gate opening in order to gain the final cut-off control necessary, while allowing for the use of the same size gate. Two-stage cut-off with a final “dribble” feed control is also used. Other methods are an adjustable mid-air compensation for individual materials for a two-stage “fast” and “slow” gate or combinations of these.

Lever-system scales should be designed such that the center of gravity of gross load always lies between load pivots. All beam-type scales should be equipped with a tare beam and they should have provisions for indicating that the required load in the hopper is being approached. This indication should be by means of graduated beam or dial showing at least the last 10% of the batch weight, and separate weighing beams for each ingredient of a batch to be weighed on the same scale. Balance indicators should be sufficiently sensitive to show movement when weight corresponding to 0.10% of scale capacity is placed in the batch hopper at a load equal to or above 50% of scale capacity. Pointer travel of balance indicators should be at least 5% of net rated capacity of the largest weight beam or 200 lb (90 kg), whichever is less, for underweight and 4% or 100 lb (45 kg), whichever is less, for overweight. Provision should be made for damping oscillation of the indicator pointer.

Dial indicating scales should have the dial-head mechanism enclosed to be dust-tight. Dials should indicate the load in the batcher continuously from zero balance to the full weighing capacity of the scale. Dial faces should have a minimum of 1000 graduations on a circular reading line at clear intervals of not less than 0.03 in. (0.76 mm).

Digital indicators or displays should be protected from dust and have numbers large enough for good readability. The
minimum numerical increment should be equal to or less than 0.1%.

Load cell scales should be arranged to transmit loads to one or more cells directly or through a system of levers, such that the cell system registers the entire load accurately on the load-indicating device. Load cells should be indicated by the manufacturer to be accurate throughout the range of temperatures normally experienced during placement operations.

Dispensers for liquid admixtures may measure by volume or weight. Powdered admixtures, if used, should be measured by weight. Admixtures should be in liquid form. Modern liquid-admixture-batching equipment incorporating effective controls and interlocks has virtually eliminated the requirement for weighing admixtures in the powdered state.

If more than one admixture is being used through a single dispenser without flushing the dispenser with water after each cycle, it is necessary to ascertain that the admixtures are compatible and that the mixing of the admixtures prior to their introduction into the mix will not be detrimental.

Automatic equipment for measuring and dispensing admixtures is strongly recommended, provided the dispenser is equipped with a visual means of providing a cross-check of the amount of admixture batched during each cycle. This cross-check is required to help the batcher prevent large over- or under-doses of admixture due to dispenser malfunction in any batch.

The following are examples of how the cross-check might be provided:

1. Collecting the measured quantity of admixture in a calibrated container during each cycle and holding it for a short period to permit a visual check.

2. Measuring the dispensed quantity through the use of an independent meter to obtain a rough check on the amount measured by observation of a volumetric indicator.

A tare-adjustable 0-to-200-lb-capacity (0 to 90 kg) scale with 0.1 lb (0.05 kg) dial graduation can be used to weigh cement and sand individually or as a batch scale. A tare-adjustable 0-to-50-lb-capacity (0 to 23 kg) scale with \(\frac{1}{4}\) or 0.1 lb (0.05 kg) graduation is necessary to weigh mix water. This scale can also be used during operations to keep track of the weight of the roving package.

If a drop tank is being used to measure mix water, the water-charge weight should be checked periodically.

Preweighed containers of sand should be kept covered and free from contamination until used.
5.1 Inspection

5.1.1 Necessity for Inspection

To ensure that proper methods of all phases of production are being followed and the finished product complies with specified requirements, inspection personnel and a regular program of inspecting all aspects of production shall be provided in all plants. Inspectors shall be responsible for the monitoring of quality only and shall not be responsible for or primarily concerned with production.

Every effort toward cooperation shall be observed between production personnel who are responsible for quantity and quality and inspection personnel who are responsible for observing and monitoring quality.

5.1.2 Scope of Inspection

To establish evidence of proper manufacture and quality of GFRC products, a system of records shall be used in each plant. The system of records shall provide full information regarding the materials, proportioning, spraying, curing, inspection of finished products, member dimensions, and GFRC strength.

In general, the scope for quality control inspections to be performed in GFRC plants shall include, but not necessarily be limited to, the following:

1. Plant testing and inspection of materials and embeds required for acceptance prior to spray-up and daily check testing for quality maintenance.
2. Providing and checking conformity of mix designs for all face mixes and required ingredients for concrete testing.
3. Inspection of molds and new setup changes prior to spray-up. The plant shall prepare its own list of items to be checked as part of the pre-spray-up inspection and emphasis shall be on items that cannot readily be checked after spraying.
4. Checking of blockout positioning, sealing strips, rustication strips, cast-in items, positioning of panel frames or integral ribs, and any other critical tolerance items, as well as the proper securing of those items during placement of GFRC.

Every effort toward cooperation shall be observed between production personnel who are responsible for quantity and quality and inspection personnel who are responsible for observing and monitoring quality.

C5.1 Inspection

C5.1.1 Necessity for Inspection

Pre-spray-up and post-spray-up inspections are useful for managing quality. Recurring defects require decisive corrective action by management.

Plant management should give the quality control department sufficient time and resources to do an adequate job. Inspection operations should be managed so that production is not delayed as long as specified procedures are being followed. Many items must be checked during the pre-spray-up inspections, and each type of element (different mark numbers) may have a different set of requirements. A plant’s training program should include a definitive outline of items to be inspected.

C5.1.2 Scope of Inspection

To document the pre-spray-up inspection, quality control records should be identified with the same job number, mark number, and other information used to identify the product after inspection.

The post-spray-up inspection is frequently the last and sometimes the only opportunity to confirm that products were made in conformance with the shop drawings. The most important aspect of the post-spray-up inspection is the timeliness of the inspection. Post-spray-up inspections should be made as soon as practical after products are stripped from their molds. If a defect is evident, or a mistake has been made, and the defect or mistake is detected during the post-spray-up inspection, similar defects and/or mistakes in products yet to be cast can be prevented.

The number of workers required to perform inspecting services will vary with the size and scope of operations within the plant. It is important that a sufficient number of inspection personnel be available to carry out all prescribed tasks to maintain the thoroughness of inspections and tests. Assignments and responsibilities for all inspecting functions should be clearly defined and planned in production scheduling.
DIVISION 5 – QUALITY CONTROL

Standard

5. Checking of panel frames including size, position, and welding of structural steel and light-gauge steel components.
6. Checking of molds and appurtenances for adequate maintenance by verification of tightness, dimensions, and overall general quality.
7. Inspection of batching, mixing, conveying, placing, spraying, compacting, curing, and finishing of concrete facing and GFRC backing.
8. Daily inspection of stripping product from the mold and checking for failed anchors or cracking.
9. Monitoring of plant, equipment, working conditions, weather, and other items affecting production.
10. Preparation of test boards for GFRC testing both wet and after curing, including fiber content, unit weight, flexural strength tests, bulk density tests, anchor tests, and other tests as required.
11. Inspection of finish to make sure that the product matches the standard established by the approved project mockup or sample in color, texture, and uniformity. Finish defects, cracking, and other problems shall be reported and a decision made as to acceptance, repairs, or manufacturing change. Units that are damaged shall be recorded and marked.
12. Check of finished product against approved shop drawings and approved samples to ensure that proper finishes are on all required areas, product measurements are correct, cast-in items are correctly located, panel is properly identified and marked, and all measurements are within allowable tolerances.
13. Monitoring of storage area for proper blocking, methods for prevention of chipping, warping, cracking, contamination, or blocking stains and any other items that may adversely affect the quality of the product.
14. Inspection of product during loading for proper blocking and to detect stains, chips, cracks, warpage, or other defects.
15. Inspection of products following any repair.

Commentary

Information gained through quality control inspection should be reviewed on a daily basis with production personnel. This review should be useful in identifying areas that may need production procedures reinforced or modified, or equipment that needs to be repaired or replaced.

5.2 Testing

5.2.1 General

Testing shall be an integral part of the total quality control program. Testing for quality control of the GFRC unit shall follow plant standards as well as standards.
required by the specifications for a particular project.
For control tests of materials and testing of the composite, both in uncured and cured states, each GFRC plant shall be equipped with adequate testing equipment and staffed with personnel trained in its proper use, or the plant shall employ the services of an independent laboratory.

Independent laboratories providing quality control services shall meet the following criteria:

1. Conform to the requirements of ASTM E329*.
2. Be inspected by the Cement and Concrete Reference Laboratory of the NIST.
3. Have the testing equipment required to perform the following tests on GFRC:
   - ASTM C947: Flexural Properties of Thin-Section Glass fiber reinforced Concrete
   - ASTM C948: Dry and Wet Bulk Density, Water Absorption and Apparent Porosity of Thin Sections of Glass fiber reinforced Concrete
   - ASTM C1230: Performing Tension Tests on Glass fiber reinforced Concrete Bonding Pads.

Specified properties of all materials used in manufacture of GFRC panels shall be verified by ASTM or other appropriate tests conducted by either the material supplier or the panel manufacturer.

In order to establish evidence of proper manufacture and conformance with plant standards and project specifications, a system of records shall be maintained to provide full information on material tests, mix designs, composite tests, and other necessary information.

Each pump/spray gun unit shall be assigned an equipment identification number that shall not change throughout the duration of the project.

5.2.2 Acceptance Testing of Materials and Preproduction Testing

Material suppliers shall be required to furnish certified test reports for cement, aggregates, admixtures, curing materials, glass fiber, and hardware materials to show compliance with the applicable ASTM standards, project specifications, and plant standards.

Cement. If mill certificates are not supplied, representative testing of each shipment of cement is required

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*C Titles for all standards and other documents referred to in the manual are given in Appendix J.
DIVISION 5 – QUALITY CONTROL

Standard

Glass Fiber. Plant testing of glass fiber shall not be required if the glass fiber strand is certified as being manufactured with an alkali-resistant glass produced using a minimum of 16% zirconia and conforms to the specification requirements detailed in Appendix F.

Sand for Backing. Sieve analyses per ASTM C136 shall be conducted on samples taken from each shipment received at the plant.

Facing Aggregates. Fine and coarse aggregates shall be regarded as separate ingredients. Aggregates shall conform to ASTM C33 or C330 except for grading and soundness. The grading requirements (only) of ASTM C33 or C330 shall be waived or modified to meet the special requirements of face mixes and provide the advantages in having the GFRC backing mix as compatible as possible with the face mix. Sieve analysis in accordance with ASTM C136 shall be conducted on samples taken from the initial shipment received at the plant.

Commentary

from lower cube strength, lower tricalcium silicate (C₃S), lower fineness, higher percent retained on No. 325 sieve (45 µm), and higher loss on ignition. Increase in total alkali may reduce GFRC strength gain after seven days and impair the strength-producing efficiency of water-reducing admixtures. Variation in the color of gray cement may in part be traced to a variable Fe₂O₃ content (a 2% variation in Fe₂O₃ being significant).

If the C₃S content varies by more than 4% from the mean values used in mix-design confirmation tests, the ignition loss varies by more than 0.5%, or the fineness by more than 375 cm²/g, Blaine (ASTM C204), then problems in maintaining a uniform high strength may result. Sulfate (SO₃) variations should be limited to ±0.20%.

Until project acceptance, it is good practice to keep a 10-to-15-lb sample of each cement shipment (composite from two or three subsamples) in an airtight and moisture-proof container with a minimum air space over the sample to check color and strength development, if necessary.

If problems have occurred with cement-color variations, a visual check in sunlight of a cement sample for color conformity for each project should be made before allowing the cement to be unloaded. A visual check of cement color should be made and compared to previous samples by placing the sample between two pieces of plate glass and taping the edge to hold in the cement. This is helpful in verifying that cement is from a standard mill source. Unannounced changes in mill sources may result in variable GFRC properties such as strength, setting, and color.

Sand for Backing. Tests should be conducted more often than each shipment if evidence suggests a change in the sand gradation. Shipments of bagged sand may come from different production lots, so more frequent testing may be necessary.

Facing Aggregates. Sampling preferably should be from conveyors or the discharge opening of bins. Stockpiles are most difficult to sample properly and should be avoided as sample sources, if possible. Sampling of stockpiles or conveyor belts for aggregate should be in accordance with ASTM D75. Once a sample has been taken, the sample should be mixed and then quartered in accordance with ASTM C702. Once the sample has been reduced to a test size, testing should follow ASTM C136. Sieve analysis tests are required to ensure uniformity of materials received and
plant. Specific gravity, absorption, and petrographic analysis tests conducted within the past five years shall be obtained from the supplier prior to its first use, when a new lift or horizon in a quarry is used, or when there appears to be a change in quality of the aggregate.

Evaluation of aggregates for potential alkali-silica or alkali-carbonate reactions (excessive expansion, cracking, or popouts in concrete) shall be based on at least 15 years of exposure to moist conditions of structures made with the aggregate in question, if available, or petrographic examination (ASTM C295) to characterize aggregates and determine the presence of potentially reactive components. If an aggregate is found to be susceptible to alkali-silica reaction using ASTM C295, it shall be evaluated further using ASTM C1260 and C1293. Aggregates that exhibit ASTM C1260 mean mortar bar expansion at 14 days greater than 0.10% shall be considered potentially reactive. Aggregates further evaluated by ASTM C1293 that exhibit mean concrete prism expansion at one year greater than 0.04% shall be considered potentially reactive.

Aggregate sources exhibiting expansions of no more than 0.04% and demonstrating no prior evidence of reactivity in the field shall be considered nonreactive. Reliance shall not be placed upon results of only one kind of test in any evaluation.

If an aggregate is judged to be susceptible to alkali-carbonate reaction using ASTM C295, it should be evaluated further for alkali-carbonate reaction in accordance with ASTM C586 or ASTM C1105.

Tests for deleterious substances and organic impurities shall be done at the start of a new aggregate supply and annually thereafter, unless problems are en-
countered requiring more frequent testing. Deleterious substances in aggregates shall be limited to the allowances given in ASTM C33 for exposed architectural concrete located in severe-weathering regions with the following exceptions: (1) fine aggregate shall not exhibit a color darker than Organic Plate 1 when tested for organic impurities in accordance with ASTM C40; and (2) clay lumps and friable particles in fine aggregate shall be limited to maximum of 1% and in coarse aggregate to a maximum of 0.25%.

Coarse aggregates may occasionally contain particles with an iron sulfide content that results in unsightly stains. Since this aggregate could meet the staining requirements of ASTM C330, the requirements shall be tightened. If ASTM C295 indicates the presence of iron sulfides, the aggregates tested by ASTM C641 shall show a stain index less than 20.

GFRC units, although not normally exposed to salting or intense freezing and thawing, may be exposed to strong wet-dry cycling. Wet-dry-sensitive coarse aggregates may crumble and such crumbling may be noticeable even if the aggregate is used in small quantities.

Staining due to iron sulfides generally becomes noticeable at a later date due to moisture and oxidation from exposure to the atmospheres.

An additional test for the staining potential of gravel or crushed carbonate rock is to immerse a sample in a lime slurry (CaOH dissolved in water with an excess of CaOH). The test shall be conducted on a freshly fractured or sandblasted aggregate surface. If staining particles are present, a blue-green gelatinous precipitate is formed within 5 to 10 minutes; this will rapidly change to a brown color on exposure to air and light. The reaction should be complete within 30 minutes. If no brown gelatinous precipitate is formed when a suspect aggregate is placed in a lime slurry, there is little likelihood of any reaction taking place in the face mix. These tests should be required if the aggregate does not have a record of prior use.

Unless all aggregate is stockpiled at the beginning of a project, a sample of the approved aggregate for exposed surfaces shall be maintained until all units are accepted by the architect. As shipments of aggregates are received, a visual inspection shall be made such that the general appearance of the material can be compared with the approved aggregate sample.

Water. Water shall be potable or chemically analyzed when a private well or nonpotable water is used in the face or GFRC backing mix. Except for water from a municipal supply, an analysis of the water shall be on file at the plant, updated annually, and clearly related to the water in use. Seawater or other sources of water that contain concentrations of substances known to be deleterious to concrete shall not be used.

Mortar cubes made in accordance with ASTM C109 using nonpotable or questionable mixing water shall have seven-day strengths equal to at least 90% of the strengths of companion specimens made with potable or distilled water. Time of set (ASTM C191) for mortar made with questionable water may vary from one hour earlier to 1 1/2 hours later than the control sample.
made with potable or distilled water. Water resulting in greater variations shall not be used.

Admixtures. The manufacturer of the admixture shall certify that individual lots meet the appropriate ASTM requirements. All relevant admixture information with respect to performance, dosages, application methods, and limitations shall be on file at the plant. Air-entraining admixtures shall conform to the requirements of ASTM C260. Other admixtures shall conform to the requirements of ASTM C494, Types A, B, D, F and G, or ASTM C1017. The supplier shall certify these admixtures do not contain calcium chloride. Fly ash or other pozzolans used as admixtures shall conform to ASTM C618 Class N requirements and silica fume to ASTM C1240.

Laboratory test reports submitted by the supplier of chemical admixtures shall include information on the chloride-ion content and alkali content expressed as Na₂O equivalent. Test reports are not required for air-entraining admixtures used at dosages less than 2 fl oz per 100 lb (130 ml per 100 kg) of cement or nonchloride chemical admixtures used at maximum dosages less than 5 fl oz per 100 lb (325 ml per 100 kg). Both the chloride-ion and total alkali content of the admixture are to be expressed in percent by mass of cement for a stated or typical dosage of the admixture, generally in fluid ounces per 100 lb of cement (milliliters per 100 kg).

Curing Admixtures. Plant testing of curing admixtures is not required if curing admixtures are certified to conform to specification requirements in Appendix G. Curing admixtures are sensitive to freezing and shall be visually inspected for color changes and/or coagulation upon delivery and prior to use.

Pigments and Pigmented Admixtures—The supplier shall certify that pigments or other coloring agents comply with the requirements of ASTM C979.

Form Release Agents, Surface Retarders, and Sealers—Instructions for proper use and application shall be obtained from suppliers and kept on file at the plant for all such materials used in the plant. Before using these materials in a production run, they shall be tested with the project design mix under simulated production conditions to verify that materials perform satisfactorily.

Pigments and Pigmented Admixtures—Synthetic mineral oxide pigments may react chemically with other products used on the surface, such as surface retarders or muriatic acid, and should be tested for these reactions prior to use.

Admixtures. The proprietary name and the net quantity in pounds (kilograms) or gallons (liters) should be plainly indicated on the packages or container in which the admixture is delivered. The admixture should meet ASTM requirements on allowable variability within each lot, between lots, and between shipments.

It is desirable to determine that an admixture is the same as that previously tested or that successive lots or shipments are the same. Tests that can be used to identify admixtures include solids content, specific gravity using hydrometer, infrared spectrophotometry for organic materials, chloride content using silver nitrate solution, pH, and others. Admixture manufacturers can recommend which tests are most suitable for their admixtures and the results that should be expected. Guidelines for determining uniformity of chemical admixtures are given in ASTM C494, C233, and C1017.

Normal setting admixtures that contribute less than 0.1% chloride by weight (mass) of cement are most common. Their use should be evaluated based on an application basis, the final use of the GFRC element. If chloride ions in the admixture are less than 0.01% by weight (mass) of cementitious material, such contribution represents an insignificant amount and may be considered innocuous.
**Face Mixes**—Face-mix proportions shall be established under carefully controlled laboratory conditions. All face mixes shall be developed using the brand and type of cement, the type and gradation of aggregates, and the type of admixtures proposed for use in production mixes. If at any time these variables are changed, the mix shall be re-evaluated. This re-evaluation shall include one or more of the following concrete properties:

1. **Strength**
2. **Air content** or freeze-thaw durability
3. **Shrinkage**

Comparison of face-mix shrinkage values to shrinkage values of the GFRC backing mix is a good means for evaluating the compatibility of a face mix with the GFRC backing mix. Shrinkage values should be similar. Large variations of results would indicate possible noncompatibility. Variations of more than 0.04% have been known to produce excessive bowing, cracking, and delamination in composites. Visual evaluation can be made through the use of large unrestrained samples (2 × 10 ft). A sample of GFRC backing only can be compared to a composite face-and-backing-mix sample. Samples should be stored on edge unrestrained and the amount of bowing measured at 14 days. The amount of bowing should be similar.

GFRC backing mixes have a higher cement content than conventional concrete face mixes with resultant greater shrinkage and coefficient of thermal expansion factors. Therefore, face mixes or facing material should be tested to ensure compatibility with the GFRC backing mix. The differential moisture movement data should be used to provide input for panel design as well as to provide a basis for establishing final mix designs.

Records of all face mixes at a plant and their respective test results shall be on file. Acceptance tests for face mixes shall include:

1. **Compressive strength**—Test specimens made and cured in accordance with ASTM C31 and ASTM C39. The diameter of a cylindrical specimen or minimum cross-sectional dimension of a rectangular section shall be at least three times the nominal maximum size of the coarse aggregate with the minimum size limited to either a 2 × 4 in. (50 × 100 mm) cylinder or a 2 in. (50 mm) cube. Test specimens other than ASTM standard sizes are permitted providing proper and proven correlation with the standard test specimen is available.

2. **Absorption**—The procedure for water-absorption determination of the proposed face mixes is described in Appendix H. The absorption of the face mix shall be verified in accordance with Appendix H whenever the materials and/or production methods are modified.

3. **Unit weight**—Unit weight shall be tested in accordance with ASTM C138 or C567.

4. **Air content**—The volumetric method (ASTM C173) may be used on any type of aggregate, whether it be dense, cellular, or lightweight. The pressure method (ASTM C231) gives excellent results when used with face mixes made with relatively dense natural aggregates for
5. **Shrinkage.** Shrinkage tests shall be conducted in accordance with ASTM C157.

**GFRC Backing**—To determine the allowable design values for the GFRC backing, a minimum of 20 consecutive flexural tests (of six specimens each) produced on 20 separate days shall be analyzed statistically at the yield and ultimate levels in accordance with Section 5.4.1 of PCI’s *Recommended Practice for Glass Fiber Reinforced Concrete Panels*. If testing is conducted on unaged specimens, the producer shall determine the strength relationship between aged and unaged specimens for each different GFRC backmix design by accelerated aging of the flexural test specimens as described in Appendix H.

**Structural Shapes and Cold Formed Steel**—Mill certificates shall be obtained on all steel items used for fabricating panel frames; flex, gravity, and seismic anchors; panel connections; and other steel hardware. In lieu of mill certificates, three specimens of each size and lot of a steel item shall be tested in accordance with ASTM A370 to verify conformance with the applicable ASTM specification.

**Hardware and Inserts**—Plant tests shall not be required for hardware but mill certificates shall be obtained for mild-steel materials and each different grade of steel to verify compliance with specifications. Pre-design/production tests on inserts shall be conducted in accordance with the flex anchor tests described in Appendix H to determine insert capacities. Records shall be kept on file establishing capacity of each kind and size of insert and its associated embedment that is used for handling and/or connection.

**Flex Anchor and Gravity Anchor Pull-Off or Shear Tests**—Each producer shall have pre-design/production tests conducted on bonding pads to verify the strength in pull-off and shear of the attachment of the GFRC backing to the panel frame. A minimum of 20 unaged samples of each type of connection and anchor size, made in an identical manner as the production panel anchors, shall be tested in accordance with ASTM C1280 to determine the allowable design values.

The producer shall determine the strength relationship between aged and unaged specimens for each different anchor by accelerated aging of the anchor test specimens as described in Appendix H.

**Hardware and Inserts**—The yield strength of the flex, gravity, or seismic anchors’ steel may be well above specification and should be determined from a mill certificate or by testing in accordance with ASTM A370. It is not unusual for A36 steel to have a yield point over 45 ksi (310 MPa).

**Flex Anchor and Gravity Anchor Pull-off or Shear Tests**—The specimens and test procedures should accurately simulate the various service conditions expected to be encountered during the life of the project.
Standard

Bonding Pads—Bonding-pad repair methods shall be confirmed and documented by test data.

5.2.3 Production Testing of Aggregates*

A sieve analysis (ASTM C136) shall be conducted in the plant with test samples taken at any point between and including stockpile and batching equipment. If material is stored in bulk, a sieve analysis shall be conducted at least monthly while the material is being used or more frequently if deemed necessary. Each shipment of aggregate shall be visually compared with the approved aggregate sample.

Moisture tests are not required for bagged aggregates stored indoors. Surface moisture in bulk aggregates shall be evaluated and compensated for in all face-mix and backing slurry proportioning.

Either a moisture meter or electric probe is satisfactory for continuous moisture determination, provided the meters are calibrated against the drying method (ASTM C566).

If moisture meters are not used, the free moisture shall be determined at least daily, or any time a change in moisture content becomes obvious.

5.2.4 Production Testing—Wet*

Slurry Consistency slump test. Slurry consistency slump tests for each mixer shall be conducted at the beginning of each shift in accordance with Appendix H. With the use of high-range water reducers in a mix design, the slump test may not be appropriate. As an alternative, each mixer shall be equipped with an ammeter that indicates the relative resistance of the mixer motor. The ammeter reading shall be maintained constant after a slump consistency is determined to provide a good “wet-out” of the glass fibers with no segregation of the aggregate from the cement paste. If a continuous mixer/pump unit system is used for spray-up, the ammeter shall be monitored to ensure consistent slurry flow rate and a constant glass fiber content.

Slurry Unit Weight. The unit weight test (ASTM C138) shall be conducted once per day before starting production. The unit weight shall not vary more than 3 pcf

Commentary

Bonding Pads—Consideration should be given to the service life of epoxy under elevated temperatures.

C5.2.3 Production Testing of Aggregates

Close control over gradation of aggregates is essential to minimize variations in surface texture and color in the finished product. Aggregates should be handled and stored in a way that minimizes segregation and degradation and prevents contamination by deleterious substances.

Compensation for surface moisture is particularly important for face mixes where the amount of fine aggregate batched by weight may vary enough to significantly affect the color and texture of the finished face. The free moisture on aggregates affects net aggregate weights as well as the amount of water added to the batch. It is recommended that weighing hoppers be equipped with electric moisture meters calibrated to detect changes of 1% in the free moisture content of fine and coarse aggregates so corrections can be made and mixes adjusted at any time. Moisture-metering devices based on conductivity are dependent on the density of the aggregates and are not recommended.

Moisture content may be determined by drying or by a meter that measures moisture by the pressure of chemically generated gas.

C5.2.4 Production Testing—Wet

Slurry Consistency slump test. This test indicates whether a slurry is suitable for spraying. It also provides a means for comparing the consistency of slurries made with varying materials, mix designs, mixers, and spray equipment. Stiff mixes may be difficult to pump and spray. Each operator should determine the range of slump values representing the sprayable range. If slump test results indicate that the mix consistency varies significantly from batch to batch, chemical admixtures should be used to make adjustments. In production, however, routine use of a slump test may be impractical. Therefore, some manufacturers have installed ammeters on their mixers to provide an indication of slurry consistency during the mixing operations by measuring the amperage (load) of the mixer motor. Chemical admixtures are typically used during mixing to achieve consistent ammeter readings from batch to batch.

Slurry Unit Weight. Most GFRC strength properties vary directly with the density of the slurry—the higher the density, the better the performance. When using an acrylic ther-

* See Appendix H for test procedure details.
**Slurry Temperature.** Temperature shall be measured in accordance with ASTM C1064 and recorded when test specimens are made, at frequent intervals in hot or cold weather, and at start of operations each day. An armored thermometer accurate to ±2 °F (±1 °C) shall remain in the sample until the reading becomes stable.

**Spray Rate.** The slurry flow rate (bucket test) and the fiber roving chopping rate (bag test) shall be used to determine whether the fiber content being delivered by the spray equipment is within limits.

These tests shall be conducted for each spray machine before starting production each day and after any extended shut-down. After final setting of the fiber roving chopping rate, the length of any three fibers from the bag shall be measured and shall be within 15% of the required length.

moplastic copolymer dispersion in the mix, it is important to minimize excess entrapped air resulting from the foam generated by high-shear mixing. The appropriate amount of a defoamer in the copolymer dispersion will prevent the generation of excess air.

**Spray Rate.** Proper monitoring of the spray rate of each machine is essential in the production of quality GFRC. A change in the spray rate can occur whenever the machine is shut down. Also, whenever a machine is disassembled and reassembled there is a chance the slurry flow rates and fiber roving chopping rate will change.

The ratio of the fiber roving chopping rate to the slurry flow rate gives an indication of the fiber content.

Control of delivery rates and glass content simply by monitoring and controlling chopping-motor and pump-drive speeds is not sufficient: roving running properties can vary and different slurry consistencies will pump at different output rates. Similarly, reliance should not be placed on the use of roving counters or total changes in roving weight as a measure of glass fiber delivery rate.

Calibration should be made by means of timed weighings (e.g., every 15 seconds) of fiber into a bag, and cement into a bucket. The result of the bag-and-bucket check should be within the limits set; for example, between 5% and 6%. If it does not, then either the chopping speed or the pump speed must be adjusted accordingly and the test repeated until the values obtained reflect the acceptable, or target, glass fiber content. Substantial mix changes may affect pump speed throughout, and in this case, the bucket check can be used to readjust the flow rate.

Experience gained over a number of production runs will enable the operators to determine the fiber roving chopping rate to ensure that the specified fiber content is met. This is necessary because of:

1. Variations in the drag on the roving during production.
2. The inconsistency of take-up of the chopper gun during spraying.
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**Standard**

**Test Boards.** Test boards shall be prepared in accordance with ASTM C1228. At the very minimum, one test board shall be sprayed at least once per work shift, per operator, per spray machine, and per backing-mix design. Each test board shall be marked with a unique identification number. The test boards shall be fabricated at a different time each day so they represent the full range of production conditions and do not become part of a routine sequence of events.

The test board for a panel having a surface finish such as a mist coat or face mix shall be made without the surface finish but shall in all other respects duplicate the production panel.

**Wash-out Tests.** The wash-out test shall be conducted in accordance with ASTM C1229.

The average glass content determined by the wash-out test shall be recorded and be within the control limits of –0.5% to +1.0% by weight of the mix. If either the spray gun calibration or spraying technique is modified, an additional wash-out test shall be conducted.

**Commentary**

**Test Boards.** Testing GFRC strengths by using test boards is a critical part of the quality control program. Test boards must be made on a strictly random basis if they are to properly measure the acceptability of the GFRC backing. The choice of GFRC batch sampling times should be made on the basis of chance alone within the period of placement in order to be representative. If batches of GFRC to be sampled are selected on the basis of appearance, convenience, or other possibly biased criteria, statistical concepts lose their validity.

If the test board is identified by using a mark number and date with a particular unit, shift or spray machine, etc., and cured with or in the same manner as the GFRC panel, then the properties of this board can be considered representative of the properties of the panel. During initial stages of production, test boards should be made at the rate of two per work shift, per operator, per spray machine, and per backing-mix design. As confidence in production uniformity increases, this can be reduced to one test board per work shift, per operator, per spray machine, and per backing-mix design. Quality control personnel should monitor test-board manufacture to ensure that fabrication and compaction are performed in the same manner as the product.

**Wash-out Tests.** The wash-out test is used to determine the glass fiber content of the composite during panel production.

Wash-out tests should be conducted with an appropriate degree of accuracy. Proper weighing equipment and methods of drying are very important to the final results. In a typical wash-out specimen, weights should be determined to the nearest 0.1 g or a significant error in the final glass fiber-weight percentage may result. Heat-convection ovens should be used to dry the glass fibers. Microwave ovens cannot dry the glass fibers sufficiently to provide an accurate result. The glass fibers should be free of moisture and residual sand particles prior to weighing. Baskets containing dried glass fiber should be repeatedly tapped on a tabletop to remove residual sand particles that were not removed during the actual slurry washout.

Sequential application of fiber and slurry may produce non-uniformity in the glass fiber content throughout the thickness. This can lead to poor product performance. A glass-starved surface can cause warpage or cracking. A variation in glass content of less than 10% between the top and the bottom is considered to be acceptable. To ensure homogeneity
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**Standard**

**Thickness.** The skin thickness specified shall be the minimum for all points on the skin. Thickness of both the face mix and GFRC backing shall each be checked with a suitable depth/thickness gauge.

GFRC backing thickness shall be determined by subtracting the face-mix thickness from the total thickness. A minimum of one thickness measurement shall be made per 5 ft² (0.5 m²) of panel surface with at least six measurements per panel. Bonding pad size, thickness, and compaction over anchors shall be visually checked.

Bonding-pad thickness over gravity anchors should be checked with a penetration gauge at 25% of the anchor locations with a minimum of one anchor per panel. Recompaction shall be performed to seal the small hole in the surface by the penetration gauge.

Additional thickness measurements shall be made at sensitive areas of the panel, such as at edges, corners, reveals (false joints) and other breaks in plane surface, and attachment inserts.

Thin areas shall be built up by spraying fresh material into the area concerned and not by transferring sprayed material from one part of the mold to another.

Thickness of GFRC products will tend to vary due to the method of manufacturing. Minimum required thickness shall be maintained, but good judgment must be applied in evaluating variations in thickness greater than design thickness. Increased tolerances on the plus side shall be allowed at changes in plane, reveals, radius sections, stiffening ribs, etc. Localized thickening at these areas may be expected to exceed $+\frac{1}{2}$ in. (+13 mm). Thickness shall never be less than the required thickness.

**Commentary**

across the section, it is essential that the glass and slurry are applied simultaneously.

The uniformity of glass distribution through the thickness (top to bottom) is important and can be checked by means of the wash-out test with split samples. This is an advisory test conducted at the discretion of the manufacturer. If a dual-head (rather than a concentric) spray gun is used (where the glass is sprayed into the slurry stream from one side), this test should be conducted weekly.

**Thickness.** The performance of the panel depends on the correct thickness being achieved, as thin areas produce stress risers and locations for potential cracks. The primary concerns with the face mix are uniformity and thickness. Thickness control of this first unreinforced layer is important to ensure that sufficient material is available for surface treatments that expose the aggregates. However, it is critically important that the facing thickness be controlled and uniform because the thickness of the GFRC skin, to be subsequently applied on top of the facing, will be determined based on a measurement of the total thickness of the skin (GFRC backing plus face-mix thickness). A non-uniform facing layer will result in a non-uniform and possibly insufficient GFRC backing thickness.

Checking thickness is best done using a simple penetration gauge. A further derivation of the pin gauge is the indentation gauge, which has a wire cross or circle arrangement attached at right angles to the pin shaft. This produces a pattern on the GFRC surface if the composite is equal to, or greater than, the required thickness. Its chief benefit is that it offers a simple visual check. Production thickness limits can be checked by having two patterns—for example, a cross for minimum thickness and a circle for maximum thickness.

Inside corners require special attention to ensure that thin areas, voids, and nonreinforced areas are not incorporated into the panel.
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Standard

Face Mix. Air content tests shall be conducted daily on mixes containing air-entraining admixtures.

Commentary

Face Mix. For most architectural face mixes, it may be impractical to entrain a specific air content due to gradation or high cement contents and low slumps. Instead, the use of an air-entraining agent to provide a “normal” dosage is recommended in areas subjected to freezing and thawing. The normal dosage of air-entraining agent should produce an 8% to 10% air content when tested in accordance with ASTM C185, but using only the mortar (material less than 1/4 in. [6 mm]) portion of the mix. The addition of normal amounts of an air-entraining agent to harsh gap-graded face mixes will improve the workability and increase resistance to freezing and thawing even though only a small amount of air is usually entrained. Once established for the mixture, the corresponding entrained-air content of the total concrete mixture may be determined and the value used in production control.

5.2.5 Production Testing—After Curing

Backings Strength Tests. Flexural tests of the GFRC backing shall be conducted at 28 ± 2 days in conformance with the requirements in ASTM C947. Quality assurance flexural strength tests shall be conducted on six samples saw-cut from the test boards. One test shall be conducted each day for each operator, spray machine, and backing-mix design. When variability in these factors decreases, as demonstrated by test results, frequency of testing shall be reduced to a minimum of one test per backing mix per day. These reduced-frequency tests shall be selected to check all operators and machines on a rotating basis, and the results of these tests shall be plotted daily to verify consistency of test results.

The strength level shall be considered satisfactory if both of the following requirements are met:

1. The average of all sets of three consecutive yield strength test values shall be equal to or exceed $f'_{y}$ used in design, and the average of all sets of three consecutive ultimate strength test values divided by three shall be equal to or exceed the $f'_{u}$ used in design.

2. No individual yield strength test value shall be less than 90% of the $f'_{y}$ used in design, and no individual ultimate strength test value divided by three shall be less than 90% of the $f'_{u}$ used in design.

If any strength test falls below these requirements, the GFRC design engineer shall take steps to ensure that the GFRC panels represented by the test coupons are not jeopardized. The design engineer may request additional coupon testing from the same test board, have the panel load tested, have coupons cut and tested

Because strength tests are carried out after curing, this cannot be used for timely process control. (This feature dramatically increases the need for wet quality control checks to ensure acceptable quality.) Strength tests serve as a reassurance to both the producer and the customer that the assumptions on which the component design is based are being realized in production.

GFRC strengths can vary due to the spray operator, spray machine, and backing-mix design. Until confidence is built up in all of these factors, a minimum of one flexural test should be conducted every day for each combination of operator, machine, and backing-mix design. The best way to establish confidence in these factors is to plot the flexural test results on a daily basis. Plotting test results provides a quick and easy reference to evaluate the variability in strengths. As the strength variations are minimized, the amount of testing required can be reduced to one test per backing-mix design per day.

The coefficient of variation of strength properties will vary in accordance with the skill of the operator, the degree to which the results of quality control tests are used to adjust spray-up variables, and the type of equipment used.
from suspect GFRC panels, or take other appropriate action.

**Bulk Density and Absorption.** These measurements shall be used to establish the level of compaction of the GFRC and shall be performed weekly for each operator, spray machine, and backing-mix design in accordance with ASTM C948. A test sample (two specimens) shall be prepared from the test boards. Specimens may be taken from portions of actual flexural specimens. The wet bulk density shall not be less than 125 pcf (2003 kg/m³) and the dry bulk density shall not be less than 110 pcf (1762 kg/m³). The bulk density shall not vary more than –5 pcf (80 kg/m³) or +10 pcf (160 kg/m³) from the established bulk density for the particular mix design in use. The absorption shall not exceed 16% by weight.

**Flex Anchor and Gravity Anchor Pull-off or Shear Tests.** Anchor connection tests shall be conducted in accordance with the requirements of Appendix H. Flex anchor tests shall also meet the requirements of ASTM C1280. To confirm production values, two test specimens of one type and size of anchor shall be made from the test boards produced during a week. During the following weeks, additional types and sizes of anchors shall be tested so that all types and sizes of anchors are evaluated. Of the specimens produced during one week, one test (two test specimens) of an anchor type and size shall be randomly selected and tested at an age of approximately 28 days after spray-up date.

The anchor strength level shall be considered satisfactory if both of the following requirements are met:

1. The average of all sets of three consecutive anchor strength tests equals or exceeds $1\frac{1}{2}$ times the $P_u$ used in design.

2. No individual anchor strength test is less than $1\frac{1}{2}$ times the $P_u$ used in design.

Bonding-pad repair methods shall be evaluated and documented by anchor test data.

The surface layer of a panel may consist of reinforced cement/sand mortar, or it may be exposed-aggregate concrete. It is, therefore, important that such layer not be included in the flexural test samples.

The flexural ultimate test results from samples cut from different directions in the test board can indicate preferential fiber-orientation effects. The results of tests with either the top or bottom face of the test board in tension can indicate differences in fiber distribution through the thickness of the test board.

**Bulk Density and Absorption.** The dry density of GFRC depends primarily on fiber content, water–cement ratio, polymer content, sand content, compaction, and spray techniques. These factors also influence porosity. The typical range of dry density is 120 to 140 psf (1920 to 2240 kg/m³). A knowledge of the density gives information on the general quality of manufacture and is used as a measure of plant quality control procedures.

Moisture absorption varies according to the density and polymer content of GFRC but will normally be in the range of 8% to 16% by weight. Moisture content of GFRC in an environment of 65 °F (18 °C) and 60% relative humidity will reach equilibrium in the range of 4% to 8%.

**Flex Anchor and Gravity Anchor Pull-off or Shear Tests.** The mix proportions for GFRC bonding pads and techniques for applying the bonding pads are different for each producer. Since these items affect the strength of the pad, it is necessary for each producer to have tests conducted on their bonding pads. The properties achieved in practice will depend on bonding-pad diameter, type of insert or embedment used, quality control of materials, degree of compaction, thickness and area of bonding pad, and adequacy of curing.
DIVISION 5 – QUALITY CONTROL

Standard

Face-Mix Strength Tests. Compressive strength tests of the face mix shall be conducted weekly in accordance with ASTM C39.

5.3 Records

5.3.1 Record Keeping

To establish evidence of proper manufacture and conformance with the plant standards and project specifications, a system of record keeping shall be used that provides full information regarding testing of materials, mix designs, production tests, and any other information specified for each project. Records shall be designed for minimal writing (see Sample Records in Appendix E).

Each GFRC unit shall be marked on its back side with the date produced and the unique identification number that can be referenced in production and erection drawings and testing records.

Unless otherwise noted herein, record keeping shall be the responsibility of the quality control inspection personnel. In the absence of project specification requirements or state statute, records shall be kept for a minimum of five years after final acceptance of the structure, or for the period of product warranty provided by the manufacturer, whichever is longer.

5.3.2 Suppliers’ Test Reports

Certified test reports for materials not plant tested shall be required of suppliers. Refer to Article 5.2.2 for this requirement. These reports shall show the results of suppliers’ mill or plant tests, tests by an independent testing laboratory, petrographic analysis of aggregate for face mixes, and other testing required by the project specification. These reports shall state compliance with applicable specifications.

Mill or supplier test certificates or standard test results are generally provided on the following materials:

1. Cement
2. Aggregates
3. Admixtures
4. Curing admixtures
5. Glass fiber
6. Light-gauge cold-formed steel
7. Structural steel or other hardware items
8. Inserts or proprietary items as specified for individual jobs

Commentary

C5.3 Records

C5.3.1 Record Keeping

Records provide the vehicle for transmitting and evaluating deficient procedures or products, and should result in their correction by communication of problems.

Units should be marked in an area that is not exposed to view when in place on the structure but accessible for review and inspection while in storage. Member markings related to mold number when several identical molds are needed make it possible to relate quality control data to specific units. Such markings also facilitate documentation of member production, inspection, and repair.

C5.3.2 Suppliers’ Test Reports

Project specifications require standards for materials used in production. A manufacturing facility must obtain certificates of compliance to ensure the integrity of the product and to protect its own interest. Correlation of certificates of compliance to a specific project is needed for conformance with the design and specifications. Plants that use materials fabricated or supplied by outside vendors should periodically inspect the operations of those vendors to ensure compliance with the specifications of this manual. All vendors should be required to submit proof of compliance for both materials and workmanship.
### 5.3.3 GFRC Records

Records of GFRC operations and tests shall be kept so the following data shall be available for each unit or daily or weekly production as required:*  
1. Unit and job identification  
2. Production date  
3. Mix proportions by weight  
4. Mixing-water corrections  
5. Identification of production area, mold, or bed  
6. Test-specimen identification  
7. Face-mix and backing-mix temperatures  
8. Air temperature, weather conditions if applicable, and any measures taken for cold or hot weather spray-up operations  
9. Slurry slump  
10. Slurry flow rate tests  
11. Unit weight, fresh  
12. Fiber content  
13. Inspection of batching, conveying, spray-up, compacting, and finishing of GFRC  
14. Skin thickness and bonding-pad inspection  
15. When no copolymer is used, curing records—time duration, temperature, humidity  
16. Flexural strength—yield and ultimate  
17. Bulk density and absorption  
18. Pre- and post-production inspection reports  
19. Skin anchor tests  
20. Aggregate gradation and moisture content

* See sample forms in Appendix E.

### C5.3.4 Calibration Records for Equipment

Calibration records are required as specified for each type of equipment, and equipment should be periodically recalibrated as required. Records that show deviations between
DIVISION 5 – QUALITY CONTROL

Standard

plied by the testing agency or others involved in calibration, and the equipment operator shall have ready access to the records.

5.4 Laboratory Facilities

5.4.1 General

The plant shall maintain an adequately equipped laboratory or retain the services of a testing agency in which investigation and development of suitable GFRC mixes may be conducted and ongoing quality control testing may be conducted.

The laboratory facilities shall be in a protected area with environmental controls to ensure proper working conditions. Laboratory equipment shall be maintained in proper condition and calibrated as needed, but not less than annually. Calibration records shall be kept on file.

5.4.2 Quality Control Testing Equipment

The plant shall have all equipment required for performing the testing procedures. Equipment shall meet the requirements of the test procedure specification.

Commentary

instrument readings and actual values should be used by plant personnel to obtain correct readings.

C5.4 Laboratory Facilities

C5.4.2 Quality Control Testing Equipment

The laboratory should have the facilities necessary for the development and assessment of mixes and the quality control tests to be conducted by the manufacturer.

Testing equipment should include the following:

1. Scale with 25 lb (12 kg) capacity and accuracy of 0.1 lb (50 g)
2. Scale with 2 kg capacity and accuracy of 0.1 g
3. 5 gallon (18 liter) plastic bags
4. Measuring bucket of 5 gallon (18 liter) capacity.
5. Slump tube 2 1/4 in. (57 mm) ID × 3 3/16 in. (81 mm) or 2 1/4 in. (57 mm) long. Slump plate with concentric rings numbered to indicate slump values. (Some GFRC plants may use an ammeter for slump control.)
6. Maximum-minimum thermometer
7. Concrete thermometer
8. Two 7 in. × 4 in. × 1 in. (178 mm × 102 mm × 25 mm) deep trays with 1/8 in. (3 mm) stainless steel screen face
9. Measuring tapes
10. Depth probe
11. Saw with masonry blade
12. Access to a flexural testing apparatus conforming to ASTM requirements
13. Load cell for pull-off tests
14. Drying oven (convection) or muffle furnace
Standard | Commentary
--- | ---
15. Mechanical shaker with a series of standard sieves conforming to ASTM E11 for aggregates | 
16. Trowels, pails, knives, shovels, etc. | 
17. Timer | 
18. Applicable ASTM, ACI, AWS, and PCI reference literature | 
The following items are required only for face-mix testing:

1. Air meter of pressure type, or volumetric type when polymer is not used | 
2. Cube molds for face-mix compression tests | 
3. Access to compression-testing machine conforming to ASTM requirements | 
4. Water tank or fog room for face-mix cube curing | 

Additional equipment that would be useful includes:

1. Heating element or hot-plate with flat pans for drying materials | 
2. Set of 2 or 4 in. (50 or 100 mm) cube molds for compression testing | 
3. Aggregate splitter (for gradation samples) | 
4. Miscellaneous chemical glassware | 
5. Recording thermometers | 

**5.4.3 Test Equipment Operating Instructions**

Operating instructions shall be obtained for all testing equipment as well as national and industry standards for materials and testing. These instructions shall be kept in the laboratory and shall be carefully followed by all testing personnel.

Testing machines shall be kept clean and no attempt shall be made to use them beyond their rated capacities. Machines shall be capable of applying loads at the specified rate. Testing machines shall be calibrated so that the maximum error is not more than ±1% of full-scale reading. Calibration shall be performed whenever there is reason to doubt the accuracy of indicated loads, but not less than annually. Calibration curves shall be available at all times and used by testing personnel.

**5.4.4 Welding**

As required by AWS D1.1 and/or AWS D1.3. Welding Procedure Specifications (WPS) shall be developed for all welding processes and weld types whether prequalified or qualified by testing. All welders shall be qualified to the applicable WPS in accordance with AWS guidelines.
Standard

All completed welds shall be visually examined to ensure compliance with approved drawings and project specifications. Visual acceptance criteria shall be in accordance with the applicable AWS code. The size, length, and spacing of welds shall comply with approved drawings.

Commentary

Visual-inspection guidelines are given in AWS B1.11, and radiographic and ultrasonic testing procedures and limits are given to AWS D1.1 and D1.4. If required by specifications, radiographic testing (though very costly) is good, and ultrasonic testing is poor in detecting volumetric discontinuities, such as porosity. Ultrasonic testing is good for detecting planar discontinuities, such as incomplete sidewall fusion, while radiographic testing can miss such discontinuities unless oriented parallel or near parallel to the radiation direction.

Visual inspection for cracks in welds and base metal and other discontinuities should be aided by a strong light, magnifier, or other such devices as may be found helpful.

Personnel responsible for acceptance or rejection of welding workmanship shall be qualified in accordance with AWS D1.1.

The qualification of the responsible personnel shall remain in effect indefinitely, provided such personnel remain active in inspection of welded steel fabrication, unless there is specific reason to question the personnel’s ability.

Prior to welding or at suitable intervals, inspections shall include the following:

a. Review of approved drawings and welding-procedure specifications
b. Ensuring that welding materials and consumables are in accordance with specifications
c. Checking and identifying as-received materials against specifications
d. Checking storage of filler material
e. Checking welding equipment
f. Checking weld-joint preparations
g. Checking for base-metal discontinuities

In addition to checking that the required weld size, length, location, and type are as indicated on the approved drawings, and that no welds are omitted, a check shall be made to ensure that no welds have been added without approval.

Deficient welds shall be corrected by rewelding or removal in accordance with specified procedures.

Size, length, and contour of welds should be measured with suitable weld-size gauges. Groove welds should be measured for proper reinforcement on both sides of the joint.
6.1 Requirements for Finished Product

6.1.1 Product Tolerances—General

The tolerances listed in this division shall govern unless other tolerances are noted in the contract documents for a specific project.

Tolerances are divided into three categories: product tolerances, erection tolerances, and interfacing tolerances.* See Appendix K for erection tolerances.

Project specifications may require small, or allow for large, tolerance limits depending on the construction details and provisions for interfacing with other materials.

Tolerances are specified permissible variations from exact requirements of the contract documents. A tolerance may be expressed as an additive or subtractive (±) variation from a specified dimension or relation, or as an absolute deviation from a specified relation.

Tolerances should be established for the following reasons:

1. **Structural:** To ensure that the structural design properly accounts for factors sensitive to variations in dimensional control. Examples include eccentric loading conditions, bearing areas, hardware and hardware anchorage locations, and locations of the panel frame.

2. **Feasibility:** To ensure acceptable performance of joints and interfacing materials in the finished structure and to ensure that designs are attainable with available manufacturing and construction techniques.

3. **Visual effects:** To ensure that the variations will be controllable and result in acceptable appearance.

4. **Economics:** To ensure a reliable and efficient rate of production and erection by having a known degree of accuracy in the dimensions of GFRC products.

5. **Legal:** To avoid encroaching on property lines and to establish a tolerance standard against which the work can be compared in the event of a dispute.

6. **Contractual:** To establish a known acceptability range and also to establish responsibility for developing, achieving, and maintaining mutually agreed-upon tolerances.

It is very important to clearly define at the onset of the project the entity (architect or engineer of record) responsible for establishing project tolerances.

*See the full report of the PCI Committee on Tolerances, *Tolerances for Precast and Prestressed Concrete*, MNL–135, for a complete discussion of tolerances, including erection and interfacing tolerances.
DIVISION 6 – PRODUCT TOLERANCES

Standard

Applicable product tolerances shall be clearly conveyed to production and quality control personnel.

6.2 Measurement

Accurate measuring devices and methods with a level of precision that is appropriate for the specified tolerance shall be used for both setting and checking product dimensions. To ensure proper accuracy, products shall not be measured in a manner that creates the possibility of cumulative error, such as measuring multiple increments for single dimensions.

Commentary

The architect/engineer should be responsible for coordinating the tolerances for GFRC work with the requirements of other trades whose work adjoins the GFRC construction. In all cases, the tolerances must be reasonable, realistic, and within generally accepted limits. It should be understood by those involved in the design and construction process that tolerances shown in Article 6.3 should be considered as guidelines for an acceptable range and not limits for rejection. If these tolerances are met, the unit should be accepted. If these tolerances are exceeded, the unit may still be acceptable if it meets any of the following criteria:

1. Exceeding the tolerances does not affect the structural integrity or architectural performance of the unit.
2. The unit can be brought within tolerance by structurally and architecturally satisfactory means.
3. The total erected assembly can be modified economically to meet all structural and architectural requirements.

Where a project involves particular features sensitive to the cumulative effect of generally accepted tolerances on individual portions, the architect/engineer should anticipate and provide for this effect by setting a cumulative tolerance or by providing escape areas (clearances) where accumulated tolerances can be absorbed.

Specified tolerances should allow for construction with industry-standard means and methods. Specification should be reasonable with respect to the level of precision that can be attained with standard manufacturing methods. For example, a requirement that states that “no bowing, warpage, or movement is permitted” is not practical or possible to achieve.

Required tolerances other than those given in this manual should be noted on the product drawings or in a special tolerance document.

C6.2 Measurement

Typically, the precision of the measuring technique used to verify the dimension should be capable of reliably measuring to a precision of 1/8 the magnitude of the specified tolerance. For this reason, the use of standard metallic measuring tapes graduated in feet, inches, and fractions of inches (meters and millimeters) is appropriate for measurement to a tolerance of no less than 1/8 in. (3 mm).

Measurements should always be made from a fixed reference point, rather than measuring the relative distance between elements, to minimize the potential for cumulative error.
Any special measuring or record keeping methods specified in the contract documents shall be observed by the plant quality control personnel.

### 6.3 Product Tolerances

Product tolerances are those needed in any manufacturing process. They are normally determined by economical and practical production considerations, as well as by functional and appearance requirements. The architect/engineer should specify product tolerances or require performance within generally accepted limits. Tolerances for manufacturing are standardized throughout the industry and should not be made more exacting, and therefore more costly, unless absolutely necessary.

During the pre- and post-spray-up check of dimensions, the inspector shall have access to the approved shop drawings for reference. Discrepancies shall be noted on the post-spray-up record and transmitted to management or engineering for their evaluation.

GFRC panels shall be fabricated within tolerances shown in Fig. 6.3(a).

#### Figure 6.3(a) Tolerance locations

**a.** Overall height and width of units measured at the face adjacent to the mold:
   1. 10 ft (3 m) or under .......... ±1/8 in. (±3 mm)
   2. 10 ft (3 m) and over .......... ±1/8 in. per 10 ft (±3 mm per 3 m); 1/4 in. (6 mm) maximum

**b.** Edge return …+1/2 in., −0 in., (+13 mm, −0 mm)

**a.** Length or width dimensions and straightness of a unit will affect the joint dimensions, opening dimensions between panels, and perhaps the overall length of the structure.
c. Thickness:
   1. Architectural face mix thickness +\(\frac{1}{8}\) in., −0 in.
      (+3 mm, −0 mm)
   2. GFRC backing +\(\frac{1}{4}\) in., −0 in.
      (+6 mm, −0 mm)
   3. Panel depth from face of skin to back of panel frame or integral rib +\(\frac{3}{8}\) in., −\(\frac{1}{4}\) in.
      (+10 mm, −6 mm)

d. Angular variation of plane of side mold ±\(\frac{1}{32}\) in. per 3 in. (±1 mm per 75 mm) depth or ±\(\frac{1}{16}\) in. (±2 mm) total, whichever is greater.

e. Variation from square or designated skew (difference in length of two diagonal measurements) ±\(\frac{1}{8}\) in. per 6 ft (3 mm per 2 m) or ±\(\frac{1}{4}\) in. (6 mm) total, whichever is greater.

f. Local smoothness ±\(\frac{1}{4}\) in. per 10 ft (6 mm per 3 m)

j. Warpage: Maximum permissible warpage of one corner out of the plane of the other three shall be ±\(\frac{1}{16}\) in. per ft (5 mm per m) of distance from the nearest adjacent corner, unless it can be shown that the member can meet erection tolerances using connection adjustments.

k. Position of integral items
   1. Panel frame and track ±\(\frac{1}{4}\) in. (±6 mm)
   2. Flashing reglets at edge of panel ±\(\frac{1}{4}\) in. (±6 mm)
   3. Inserts ±\(\frac{1}{2}\) in. (±12 mm)
   4. Special handling devices ±3 in. (±75 mm)
   5. Locations of bearings devices ±\(\frac{1}{4}\) in. (±6 mm)
   6. Blockouts ±\(\frac{3}{8}\) in. (±10 mm)

l. Panel frames shall be fabricated within the following tolerances shown in Fig. 6.3(b).
Figure 6.3(b) Location of panel frame tolerances

$\ell_1$. Vertical and horizontal alignment
..........................$\frac{1}{4}$ in. in 10 ft (6 mm in 3 m)

$\ell_2$. Spacing of framing members
.................................$\pm \frac{3}{8}$ in. ($\pm 10$ mm)

$\ell_3$. Squareness of frame (difference in diagonals)
.................................$\frac{3}{8}$ in. (10 mm)

$\ell_4$. Overall size of frame ..............$\pm \frac{3}{8}$ in. ($\pm 10$ mm)
APPENDICES

APPENDIX A
Guidelines for Developing the Plant Quality System Manual

APPENDIX B
Considerations for the Architect/Engineer in Preparing Plans and Specifications

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Finish Samples

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APPENDIX L
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APPENDIX M
Premix
INTRODUCTION

Documented quality system procedures should be the basis for the overall planning and administration of activities that affect quality. These documented procedures should cover all the elements of the company’s quality system standard. They should describe (to the degree of detail required for adequate control of the activities concerned) the responsibilities, authorities, and inter-relationships of the personnel who manage, perform, verify, or review work affecting quality. The procedures should also address how the different activities are to be performed, types of documentation, and the controls to be applied. All of this is particularly important for personnel who need the organizational freedom and authority to: 1) initiate action to prevent non-conformances of any kind, 2) identify and document any problems relating to product, process, and/or quality systems, 3) initiate, recommend, or provide solutions through designated channels, 4) verify the implementation of solutions, and 5) control further processing, delivery, or installation of non-conforming production until the problems have been corrected.

Documented quality system procedures should not, as a rule, enter into purely technical details of the type normally documented in detailed work instructions.

The quality manual should identify the management functions, address or reference the documented quality system and procedures, and briefly cover all the applicable requirements of the quality system standard selected by the organization. Wherever appropriate, and to avoid unnecessary duplication, reference to existing recognized standards or documents available to the quality manual user should be incorporated.

Release of the quality manual should be approved by the management responsible for its implementation. Each copy should bear evidence of this release authorization.

Although there is no required structure or format for a quality manual, it should convey accurately, completely, and concisely the quality policy, objectives, and governing documented procedures of the organization.

One method of ensuring that the subject matter is adequately addressed and located is to key the sections of the quality manual to the quality elements of this manual. Other approaches, such as structuring the manual to reflect the nature of the organization, are equally acceptable.

MANUAL CONTENTS

A quality manual should normally contain the following:

Table of Contents

The table of contents of a quality manual should show the titles of the sections within it and how they can be found. The numbering and coding system of sections, subsections, pages, figures, exhibits, diagrams, tables, etc., should be clear and logical and include revision status.

Definitions

Definitions of terms or concepts that are uniquely used within the plant should be included, although it is recommended, when practical, to use standard definitions and terms shown in this manual.

Management Responsibility

A. Quality Policy Statement

1. In the most general sense, a quality policy should be a short, clear statement of commitment to a standard of quality. This should include a warranty from the highest level of management that quality will not be compromised when it conflicts with other immediate interests. The quality policy also should define objectives pertaining to quality. The objectives focus and direct the quality system toward concrete goals, giving the plant’s personnel the motivation to develop and maintain the system. To the customer, the objectives are an expression of an implied promise that satisfying their needs will be the point of reference in their relationship with the plant.
2. This section describes how the quality policy is made known to and understood by all employees. It should also describe how the policy will be implemented and maintained at all levels. Management should ensure that individuals are familiar with those contents of the manual appropriate for their position within the organization.

To ensure proper distribution of the quality manual, which may contain confidential information, a statement should be included to address whether the manual is used only for the plant’s internal purposes or whether it can be made available externally.

B. Organization

1. Responsibility and Authority
   a. This section of the manual should provide a graphical organization chart showing key personnel, their duties and responsibilities, authorities, and the interrelationship structure. This is the most effective and straightforward way to define and document an organization’s structure. Include a general organization chart for the whole company, supplementing it with more detailed charts that represent internal organizations of departments directly concerned with the QA and QC activities. It is not practical or required to include in the charts the names of assigned personnel. Documents evidencing individual assignments to organizational functions shall be maintained elsewhere; for example, in the human resources department.

   b. Although the charts document general functional responsibilities, there is also a need to assign personnel the authority and responsibility to carry out specific actions referenced in the quality system. Details of the responsibilities, authorities, and hierarchy of all functions that manage, perform, and verify work affecting quality should be provided. Assignments and documentation of those specific responsibilities is best made directly within procedures dealing with the corresponding actions. For example, personnel responsible for identifying and recording product quality problems can be defined in the inspection and testing procedures sections.

2. Verification Resources and Personnel
   a. Procedures and quality plans should completely define the review, monitoring, inspection, and testing needs at specific points in purchasing, receiving, manufacturing, and shipping. The extent and scope of the verifications must be established by the plant.

   The verification activities should be supported with qualified personnel and adequate resources. The plant should identify the level of training and experience needed to perform specific verification functions and indicate that the assigned personnel meet those requirements. All training, no matter how informal, should be documented and recorded.

   b. Self-inspection may be adopted provided that it is qualified, documented, and regularly audited. Audits should be carried out by personnel independent from those having direct responsibility for the work. Inspection and testing are excluded from this requirement of independence.

C. Management Review

In addition to an analysis of PCI Plant Certification audit results, rules for scheduling, conducting, and recording management reviews of the quality system should be established.

Quality System

The manual should describe and document the applicable elements of the plant quality management system. The description should be divided into logical sections revealing a well-coordinated quality system. The quality manual should include policies, operating procedures, work instructions, process procedures, company standards, PCI standards, and the production and quality plans. This may be done by inclusion of, or reference to, documented quality system procedures. Auditing and review of the implementation of the quality system should be discussed.

The purpose is to:

1. Define the purpose, contents, and format of the quality system documentation.
2. Assign responsibility for establishing and maintaining the quality system documentation.

Document Control

The purpose, scope, and responsibility for controlling each type of quality system document should be defined. This section should provide a system and instructions and assign responsibilities to establish, review, authorize, issue, distribute, and revise the quality system documents.
APPENDIX A

Plant Quality System Manual

Provide a brief description of how the quality manual is revised and maintained, who reviews its contents and how often, who is authorized to change the quality manual, and who is authorized to approve it. A method for determining the history of any change in procedure may also be included, if appropriate.

To ensure that each manual is kept up to date, a method is needed to ensure that all changes are received by each manual holder and incorporated into each manual. A table of contents, a separate revision-status page, or other suitable means should be used to provide assurance to users that they have a copy of the authorized manual.

Purchasing

There should be a clear and full description of ordered products and vendor-monitoring procedures to verify that quality requirements of the plant are met. Procedures for disposition of nonconforming materials should be described.

Rules applicable to the preparation, review, and approval of purchasing documents and the use of approved vendors should be provided.

Product Identification and Traceability

Describe the system to readily identify each unit produced and to distinguish among different grades of otherwise similar materials, components, subassemblies, products, and maintenance procedures for records.

Process Control

Process refers to all activities connected with production planning, environment, equipment, technology, process control, work instructions, product characteristics control, criteria for workmanship, and so forth.

The production plan should define, document, and communicate all manufacturing processes and inspection points as well as workmanship standards. A production flowchart should be included. Work instructions should indicate how to operate and adjust equipment, describe steps required to perform certain operations and inspections, warn against safety hazards, etc. Maintenance, equipment calibration, and testing apparatus schedules should be established and recorded.

Establish a system with instructions that assigns the responsibility for:

1. Establishing and use of work order, work instructions, and change orders
2. Checking and monitoring production equipment
3. Qualification and control of special processes such as welding
4. Establishing criteria and responsibility for maintenance of the production environment or such conditions that adversely affect performance

Inspection and Testing

A. Receiving Inspection and Testing

The purpose of this section is to provide for a system with instructions that assigns the responsibility for performing receiving inspections of purchased products. The scope and form of receiving inspections should be established.

As a minimum, the scope of receiving QC inspections comprises:

1. Review of material certification, source inspection and test records, compliance certificates, and other such documentation delivered with the product
2. Visual inspection to detect any damage or other visible quality problems
3. Taking measurements and testing, as required
4. Recording actual measurements and test results

B. In-Process Inspection and Testing

Degree, scope, and manner of in-process inspections should be established to ensure that products are produced in accordance with production drawings and approved samples. Inspection of special processes, such as welding, must be monitored and controlled. Include sample copies of checklists or forms used by plant personnel for quality control functions.
Specific items to be covered are:

1. Planning and documentation of inspection in the company’s quality plans or procedures
2. Handling of changes to shop drawings during production
3. Identification of inspection status of product
4. Handling of nonconforming product
5. Identifying those product characteristics that can be inspected only at specific stages of production

C. Final Inspection

The quality plan and procedures should define the extent and scope of the final inspections and tests to verify that all receiving and in-process inspections specified for the product have been carried out with satisfactory results. The means of identifying nonconforming products should be described.

D. Inspection and Test Records

Describe the recording of each inspection, sign-off procedure, and the maintenance of records.

Inspection and Test Records

The purpose of this section is to provide:

1. A system with instructions
2. Assignment of responsibilities for calibration at prescribed intervals
3. Identification, including type, model, range, and accuracy
4. Maintenance of measuring and test equipment

Calibration procedures and records should be established and maintained.

Identification of measurements to be made with the allowable tolerances should be documented in the quality plan, product drawings, and specifications.

The system of checking and certifying jigs, templates, and patterns or molds used in manufacturing or inspection should be established.

Corrective Action

All activities relating to corrective actions should be covered by written procedures. The corrective action system should comprise an investigation of causes, the implementation of corrective actions, and the verification of their effectiveness.

Handling, Storage, and Loading/Delivery

A. General

The purpose of this section is to define specific rules for handling different units, prescribe a management system for stored units, and specify arrangements for protection of products during transportation.

B. Handling

Describe procedures to regulate the use of and instruct in operating handling equipment, as well as handling-equipment maintenance.

C. Storage

The purpose of this section is to provide for a system with instructions and responsibility assignments for:

1. Ensuring products are stored in accordance with the drawings
2. Use and maintenance of stored areas for both materials and finished products
3. Periodic assessment of stored materials and product to check on damage, stains, or contamination
APPENDIX A

Plant Quality System Manual

D. Loading/Delivery

Describe the procedure for providing a system with instructions and responsibility assignments for loading and protecting products during delivery, whether delivery is required by the contract or not.

Quality Records

Compliance with the following requirements should be documented in written procedures:

1. Identifiable and legible records
2. Easily retrievable records for files in a suitable environment
3. Retention of records for a specified period of time

Format, identification, applicable processing, and filing location for a record should be stipulated in the procedure that requires creation of the record. There should be an index listing the types of records and their locations.

<table>
<thead>
<tr>
<th>EXAMPLE OF POSSIBLE FORMATTING FOR A SECTION OF A QUALITY MANUAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organization</td>
</tr>
<tr>
<td>Unit issuing</td>
</tr>
</tbody>
</table>

Policy or policy reference
Give governing requirement.

Purpose and scope
List why, what for, area covered, and exclusions.

Responsibility
Give organizational unit responsible for implementing the document and achieving its purpose.

Actions and methods to achieve system element requirement
List, step by step, what needs to be done. Use references, if appropriate. Keep in logical sequence. Mention any exceptions or specific areas of attention. Consider the use of flowcharts.

Documentation and references
Identify which referenced documents or forms are associated with using the document or what data have to be recorded. Use examples, if appropriate.

Records
Identify which records are generated as a result of using the document, where these are retained, and for how long.

Notes
1. This format may also be used for a documented quality system procedure.
2. The structure and order of the items listed above should be determined by organizational needs.
3. The approval and revision status should be identifiable.
**APPENDIX A  Plant Quality System Manual**

**Internal Quality Audits**

The purpose of this section is to provide for a system with instructions and responsibility assignments for conducting and documenting internal quality audits. Internal quality audits should be used to verify compliance with the quality manual and to measure the effectiveness of activities in achieving defined quality objectives. The audit plan should list all the activities in the various sections of the company’s quality manual, identify where each activity takes place, and schedule the audit for each activity and location. Activities that receive more frequent auditing by plant personnel should be described. A corrective action and follow-up procedure for any deficiencies found during an audit should be established and documented to verify the implementation and effectiveness of the corrective action. In addition, discuss the external audit procedures of the PCI Plant Certification program and the corrective action and follow-up procedures.

**Training**

The purpose of this section is to provide for a system with instructions and responsibility assignments for determining training needs, providing the training, and keeping training records.

As a minimum, the training should comprise:

1. Product orientation with emphasis on crucial quality characteristics
2. Presentation of the company’s quality system
3. The role of employees in maintaining the quality system and improving its efficiency

Recording procedures for employee participation in training and maintenance of the records should be discussed.

---

**Typical quality system document hierarchy**

```
Quality manual
(Level A)

Documented quality system procedures
(Level B)

Other quality documents (work instructions, forms, reports, etc.)
(Level C)
```

**Document contents**

- Describes the quality system in accordance with the stated quality policy objectives and the applicable standard.
- Describes the activities of individual functional units needed to implement the quality system elements.
- Consists of detailed work documents.

**NOTE:** Any document level in this hierarchy may be separate, used with references, or combined.
Design calculations should be performed under the supervision of a registered professional engineer with experience in GFRC design. The GFRC manufacturer should be prepared to assist in the design of panels and connections. The owner’s design team (architect/engineer) maintains overall design responsibility.

The architect/engineer inexperienced in GFRC design can benefit from early contact with experienced manufacturers who can offer constructive advice during preliminary design.

It is common practice for the architect/engineer to rely on the GFRC manufacturer for handling and erection procedures, and for ensuring that the unit is adequately designed for loads incurred during manufacturing, handling, shipping, and installation. All procedures should be checked to ensure that they do not cause:

1. Cracking.
2. Structural damage.
3. Architectural impairment.
4. Permanent distortion.

Contract drawings prepared by the architect/engineer should show connections in sufficient detail to permit design, estimating, and bidding. During the preparation of shop drawings, panel manufacturers usually review connections for tolerances, clearances, practicality, and performance. The manufacturer should call to the architect/engineer’s attention any potential problems.

The general contractor is responsible for the location of all panel bearing surfaces and anchorages on the structural frame. Changes, other than adjustments within the prescribed tolerances, require approval by the architect/engineer.

Architect/Engineer Responsibilities
Responsibility for both structural and aesthetic design of GFRC should rest with the architect/engineer, who should:

1. Provide clear and concise drawings and specifications and, where necessary, interpretation of the contract documents. Identify the design loads and applicable codes on the contract drawings.
2. Establish the standards of acceptability for surface finish, color range, and remedial procedures for defects and damage. The architect/engineer’s right to reject work is provided to protect the owner against work that does not meet these standards.
3. Determine the part, if any, played by the GFRC in the support of other items or of the structure as a whole.
4. As part of the design, allow for the effect of differences in material properties, stiffness, temperatures, and other elements that might influence the interaction of GFRC units with the structure.
5. Determine the load reactions necessary for the accurate design of connections.
6. Evaluate thermal movements as they might affect requirements for joints, connections, reinforcement, and compatibility with adjacent materials.
7. Analyze the watertightness of GFRC panel systems, evaluating joint treatment, including the performance of adjacent materials for compatibility in joint treatment and the proper sealing of windows and other openings, except where such systems are manufactured and marketed as proprietary items.
8. Make selection of surface finishes, recognizing certain limitations in materials and production techniques in regard to uniform color, texture, repairability, and performance, especially the limitations that are inherent in natural materials.
9. Design the supporting structure so that it will carry the weight of GFRC as well as any superimposed loads; including provisions for deflection and rotation of the supporting structure during and after erection of the GFRC. Specify members of the supporting structure that are to support the GFRC—e.g., beams, columns, or slabs.
10. Design the supporting structure for the temperature loading conditions associated with the proposed erection sequence and methods. However, the general contractor is responsible for the construction means, methods, techniques, sequences, or procedures.
11. Provide details for the interfacing of GFRC and other materials and coordinate them with the general contractor.
12. Make selection of interior panel finishes and the interior appearance for occupancy requirements, again recognizing material and production limitations.

13. Keep in mind that interior finishes may affect deflection criteria if attached to panels.

14. Design for durable exterior walls with respect to weathering, corrosive environments, heat transfer, fire resistance rating, vapor diffusion, and moist air or rain penetration.

15. Review and approve the producer’s shop drawings (erection and typical shape drawings) and typical calculations.

16. Specify dimensional and erection tolerances for GFRC and tolerances for supporting structure and contractor’s hardware. Any exceptions to PCI standard tolerances should be clearly identified.

Contract drawings should provide a clear interpretation of the configurations and dimensions of individual units, and their relation to the structure and to other materials. The drawings must supply the following information:

1. All sections and dimensions necessary to define the size and shape of the unit.

2. Location of all joints, both real (functional) and false (aesthetic). Joints between units should be completely detailed.

3. The materials and finishes required on all surfaces, and a clear indication of which surfaces are to be exposed when in place.

When the surface of a GFRC element has two or more different mixes or finishes, a demarcation (reveal) feature is a necessary part of the design. The depth of the groove should be at least 1 1/2 times the aggregate size, and the width should be in dimensional lumber increments such as 3/4 or 1 1/2 in. (19 to 38 mm). The groove should generally be wider than it is deep in order to strip the element without damaging the mold. The importance of the separation provided by a demarcation feature depends on the configuration of the unit on which the finishes are combined. For example, a groove or offset is necessary when an exposed-aggregate flat surface is located between widely spaced ribs with a different surface finish, but not necessary when a similar flat surface lies between closely spaced ribs. Proper samples should be used to assess the problem. The importance of the separation also depends on the specific types of finishes involved. If a demarcation groove occurs near a change of section, it may create a weakness and counter any attempt to provide a gradual transition from one mass to another.

4. Details for the corners of the structure.

5. Details for jointing to other materials.

6. Details for unusual conditions and fire endurance requirements.

7. Design loads and moments, which include eccentricities.

8. Deflection limitations.

9. Specified tolerances and clearance requirements for proper product installation.

10. Support locations for gravity and lateral loads.

11. Specific mention of any required erection sequences.

12. Details of connections to the supporting structure.

This information should be sufficiently detailed to enable the producer to design and produce the units and for the erector to install them. In most instances, producers will make their own erection drawings to identify the information for GFRC units and translate these details into production and erection requirements. A major reason for leaving most panel design and hardware details to the producer would be that they normally have extensive experience in this field and can choose details suitable for their plant’s production and erection techniques.

If connections are not detailed by the architect/engineer, the performance requirements for the design must be clearly identified. The amount of space allowed for connections should also be indicated. It is generally recommended that the architect/engineer define dead, live, wind, and seismic loads; describe a section adequate to receive loads; and design the connection for each typical unit. This approach provides a design compatible with structural capability, hardware protection, appearance, and clearance for mechanical services. In addition, it will establish parameters for reasonable modifications that may be suggested by producers to suit their production and erection techniques, and at the same time satisfy project design requirements. Design deviations requested by the producer or erector will be permitted only after the architect/engineer’s approval of the proposed change.

**Constructor Responsibilities**

The general conditions of the construction contract usually state the responsibility of the constructor (usually the general contractor) in coordinating the construction work. The constructor is typically responsible for project schedule, dimensions and quanti-
ties, and coordination with all other construction trades; and for the adequacy of construction means, methods, techniques, sequences, and procedures, in addition to safety precautions and programs in connection with the project. The GFRC manufacturer should not proceed with fabrication of any products prior to receiving approval of erection drawings by the constructor.

The constructor should:

1. Be responsible for coordinating all information necessary to produce the GFRC erection drawings.
2. Review and approve or obtain approval for all GFRC shop drawings that include the scheme of handling, transporting, and erecting the units, as well as the plan of temporary bracing of the structure. (Handling and transporting responsibilities depend on whether GFRC is sold F.O.B plant, F.O.B. jobsite, or erected).
3. Be responsible for the coordination of dimensional interfacing of the GFRC units with other materials and construction trades.
4. Ensure that proper tolerances are maintained in the supporting structure to provide for accurate fit and overall conformity with GFRC erection drawings.
5. Incorporate, on or in the structure, contractor’s hardware according to a layout or anchor plan supplied by the producer.

It is the responsibility of the constructor to establish and maintain, at convenient locations, control points and bench marks in an undisturbed condition for use by the erector until final completion and acceptance of a project.

The constructor must be responsible for coordinating GFRC erection drawings with shop drawings from other trades so that related items can be transmitted to the designer in one package. The constructor must immediately notify the producer of any deviations found in dimensions due to plan or construction errors or changes to the structure.

After erection of GFRC units, the constructor should notify the architect for the pre-final inspection of the work. Representatives of the producer and the erector should be prepared to participate in this inspection tour and answer any questions posed by the architect.

GFRC Manufacturer Responsibilities

The extent of design responsibility vested with the GFRC manufacturer should be clearly defined by the architect/engineer in the contract documents. Table B.1 outlines the typical options.

Most work is covered in Table B.1, Option II, due to the specialized nature of GFRC design. Additional design responsibilities for the manufacturer may occur when the architect/engineer uses methods of communication described in Options II and III in Table B.1. Option II (b) may occur when no engineer is involved with the architect for GFRC product design and where doubtful areas of responsibility may exist. Under this option, the manufacturer should employ or retain a structural engineer experienced in the design of GFRC, who will ensure the adequacy of those structural aspects of the erection drawings, manufacture, and installation for which the manufacturer is responsible. Option III is not yet a common practice but might be used for design of systems buildings or with performance specifications.
### Table B.1 Design Responsibilities

<table>
<thead>
<tr>
<th>Contract information supplied by architect/engineer</th>
<th>Responsibility of the manufacturer of GFRC units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OPTION 1</strong></td>
<td>The manufacturer shall make shop drawings (erection and production drawings), as required, with details as shown by the designer. Modifications may be suggested that, in the manufacturer’s estimation, would improve the economics, structural soundness, or performance of the GFRC installation. The manufacturer shall obtain specific approval for such modifications. Full responsibility for the product design, including such modifications, shall remain with the designer. Alternative proposals from a manufacturer should match the required quality and remain within the parameters established for the project. It is particularly advisable to give favorable consideration to such proposals if the modifications are suggested so as to conform to the manufacturer’s normal and proven procedures.</td>
</tr>
<tr>
<td>Provide complete drawings and specifications detailing all aesthetic, functional, and structural requirements plus dimensions.</td>
<td></td>
</tr>
<tr>
<td><strong>OPTION II</strong></td>
<td>The manufacturer has two options:</td>
</tr>
<tr>
<td>Detail all aesthetic and functional requirements but specify only the required structural performance of the GFRC units. Specified performance should include all limiting combinations of loads together with their points of application. This information should be supplied in such a way that all details of the unit can be designed without reference to the behavior of other parts of the structure. The division of responsibility for the design shall be clearly stated in the contract.</td>
<td>(a) Submit erection and shape drawings with all necessary details and design information for the approval and ultimate responsibility of the designer.</td>
</tr>
<tr>
<td></td>
<td>(b) Submit erection and shape drawings and design information for approval and assume responsibility for the panel structural design—i.e., the individual units but not their effect on the building. Firms accepting this practice may either stamp (seal) drawings themselves or commission engineering firms to perform the design and stamp the drawings.</td>
</tr>
<tr>
<td></td>
<td>The choice between options (a) and (b) should be decided between the designer and the manufacturer prior to bidding with either approach clearly stated in the specification for proper allocation of design responsibility.</td>
</tr>
<tr>
<td></td>
<td>Experience has shown that divided design responsibility can create contractual problems. It is essential that the allocation of design responsibility is understood and clearly expressed in the contract documents.</td>
</tr>
<tr>
<td></td>
<td>The option (b) is normally adopted where the architect does not engage a design engineer to assist in the design.</td>
</tr>
<tr>
<td><strong>OPTION III</strong></td>
<td>The manufacturer should participate in the preliminary design stage and the development of the final details and specifications for the GFRC units and should work with the design team to provide an efficient design. The manufacturer provides the engineering design of the GFRC units and their connections to the structure and should work with the design team to coordinate the interfacing work. The manufacturer should submit design information for approval and shop drawings at various stages of completion for coordination with other work.</td>
</tr>
<tr>
<td>Cover general aesthetic and performance requirements only and provide sufficient detail to define the scope of the GFRC concrete work.</td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX C

Product Dimensional Tolerances

Bowing is an overall out-of-tolerance condition, which differs from warping in that while the corners of the panel may fall in the same plane, the portion of the panel between two parallel edges is out of plane. Bowing conditions are shown in Figure C.1. Differential temperature effects and differential moisture absorption between the inside and outside faces of a panel should be considered in design to minimize both bowing and warping and ensure that the resulting stresses are kept within acceptable limits.

Differential bowing is a consideration for panels that are viewed together on the completed structure as shown in Figure C.2.

![Possible bowing condition](image)

**Figure C.1** Possible bowing condition

![Cross Section of Facade](image)

**Figure C.2** Differential bowing of panels (see page 6-4)

Warping is generally an overall variation from planeness in which the corners of the panel do not all fall within the same plane. Warping tolerances are stated in terms of the magnitude of the corner variation, as shown in Figure C.3.

![Warping definition for panels](image)

**Figure C.3** Warping definition for panels (see page 6-4)

Bowing and warping tolerances are of primary interest at the time the panel is erected, and should be checked prior to panel delivery. Careful attention to pre-erection storage of panels is necessary since storage conditions can be an important factor in achieving and maintaining panel bowing and warping tolerances.

Bowing and warping tolerances have an important effect on the edge match-up during erection and on the appearance of the erected panels, both individually and when viewed together. The requirements for bowing and warping of panels may be overridden by tolerances for panels as installed with reference to joint widths, jog in alignment, and step in face.

The likelihood that a panel will bow or warp depends on the design of the panel and its relative stiffness or ability to resist deflection as a plate member. Panels that are relatively shallow or have a “flexible” frame, when compared to their overall plan dimensions, are more likely to warp or bow as a result of a number of design, manufacturing, and environmental conditions.

Bowed or warped panels can make alignment of adjacent panels or materials difficult. To reduce the possibility of panel warpage or bowing, consideration should be made for the panel length, shape, and connection locations. The longer the panel, the more
difficult it is to control its planeness. Bowing or warpage can be reduced by the introduction of skin joints or the use of multiple tieback connections. Adding skin joints reduces the susceptibility to bowing. Multiple connections can be used to take advantage of the flexibility of a GFRC panel in order to straighten out the bow. Limits to the amount of bowing that can be removed during installation should be established by the panel design engineer. Precautions should be taken to prevent overstressing the skin. Multiple connections and skin joints may be required on panels longer than 15 ft (4.5 m).

Surface out-of-planeness, which is not a characteristic of the entire panel shape, is defined as a local smoothness variation rather than a bowing variation. Examples of local smoothness variations are shown in Figure C.4. The tolerance for this type of variation is usually expressed in fractions of an inch per 10 ft (mm per 3 m).

Figure C.4 also shows how to determine whether a surface meets a tolerance of 1/4 in. in 10 ft (6 mm in 3 m). A 1/4-in.-diameter (6 mm) by 2-in.-long (50 mm) roller should fit anywhere between the 10-ft-long (3 m) straightedge and the element surface being measured when the straightedge is supported at its ends on 3/8 in. (10 mm) shims as shown. A 1/2-in.-diameter (12 mm) by 2-in.-long (50 mm) roller should not fit between the surface and the straightedge.

![Figure C.4 Measuring local smoothness variations](image-url)
PRE-BID SAMPLES
Pre-bid samples, as for all samples, shall only be regarded as a standard for performance within the variations of workmanship and materials to be expected.

Due to individual preferences, differences in sources of supply, or different techniques developed in various plants serving the same area, the architect/engineer should not expect to select one sample and obtain exact matching by all GFRC producers.

Many architects have developed a practice of making sample selection and approval just prior to bid closing. Thus, for a specific project, the approved producers’ names and corresponding sample code numbers may be published in an addendum or approval list given in writing to the general contractor.

This practice may result in a slight variation in color, aggregate, or texture (but not necessarily quality) from different bidders, since the individual producer within specification limits selects the materials and employs the placing and finishing techniques best suited to their plant operation. The architect/engineer, when making pre-bid approval of samples part of the specifications, should adhere to the following requirements:

1. Sufficient time should be allowed for the bidder to submit samples or information for approval. Time should also be provided to enable such approvals to be conveyed to the producer in writing so that the producer can estimate and submit a bid.
2. Any pre-bid submittal should be treated in confidence and the individual producer’s solutions and/or techniques should be protected both before and after bidding.

If the characteristics of submitted pre-bid samples in any way deviate from the specifications, the manufacturer should make this clear to the architect/engineer when submitting the samples and other required information. For proper evaluation and approval of the samples, the manufacturer should state the reasons for the deviations. These reasons might be the producer’s concern over controlling variation in either color or texture within specified limits. In regard to adequacy of specified materials, concerns about satisfying all conditions of the specifications must be based upon practical plant production requirements and the performance or weathering of the product in its final location.

The architect/engineer may request data as described in Article 1.5.3 in order to evaluate these deviations. If such deviations and samples are approved, the original project specifications and contract drawings should be changed accordingly by the architect/engineer.

Since some samples are developed for specific projects with particular shapes or other characteristics, while others are more general for simple applications, it is the responsibility of the producer either to make sure that the architect/engineer does not retain these specific project samples, or that they are clearly marked with respect to limits of application to prevent their use for unsuitable applications.

IDENTIFICATION
A file of sample code numbers with all related data should be maintained by the producer to ensure future duplication of any sample submitted.

MOCK-UPS AND PRODUCTION APPROVAL
Aesthetic mock-ups can offer the opportunity to evaluate the following factors:

1. Range of acceptable appearance in regard to color, texture, details on the exposed face, and uniformity of returns.
2. Sequence of erection.
3. Available methods of bracing units prior to final structural connections being made.
4. Desirability of the method of connection in light of handling equipment and erection procedures.
5. Colors and finishes of adjacent materials (window frames, glass, sealants, etc.).
6. Dimensional accuracy of the GFRC work and the constructability of the specified tolerances.
APPENDIX D

Finish Samples

7. Available methods for the repair of chips, spalls, or other surface blemishes. The mock-up will also establish the extent
and acceptability of defects and repair work.
8. Suitability of the selected sealers.
9. The weathering patterns or rain runoff on a typical section of GFRC panel facade.

Mock-ups should be produced using standard production equipment and techniques. Some important variables that should
be controlled as close to actual cast conditions include retarder coverage rate and method of application, mix design, admixtures,
age, thickness of the panel, and method of cleaning.

Special details, such as reveal patterns and intersections, corner joinery, drip sections, patterns, color and texture, and other visual
panel characteristics should be demonstrated in large production samples for approval. Changes in aggregate orientation, color
tone, and texture can easily be noted on full-scale mock-up panels.

The objective of the mock-up sample can also be to demonstrate the more detailed conditions that may be encountered in the
project (recesses, reveals, outside/inside corners, multiple finishes, textures, veneers, etc.). This sample may not be fully repre-
sentative of the exact finishes that can be reasonably achieved during mass production.

Mock-up panels should contain typical panel frame and hardware as required for the project. Handling the mock-up panels serves
as a check that the stripping methods and lifting hardware will be suitable.

The architect should visit the GFRC plant for examination and approval (sign and date) of the first production units. To avoid pos-
sible later controversies, this approval should precede a release for production. The architect should realize, however, that delays
in visiting plants for such approvals may upset normal plant operations and the job schedule. It should be clearly stated in the
contract documents how long the production units or the mock-up structure should be kept in the plant or jobsite for comparison
purposes. It is recommended that the contract documents permit the approved full-sized units to be used in the job installation in
the late stages of construction. The units should remain identifiable, even on the structure, until final acceptance of the project.
The panels should be erected adjacent to each other on the building to allow continued comparison, if necessary.

The face of each sample should contain at least two areas of approved size and shape that have been chipped out and then patched
and repaired. The color, texture, and appearance of patched areas should match those of the adjacent surface (see Article 2.10).

Plant inspection by the architect during panel production is encouraged. This helps assure both the architect and the producer that
the desired end results can be and are being obtained.
Sample Record Forms

Numerous items that require record keeping for confirmation and evaluation are outlined in this quality control manual. The following record forms are suggested for consideration in a quality control program. These are not the only forms needed for operations, but they will provide a beginning point for form development. It should be recognized that these are only SAMPLE record forms and that a plant may design its own forms to best serve its operation. The importance of any recording form is the information that it contains and not its format. The reports serve as a record of the manufacturing process in case this information is required at some future date.

Items that can be measured quantitatively are to be recorded in numerical terms. Items that must be evaluated subjectively should be rated in a consistent fashion. Items such as length and width measurements can be given a check mark or “OK” if they are within the tolerances listed in Article 6.3.

Where extra attention is required to improve material or product quality, improve worker quality performance, or identify matters beyond the control of the worker, remarks or sketches should be used. Remarks can be made on the back of the forms when there is not room on the front side.
# Mix Design, Slurry Slump, and Slurry Unit Weight

## Data Sheet

<table>
<thead>
<tr>
<th>Specified quantity</th>
<th>Quantity used</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Cement: ______ lb</td>
<td>Cement ______: ______ lb</td>
</tr>
<tr>
<td>Sand: ______ lb</td>
<td>brand type</td>
</tr>
<tr>
<td>Water: ______ lb</td>
<td>Sand: ______ lb</td>
</tr>
<tr>
<td>Water reducer: ______ oz</td>
<td>Water: ______ lb</td>
</tr>
<tr>
<td>High-range water reducer: ______ oz</td>
<td>Water reducer: ______ oz</td>
</tr>
<tr>
<td>Thickener: ______ oz</td>
<td>High-range water reducer: ______ oz</td>
</tr>
<tr>
<td>Polymer (_______% solids by weight): ______ lb</td>
<td>Thickener: ______ oz</td>
</tr>
<tr>
<td></td>
<td>Polymer ______: ______ oz</td>
</tr>
<tr>
<td></td>
<td>(_______% solids by weight): ______ lb</td>
</tr>
</tbody>
</table>

## Slurry slump

Slump: ______ rings

Amperage reading: ________________

## Slurry unit weight

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Container (A): ______ lb</td>
<td>Container (A): ______ lb</td>
</tr>
<tr>
<td>Container + slurry (B): ______ lb</td>
<td>Container + slurry (B): ______ lb</td>
</tr>
<tr>
<td>Container + water (C): ______ lb</td>
<td>Container + water (C): ______ lb</td>
</tr>
</tbody>
</table>

Unit weight = \( B - A + \frac{C - A}{\text{Density of water}} \) lb/ft³
## Glass Fiber Chopping Rate Determination and Slurry Flow Rate Data Sheet

<table>
<thead>
<tr>
<th>Spray-up operator:</th>
<th>Date: ____________________</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test performed by:</td>
<td>Time: ____________________</td>
</tr>
<tr>
<td>Mix ID no.:</td>
<td>Time: ____________________</td>
</tr>
<tr>
<td>Atomizing pressure</td>
<td>Chopper pressure</td>
</tr>
<tr>
<td>______ psi</td>
<td>______ psi</td>
</tr>
</tbody>
</table>

Target glass content: ______% by weight

**Glass fiber chopping rate** — 15 sec. test (all weights to nearest 0.1 g)

Target glass fiber chopping rate: ______

Note: When glass chopping rate first falls within target range, air pressure settings are then fixed.

- Trial 1: ______ g / 15 sec.
- Trial 2: ______ g / 15 sec.
- Trial 3: ______ g / 15 sec.

Compute chopping in lb/min. = g / 15 sec. × 4 + 454 = ______ lb/min.

---

**Slurry flow rate** — 15 sec. test (all weights to nearest 0.1 lb)

Ambient temperature: ______  Slurry temperature: ______

\[
\left( \frac{\text{Target slurry flow rate}}{\text{Average glass fiber chopping rate}} \right) \times \left( \frac{100\% - \text{target glass content, \%}}{\text{target glass content, \%}} \right) = \text{Target slurry flow rate, lb/min.}
\]

Note: First trial is one that obtains the target slurry flow rate within ±0.2 lb/30 sec.

- Trial 1: ______ lb / 15 sec.
- Trial 2: ______ lb / 15 sec.
- Trial 3: ______ lb / 15 sec.

Slurry flow rate: ______ lb/15 sec. × 4 = ______ lb/min.
## Test Board and Wash-Out Test Data Sheet(s)

<table>
<thead>
<tr>
<th>Job name:</th>
<th>Project:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Panel mark no:</th>
<th>Spray-up date:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Test board ID no.:</th>
<th>Spray-up time:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Spray-up operator:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Spray-up assistants:</th>
<th>Name</th>
<th>Task</th>
</tr>
</thead>
<tbody>
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<td></td>
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</table>

<table>
<thead>
<tr>
<th>Spray-up equipment ID no.:</th>
<th>Temperature:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Mix ID no.:</th>
</tr>
</thead>
</table>

### Glass Fiber Content Determination (Wash-Out Test)

<table>
<thead>
<tr>
<th>Basket no.</th>
<th>Slurry + glass + basket, g</th>
<th>Basket, g</th>
<th>Slurry + glass, g</th>
<th>Dried glass + basket, g</th>
<th>Dried glass, g</th>
<th>Dried glass + (slurry + glass), %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

Note: All weights are to the nearest 0.1 g.

Test performed by: __________________________

<table>
<thead>
<tr>
<th>Mix no.:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Cement type:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Slump:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Admixtures:</th>
<th>Polymer:</th>
<th>Defoamer:</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Water, lb:</th>
<th>Slurry temp.:</th>
<th>Room temp.: High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

Remarks: __________________________

Report no.: __________________________
# APPENDIX E  
Sample Record Forms

## Physical Properties Test Board Data Sheet(s)

### ASTM C947  
**Flexural Test Data**

<table>
<thead>
<tr>
<th>Mix ID no.:</th>
<th>Spray team:</th>
<th>Actual glass content: %</th>
<th>Machine no.:</th>
<th>Job no.:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test board ID:</th>
<th>Spray-up date:</th>
<th>Test date:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sample conditioning:**

_____________________________________________________________________

<table>
<thead>
<tr>
<th>Major span:</th>
<th>Crosshead speed:</th>
<th>Chart speed:</th>
</tr>
</thead>
<tbody>
<tr>
<td>in.</td>
<td>in./min</td>
<td>in./min.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Specimen number  
**Tested face up or down**

<table>
<thead>
<tr>
<th>Specimen number</th>
<th>Tested face up or down</th>
<th>Specimen length, in.</th>
<th>At break Thickness, in.</th>
<th>Width, in.</th>
<th>Flex. yield (FY) load, lb</th>
<th>Flex. yield, psi</th>
<th>Flex. ult. (FU) load, lb</th>
<th>Flex. ult., psi</th>
<th>Flex. mod. of E, psi</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

### Bulk density tests  
**(ASTM C948a)**

<table>
<thead>
<tr>
<th>Burn schedule</th>
<th>Mean</th>
<th>Std. dev.</th>
<th>C.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td>in. air</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>days</em> °F_ RH</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Oven dry wt., g</th>
<th>S.S.D. wt., g</th>
<th>Wt. in water, g</th>
<th>Dry bulk density, g/cm³</th>
<th>Wet bulk density, g/cm³</th>
<th>Water absorp., % w/w</th>
<th>Apparent porosity, % v/v</th>
</tr>
</thead>
<tbody>
<tr>
<td>(C)</td>
<td>(B)</td>
<td>(A)</td>
<td>(C)</td>
<td>(B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

**Note:** Fill in the appropriate values for each test parameter.
## APPENDIX E

### Sample Record Forms

#### QUALITY CONTROL

**INSPECTION REPORT**

**BUILDING PRODUCTS**

**MOLD SET-UP, SPRAY-UP, AND FINISHED PRODUCT**

<table>
<thead>
<tr>
<th></th>
<th>Mold no.: ____________________</th>
<th>Job no.: ____________________</th>
<th>Job mark no.: ____________________</th>
<th>Product: ____________________</th>
<th>Release agent: ____________________</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date produced: ____________________</td>
<td>Date of post insp.: ____________________</td>
<td>Inspector: ____________________</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### SETUP DETAILS

- **Mold conditions & cleanliness**
- **Seams sealed**
- **Retarders**
- **Design length (height)**
- **Mold set-up length (height)**
- **As-cast length (height)**
- **Design width**
- **Mold set-up width**
- **As-cast width**
- **Design depth (thickness)**
- **Mold set-up depth (thickness)**
- **As-cast depth (thickness)**
- **Out of square**
- **Block outs (location)**
- **Squareness of openings**
- **End & edge details (returns)**
- **Reglets**
- **Rustications**
- **Inserts**
- **Handling devices**

#### PANEL FRAME

- **Design length**
- **Design width**
- **Design depth**
- **Flex anchors**
- **Gravity anchors**
- **Seismic anchors**
- **Lifting hardware**
- **Panel connections**
- **Weld dimensions**
- **Weld paint**
- **Frame alignment**
- **Squareness**

#### CASTING

- **Mist coat**
- **Exposed finishes**
- **Compaction**
- **Bonding pads (length)**
- **Bonding pads (width)**
- **Bonding pads (thickness)**
- **Integral rib (location)**

#### FINISHED PRODUCT

- **Surface finish**
- **Color uniformity**
- **Cracks or spalls**
- **Out of square (max.)**
- **Deflection**
- **Warpage**
- **Bowing**
- **Bonding pads**
- **Inserts**
- **Chamfers & radius quality**
- **Openings**
- **Handling devices**
- **Skin to frame clearance**
- **Panel sealer applied**

#### YARDING

- **Blocking**
- **Finishing**
- **Patching & cleaning**
- **Date approval stamp applied**

#### LOADING

- **Blocking**
- **Field patching required**
- **Tie downs**
- **Driver instructions**

[ ] Product accepted [ ] Product rejected

Reason:___________________________________________________

USE BACK SIDE OF SHEET FOR REMARKS AND SKETCHES
**APPENDIX E**

**AGGREGATE GRADATION**

**ORGANIC IMPURITIES**

**MATERIAL FINER THAN 200**

**MOISTURE TEST**

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>Weight retained, g</th>
<th>% retained</th>
<th>Spec. ASTM C33</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8 in. No. 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sieve size</th>
<th>Weight retained, g</th>
<th>% retained</th>
<th>Spec. ASTM C33</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2 in. 3/8 in.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. 16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**MATERIAL FINER THAN 200 SIEVE (ASTM C117)**

<table>
<thead>
<tr>
<th>Coarse agg.</th>
<th>Fine agg.</th>
<th>Original wt. of sample</th>
<th>Dry wt. of orig. sample</th>
<th>= B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier:</td>
<td>Date del.:</td>
<td></td>
<td>Dry wt. sample after washing</td>
<td>= C</td>
</tr>
</tbody>
</table>

\[ A \text{ (\% material finer than 200 sieve)} = \frac{(B-C)}{C} \times 100 \]

**AGGREGATE MOISTURE CONTENT (C566)**

| Wt. sample & container (wet) | (D) |
| Wt. sample & container (dry) | (E) |
| Wt. of container | (F) |
| Wt. of moisture (D – E) | (G) |
| Net dry wt. of sample (E – F) | (H) |

\[ \% \text{ moisture} = \frac{(G)}{H} \times 100 \]

**ORGANIC IMPURITIES IN SAND (C40)**

<table>
<thead>
<tr>
<th>Circle color</th>
<th>Organic plate no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>of sodium</td>
<td>1</td>
</tr>
<tr>
<td>hydroxide</td>
<td>2</td>
</tr>
<tr>
<td>solution</td>
<td>3 (standard)</td>
</tr>
<tr>
<td></td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

Sand supplier

Date
# APPENDIX E

## QUALITY CONTROL

### FACE MIX TEST REPORT

<table>
<thead>
<tr>
<th>Job:</th>
<th>Job no:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Job no:</td>
<td>Date:</td>
</tr>
<tr>
<td>------------------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>Inspector:</td>
<td></td>
</tr>
</tbody>
</table>

Mix designation (sample number) ____________________________________________

### COMMENTS

__________________________

__________________________

__________________________

__________________________

__________________________

__________________________

__________________________

### CONCRETE YIELD COMPUTATION

<table>
<thead>
<tr>
<th>Cement</th>
<th>Wt. container &amp; concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine aggregate</td>
<td>Wt. container</td>
</tr>
<tr>
<td>Coarse aggregate</td>
<td>Wt. container</td>
</tr>
<tr>
<td>Admixture</td>
<td>Slump</td>
</tr>
<tr>
<td>Admixture</td>
<td>Entrained air</td>
</tr>
<tr>
<td>Water no. gals</td>
<td>Container size (cu. ft)</td>
</tr>
<tr>
<td>Total wt. per cu. yd (A)</td>
<td>Wt. per cu. ft (B)</td>
</tr>
</tbody>
</table>

Yield = \( \frac{A}{B} \) = ______________________

### AIR MEASUREMENT (ASTM C231)

<table>
<thead>
<tr>
<th>Aggregate correction factor (G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( h_1 = )</td>
</tr>
<tr>
<td>( h_2 = )</td>
</tr>
<tr>
<td>( G = h_1 - h_2 ) = ________</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Apparent concrete air content (A₁)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( h_1 = )</td>
</tr>
<tr>
<td>( h_2 = )</td>
</tr>
<tr>
<td>( A_1 = h_1 - h_2 ) = ________</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>A (air content) =</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_1 - G ) = ________</td>
</tr>
</tbody>
</table>

---

PCI Manual for Quality Control for Plants and Production of Glass Fiber Reinforced Concrete Products, 2nd Edition

E-8
This document specifies requirements for glass fibers made from alkali-resistant glass compositions and intended for use as reinforcement in portland cement concrete according to ASTM C1666/C1666M. Tests shall be carried out by the fiber supplier, who shall certify compliance.

1. **Condition and Properties**

   1.1 The product shall be packed in containers in such a manner as to give adequate protection in transport and storage. A roving package shall be free from obvious damage and should not be deformed.

   1.2 The container shall be clearly labeled "alkali-resistant glass" and indicate manufacturer, product code, filament diameter, and roving tex. The end count for roving products shall also be given.

   1.3 The rovings shall be free from oil, grease, and other visible contaminants.

   1.4 The nominal filament diameter shall be as agreed between purchaser and manufacturer, or as specified.

   1.5 The properties of rovings shall comply with the requirements given in Table F.1 below.

### Table F.1. Test Requirements

<table>
<thead>
<tr>
<th>Property</th>
<th>Specification value</th>
<th>Method of test</th>
<th>Frequency of test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zirconia content (ZrO₂)</td>
<td>16% minimum</td>
<td>X-ray fluorescence</td>
<td>Every 6 months</td>
</tr>
<tr>
<td>Density</td>
<td>2.68 ±0.3 g/cm³ (167.0 ± 19 lb/ft³)</td>
<td>ASTM D3800</td>
<td>Yearly</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>1.0–1.7 GPa (145 × 10⁶ – 246 × 10⁶ psi)</td>
<td>ASTM D2256, ISO 3341, JISR3420</td>
<td>Yearly</td>
</tr>
<tr>
<td>Range of filament diameters</td>
<td>8–30 microns (31 × 10⁻⁵ – 118 × 10⁻⁵ in.)</td>
<td>ASTM D578, ISO 1888, JISR3420</td>
<td>Continuous or monthly</td>
</tr>
<tr>
<td>Roving tex</td>
<td>±10% of manufacturer’s nominal</td>
<td>ASTM D1577, ISO 1889, JISR3420</td>
<td>Daily</td>
</tr>
<tr>
<td>Strand length</td>
<td>±3 mm (±0.118 in.) of manufacturer’s nominal</td>
<td>Caliper—average of 20 measurements</td>
<td>Monthly</td>
</tr>
<tr>
<td>End count</td>
<td>±20% of manufacturer’s nominal</td>
<td>Physical count</td>
<td>Daily</td>
</tr>
<tr>
<td>Loss on ignition</td>
<td>&lt; 3%</td>
<td>ASTM D4963, ISO 1887, JISR3420</td>
<td>Daily</td>
</tr>
<tr>
<td>Strength retention</td>
<td>Minimum value after 96 ± 1 hour in water at 80 °C (± 1 °C) (176 °F + 2 °F) ≥ 250 MPa (36,250 psi) for water-dispersible strands ≥ 350 MPa (50,750 psi) for integral strands</td>
<td>EN 14649, “Precast concrete products – Test method for strength retention of glass fiber in cement and concrete (SIC test)”</td>
<td>Each 110,000 lb</td>
</tr>
</tbody>
</table>

### References

**ASTM Standards:**
- D 578 Specification for Glass Fiber Strands
- D 1577 Test Methods for Linear Density of Textile Fibers
- D 2256 Test Method for Tensile Properties of Yarns by the Single-Strand Method
- D 3800 Test Method for Density of High-Modulus Fibers
- D 4963 Test Method for Ignition Loss of Glass Strands and Fabrics

**ISO Standards:**
- ISO 1887 Textile Glass—Determination of Combustible-Matter Content
- ISO 1888 Textile Glass—Staple Fibres or Filaments—Determination of Average Diameter
- ISO 1889 Reinforcement Yarns—Determination of Linear Density
- ISO 3341 Textile Glass Yarns—Determination of Breaking Force and Breaking Elongation

**EN Standards:**
- EN 14649 Precast Concrete Products—Test Method for Strength Retention of Glass Fibre in Cement and Concrete

**Japanese Industrial Standards:**
- JISR 3420 Testing Methods of Textile Glass Products
Specification for Polymer Curing Admixture

1. **Property Requirements**

1.1 **Type compound**
Aqueous thermoplastic co-polymer dispersion

1.2 **Type polymer**
Acrylic-based

1.3 **% solids**
45% to 55% by weight

1.4 **Free monomer content**
Maximum 0.2% by weight in dispersion

1.5 **Appearance**
Milky white, creamy, free from lumps

1.6 **Odor**
Must meet OSHA and EPA requirements

1.7 **pH**
8 to 10

1.8 **Minimum film forming temperature**
45 to 54 °F (7 to 12 °C)

1.9 **Average polymer particle size**
150–200 mm (Malvern autosizer)

1.10 **Molecular weight**
400,000–500,000

1.11 **Ultraviolet resistance**
Good (weatherometer 500 hrs.)

1.12 **Alkali resistance**
Good
Example: Test saponification of polymer film-4 weeks in 1 mole NaOH/KOH hydrolysis (less than 5% at 50 °C)

1.13 **Viscosity**
100–300 cps
[Brookfield, spindle 2, 100 RPM, 70 °F (21 °C)]

1.14 **Freeze-thaw stability**
No gelation in a minimum of 5 cycles

2. **Performance Requirements**
To ensure GFRC product quality, curing compounds shall be tested by an independent laboratory to demonstrate that:

- The recommended quantity of polymer curing admixture in GFRC mix with no moist curing equals flexural properties of GFRC cured 7 days moist when both are tested at 28 days.
- The long-term durability of the dry-cured polymer admixture modified composite, verified by aging tests, is equal to or greater than the durability of GFRC cured 7 days moist.
- The unit weight of a mix design incorporating polymer curing admixture is greater than 120 pcf (1930 g/m3).
- The polymer exhibits durability, ultraviolet stability, and oxidation resistance and stability in a high-alkaline environment.
**APPENDIX H**

**Test Procedures**

**PRODUCTION TESTING – WET**

**TEST 1**
Determine Slump Value of Cement Slurry (“The Slump Test”)

**T1.1 Equipment**
- Open-ended non-absorbent tube
  - Inside diameter: 2.25 in. (57 mm)
  - Outside diameter: 2.50 in. (65 mm)
  - Length: 3.187 in. (80 mm) or 2.25 in. (55 mm)
- Spatula
- Non-absorbent target plate: 12 × 12 in.
  - (305 × 305 mm) × 3/8 to 1/2 in. (10 to 13 mm) thick engraved with a series of concentric circles

<table>
<thead>
<tr>
<th>No.</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.50 in.  (65 mm)</td>
</tr>
<tr>
<td>1</td>
<td>3.375 in. (85 mm)</td>
</tr>
<tr>
<td>2</td>
<td>4.25 in.  (108 mm)</td>
</tr>
<tr>
<td>3</td>
<td>5.00 in.  (125 mm)</td>
</tr>
<tr>
<td>4</td>
<td>5.75 in.  (145 mm)</td>
</tr>
<tr>
<td>5</td>
<td>6.50 in.  (165 mm)</td>
</tr>
<tr>
<td>6</td>
<td>7.25 in.  (185 mm)</td>
</tr>
<tr>
<td>7</td>
<td>8.00 in.  (205 mm)</td>
</tr>
<tr>
<td>8</td>
<td>8.875 in. (225 mm)</td>
</tr>
</tbody>
</table>

**T1.2 Method**

**T1.2.1** The dry tube is placed on the target plate coincident with the innermost ring and is filled with the slurry. If necessary, air bubbles are expelled by gently rodding the mix. The slurry should be screeded and leveled with the edge of a spatula.

**T1.2.2** The tube is lifted vertically off the plate with a slow continuous motion allowing the slurry to flow over the target area of concentric circles (Fig. T1.2.2). The slump value is given by the extent of slurry flow expressed on the 0–8 scale.

**T1.2.3** Three tests are made. The results should agree within one-half of a ring.

**T1.3 Calculation**

**T1.3.1** The slump values are read directly from the target plate.

**Notes:**

- a. The test must be carried out on a bench free from vibration.
- b. The plate and tube must be washed and dried between each measurement.
- c. The slump value of the cement slurry can vary with time, and the above test should be done at a time appropriate to the characteristics of the process being employed.
- d. The slurry can be returned to the pump hopper.
TEST 2
Determination of Slurry Flow Rate ("Pump Output") ("The Bucket Test")

T2.1 Equipment

Balance: Capacity 25 lb (12 kg)
minimum to nearest 0.1 lb (50 g)

Polyethylene bucket: 2 gal (0.00757m³)
capacity minimum

Stopwatch

T2.2 Method

T2.2.1 The weighed bucket (w₁) is positioned under the spray nozzle and the slurry is collected for a minimum of fifteen seconds (t) under actual operating conditions. Start the slurry pump and discharge into a pail other than the weighing bucket. When the line has been cleared and steady flow obtained, move the test pail into the slurry stream and start timing. The bucket and its contents are weighed (w₂).

T2.2.2 At least one such measurement is made and the delivery rate calculated in lb (kg) per minute.

T2.3 Calculation

Delivery rate, lb/min. (kg/min.) = (w₂-w₁)60/t

Where

w₂ = weight of bucket plus slurry
w₁ = weight of empty bucket
t = time of collection, sec.

Note: The slurry can be returned to the pump hopper.
APPENDIX H

TEST 3
Determination of Glass Fiber Roving Chopping Rate
(“Chopper Output Rate”) (“The Bag Test”)

T3.1 Equipment

Balance: Capacity 2 kg to nearest 0.1 g
Polyethylene bag: Approximately 2 × 3 ft (0.81 × 0.914 m):
Stopwatch

T3.2 Method

T3.2.1 The weighed polyethylene bag (w1) is held in position over the outlet of the chopping gun such that all the chopped fiber is collected. A hole is left at the top of the bag to allow air to escape to prevent interference with the air flow through the chopper. The glass chopped in a minimum of fifteen seconds (t) is collected and the bag and its contents are weighted (w2).

T3.2.2 At least one such measurement is made and is calculated in grams per minute. To obtain pounds per minute, divide by 454.

T3.3 Calculation

Delivery rate (g/minute) = \(\frac{w_2 - w_1}{t}\)
where

\(w_2\) = weight of bag plus chopped fiber (g)
\(w_1\) = weight of empty bag (g)
\(t\) = time of collection (sec.)

Note: Prior to the test, the chopping gun should be run, with or without fiber, to allow the air motor to warm up.

TEST 4
Determination of Glass Fiber Content
(“The Wash-Out Test”)

The glass fiber content of an uncured, glass fiber reinforced concrete sample panel is determined using ASTM C1229, “Standard Test Method for Determination of Glass Fiber Content in Glass Fiber Reinforced Concrete (GFRC) (Wash-Out Test).” The test coupons to be used in the wash-out tests are to be prepared in accordance with ASTM C1228, “Standard Practice for Preparing Coupons for Flexural and Wash-out Tests on Glass Fiber Reinforced Concrete.”

TEST 5
Determination of Wet Density (Unit Weight) of Slurry

T5.1 Equipment

Bucket: 0.1 ft³ (0.003 m³) (ASTM C29)
Balance: Capacity 25 lb (12 kg) minimum to nearest 0.1 lb (50 g)

T5.2 Method

The test is performed in accordance with ASTM C138, “Test Method for Unit Weight, Yield, and Air Content (Gravimetric) of Concrete,” except the weighed bucket is filled from the mixer and the slurry should not be consolidated.
APPENDIX H

Test Procedures

PRODUCTION TESTING – AFTER CURING

TEST 6
Flexural Testing

The flexural ultimate and flexural yield are determined using ASTM C947, “Standard Test Method for Flexural Properties of Thin-Section Glass Fiber Reinforced Concrete (Using Simple Beam with Third-Point Loading),” as shown in Figure T6. The test coupons to be used in the flexural test are to be prepared in accordance with ASTM C1228, “Standard Practice for Preparing Coupons for Flexural and Wash-out Tests on Glass Fiber Reinforced Concrete.”

![Figure T6 Flexural Test](image)

TEST 7
Determination of Bulk Density and Absorption of GFRC Backing

The dry and wet bulk density and water absorption are determined using ASTM C948, “Standard Test Method for Dry and Wet Bulk Density, Water Absorption, and Apparent Porosity of Thin Sections of Glass Fiber Reinforced Concrete.”

TEST 8
Determination of Absorption of Face Mix

T8.1 Equipment

- Balance: Balance sensitive to 0.025% of the weight of the specimen
- Container: Suitable container for immersing the specimen and suitable wire for suspending the specimen in water
- Drying oven: Set at 212 to 230 °F (100 to 110 °C)

T8.2 Test Specimen

Three 4 × 8 in. (102 × 204 mm) cylinders or 4 in. (102 mm) cubes should be cast from each of the mixes being tested. If possible, samples should be cast in containers made from the mold material intended for the actual production unit. Test samples should be consolidated, cured, and finished similarly to the products they represent. Test samples should be clean and free from any parting or form release agent or any sealer.
**APPENDIX H**

**Test Procedures**

**T8.3 Method**

Specimens should be tested after 28 days in accordance with ASTM C642, except procedures described in Sections 5.3 and 5.4 of the ASTM test are not required. The ASTM-defined absorption percentage is the average absorption of the three specimens. This figure may be transformed to volume percentage based on the specific weight of the concrete tested.

---

**TEST 9**

**Anchor Shear Testing**

**T9.1 Scope**

This test method covers determination of shear strength of flex anchor and gravity anchor attachments to GFRC panels by direct loading.

**T9.2 Equipment**

**T9.2.1** The testing machine shall be capable of applying loads at a uniform rate without shock or interruption. A special test fixture shall be used to hold the GFRC panel securely and without local damage during testing.

**T9.2.2** The horizontal shear loading method employs a fixture to hold the GFRC panel that will ensure that force applied to the anchor is parallel to and at the specified distance from the panel surface. A diagram showing arrangement of panel support for horizontal shear testing is shown in Fig. T9.2.2.

**T9.2.3** The vertical shear loading method employs a fixture to hold the GFRC panel that will ensure that force applied to the stud is parallel to and at a specified distance from the panel surface. A diagram showing arrangement of panel support for vertical shear testing is shown in Fig. 9.2.3(a). Fig. 9.2.3(b) is a photograph of a vertical shear test setup.

---

**Figure T9.2.2** Arrangement for horizontal shear test
T9.2.4  Direct reactions should be parallel to the direction of applied forces at all times during the test. Indirect reactions should be perpendicular to the direction of applied forces. All reactions should be positioned to resist applied loading without adding support to the bonding pad.

T9.3  Test Specimen

The test specimen shall be sawn from a representative panel or a panel fabricated in an identical manner to the production panel. The sawn edges shall be at right angles to the panel surface. Edges shall be a sufficient distance from the bonding pad to allow support during loading. The anchor shall be cut as far above the panel as possible when the sample is cut from the panel. Extension of the anchor, if needed for testing purposes, shall be by welding an extension piece of the same cross section to the anchor.

A diagram of a test specimen that meets these requirements is shown in Fig. T9.3.

Note: Dimensions are a function of bonding pad geometry and may be modified to accommodate bonding pad size.

T9.4  Method

Note: Loading and reacting techniques may be modified to suit specific specimens.

T9.4.1  For horizontal shear loading, the test specimen shall be positioned in the test apparatus with the panel face vertical and with the anchor directly below the grip of the test machine. The reaction pads shall be adjusted to hold the GFRC panel secure in position with one edge against a support. A load rod connects between the testing-machine grip and a groove that was previously cut on the side of the anchor to define a location for load application. The load shall be applied to cause a load point displacement rate of 0.2 in. (5 mm) per minute until rupture occurs or the anchor yields.

T9.4.2  For vertical shear loading, the test specimen shall be positioned in the test apparatus with the panel face vertical and the load point on the stud centered in the grip of the test machine. The reaction pads shall be adjusted to hold the GFRC panel secure in position and with one edge against a support. The load shall be applied to cause a stud displacement rate of 0.2 in. (5 mm) per minute until rupture occurs or the anchor yields.
APPENDIX H

Test Procedures

T9.5  Measurements

T9.5.1  Take a thickness measurement of the test panel at each corner. Measure the approximate dimensions of the bonding pad, including thickness over the top of the anchor foot.

T9.5.2  Record maximum load and corresponding displacement. The preferred method is to record load and corresponding displacement on a continuous plot of load displacement until failure occurs.

T9.5  Report

The report shall include the testing laboratory and testing personnel along with the following:

a. Test panel identification number
b. Conditioning of specimen
c. Age of specimen (if artificially aged, include description of process with time, temperature, etc.)
d. Type of test (horizontal shear or vertical shear)
e. Panel thickness measurements
f. Bonding pad dimensions including thickness over the top of the anchor
g. Maximum applied load in pounds (kilograms)
h. Displacement at maximum load in inches (millimeters)
i. Mode of failure
FIGURE T9.2.3(b) Vertical shear test setup

FIGURE T9.3 Test specimen
APPENDIX H

TEST PROCEDURES

TEST 10
Anchor Pull-Off Testing

The tensile load capacity of GFRC bonding pads used for attaching flex and gravity anchors to GFRC panels is determined in accordance with ASTM C1230, “Standard Test Method for Performing Tension Tests on Glass Fiber Reinforced Concrete (GFRC) Bonding Pads.”

TEST 11
Accelerated Aging Test

The aged properties of GFRC should be determined in accordance with ASTM C1560, “Standard Test Method for Hot Water Accelerated Aging of Glass Fiber Reinforced Concrete-Based Composites.”
INTRODUCTION

Since 1967, the Precast/Prestressed Concrete Institute has been a leader in the development of innovative quality programs. That year saw the beginnings of the PCI Plant Certification Program, a program that would set the pace for other construction-related certification programs to follow over the years. In 1985, PCI implemented its Plant Quality Personnel Certification Program and in 1999 introduced the Certified Field Auditor and Field Qualification Program for erectors of precast concrete. Contact PCI for information about these programs.

In an age when quality is being demanded, the certification of manufacturers, erectors, and personnel provides assurance that quality systems are in place, personnel are trained, and control is practiced through every step of the process. Independent, unannounced audits ensure it.

PCI Plant Certification

The certification of a manufacturing plant by PCI ensures that the plant has developed an in-depth quality system that is based on time-tested industry standards. First, every plant must have at least one year of production experience. Each must document their specific practices in a custom Quality System Manual and have the manual approved by PCI.

After undergoing a “Precertification Evaluation,” a plant is audited twice each year. These are unannounced audits. Auditors are independent, specially trained engineers.

Every audit ends with a meeting of auditors and key plant personnel so that if improvements are necessary, they can be started right away. A detailed written report that documents the observations and suggestions for improvements is provided after every audit. The report also includes a numerical grade sheet that determines qualification for continued certification.

The numerical grade sheet is organized exactly like the outline of this manual. The Table of Contents forms the basis of the grade sheet. During an audit, each chapter (division) of the manual is graded separately. Auditing each division must result in a minimum acceptable grade. Then, the grades for all divisions are combined into an overall grade. A minimum overall numerical grade is also required for certification.

Product Groups – A plant is evaluated and classified according to the type of products produced. This allows for product-specific inspection and analysis of a plant’s specialized capabilities. Plants may be certified in up to four general groups of products. The manuals listed in parentheses include the certification standards for the group.

Group A
Architectural Concrete Products (MNL-117)

Group B
Bridge Products (MNL-116)

Group C
Commercial Structural Products (MNL-116)

Group G
Glass Fiber Reinforced Concrete Products (MNL-130)

Groups BA and CA
A combination of A and B or A and C product groups (MNL-116) (see the detailed description BA and CA below)

Production Categories – Product groups A, B, BA, C, and CA are further divided into categories that define a product’s reinforcement or the way in which the products is manufactured or used:

Group A categories:
• AT – Miscellaneous Architectural Trim Units
• A1 – Architectural Precast Concrete Products
APPENDIX I

Certification Programs

Group B categories:
• B1 – Precast Concrete Products (no prestressed reinforcement)
• B2 – Prestressed Miscellaneous Bridge Products
• B3 – Prestressed Straight-Strand Bridge Beams
• B4 – Prestressed Deflected-Strand Bridge Beams

Group C categories:
• C1 – Precast Concrete Products (no prestressed reinforcement)
• C2 – Prestressed Hollow-Core and Repetitively Produced Products
• C3 – Prestressed Straight-Strand Structural Members
• C4 – Prestressed Deflected-Strand Structural Members

Group BA categories (Group B category products with architectural finishes):
• B1A, B2A, B3A, B4A

Group CA categories (Group C category products with architectural finishes):
• C1A, C2A, C3A, C4A

All of the categories listed above are in ascending order. A producer qualified to produce products in a given category is automatically qualified in the preceding categories but not in succeeding categories.

For more descriptive information about the types of products and projects that are represented by these categories, contact PCI, visit the PCI website, or refer to other more detailed literature.

A current listing of all PCI-Certified Plants is maintained on a convenient, searchable list at www.pci.org, or contact PCI, Director of Quality Programs.

PCI Plant Certification is included in the Master Specification of the American Institute of Architects and is required in the specification of the following federal agencies:
• Unified Facilities Guide Specifications (UFGS), which are a joint effort of the U.S. Army Corps of Engineers (USACE), the Air Force Civil Engineer Support Agency (AFCESA), and the National Aeronautics and Space Administration (NASA)
• U.S. Department of Transportation, Federal Aviation Administration
• U.S. Department of Agriculture, Food Safety and Inspection Service
• U.S. Department of Interior, Federal Bureau of Reclamation
• General Services Administration
• Federal Bureau of Prisons

Plant Certification is strongly endorsed by the Federal Highway Administration (FWHA) for precast concrete bridge products and is required or accepted by more than one-half of the individual state departments of transportation.

Plant Quality Personnel Certification

Conducting an effective quality control program requires knowledgeable and motivated testing and inspection personnel. Each must understand quality basics, the necessity for quality control, how products are manufactured, and precisely how to conduct tests and inspections. PCI has been training quality control personnel since 1974. In 1985, the first technician training manual was published by PCI and the first qualified personnel were certified.

There are four levels of Plant Quality Personnel Certification.

PPQC Level I requires a basic level of understanding of the many quality control issues normally encountered in a precast plant, such as:
• Quality and quality-control programs, testing, and measuring
• Prestressing concepts and tensioning procedures for straight strands, including basic elongation calculations
• Basic concepts about concrete—water–cementitious materials ratio (w/cm), types of cements, accelerated curing concepts
• Control of purchased materials
APPENDIX I

Certification Programs

- Precast production procedures
- Welding practices, including welding of reinforcing bars
- Interpretation of basic shop drawings

Certification at Level I also requires current certification as an American Concrete Institute (ACI) Concrete Field Testing Technician, Grade I. This certification requires a written test and precise field demonstration of seven ASTM methods to test fresh concrete. Level I must be renewed after five years unless a higher level of PCI certification is attained.

PQPC Level II requires Level I as a prerequisite. Level II must be renewed after five years unless Level III is attained. Other requirements for Level II include a greater level of knowledge of most of the topics described for Level I, as well as:

- Tensioning and elongation corrections that account for temperature effects, chuck seating, abutment movement, and bed shortening. Calculations are required.
- Effects of accelerated curing and w/cm are further emphasized. Correction to mix proportions must be calculated to account for excess moisture in the aggregates.
- Quality control tests are further explored, including aggregate gradation calculations and analysis.
- Plant topics include more detail in reading shop drawings and in procedures for welding reinforcing bars.

Certification through Level II is accomplished by passing a written examination. Examinations may be administered locally by an approved proctor or at a PCI-conducted training school. A manual for Level I and II, TM-101, is available from PCI for training and self-study.

PQPC Level III provides significant instruction in concrete materials and technology. Certification at this level requires attendance at a four-day course and Level II as a prerequisite. Certification at Level III is valid for life.

There is a training manual, TM-103, available from PCI that covers all course material, such as:

- Properties of basic concrete materials, admixtures, fresh concrete, and hardened concrete
- Mix designs using normal and lightweight aggregates
- Architectural concrete
- Troubleshooting and fine-tuning concrete mixes
- Finished product evaluation
- Stud welding
- Deflected prestressing strands and the calculation of forces

PQPC GFRC Certification is accomplished by passing a written examination covering information contained in the two PCI manuals for GFRC.

- Manual for Quality Control for Plants and Production of Glass Fiber Reinforced Concrete Products, PCI MNL-130
- Recommended Practice for Glass Fiber Reinforced Concrete Panels, PCI MNL-128

Certification requires a basic level of understanding of the many quality issues normally encountered in a GFRC plant, such as:

- Quality assurance and quality control programs
- GFRC production practices
- Raw materials and accessories used
- Mix proportioning, batching, placing, spraying, and curing
- Quality control inspection and testing procedures
- Product dimensional tolerances

Examinations may be administered locally by an approved proctor.

Summary

The GFRC industry, through PCI, has taken bold steps to establish industry standards. The standards apply to personnel, to production and operation, to quality control, and to field operations. The standards have been published and widely disseminated and are open for evaluation.
APPENDIX I  Certification Programs

The PCI industry standards for quality production are demanding to achieve. But once attained and regularly practiced, they contribute to continued customer satisfaction as well as reduced overall operating costs.

Certification by PCI ensures compliance to the standards for quality production. Certified personnel and producers choose to demonstrate their proficiency by voluntarily undergoing examinations and audits by accredited third-party assessors.

PCI Plant and Personnel Certification are your most reliable means for qualifying your GFRC producer. Specify PCI Certification Programs for your projects.

Guide Qualifications Specification

Manufacturer Qualifications for Glass Fiber Reinforced Concrete – The GFRC manufacturing plant shall be certified by the Precast/Prestressed Concrete Institute's Plant Certification Program. Manufacturers shall be certified at the time of bidding. Certification shall be in Group G, Glass Fiber Reinforced Concrete.

Personnel Qualifications

The manufacturer shall employ a minimum of one person, regularly present in the plant, who is certified by the Precast/Prestressed Concrete Institute as a GFRC Technician/Inspector.
This manual and its commentary refer to many standards and outline recommendations based on the available body of knowledge involving glass fiber reinforced concrete. This appendix provides a basic outline of applicable standards and reference material. It is essential that production personnel be furnished with current reference literature and be encouraged to read and use it.

A minimum reference list should include applicable and current publications of ASTM International, the American Concrete Institute, the Precast/Prestressed Concrete Institute, the Portland Cement Association, and similar agencies having pertinent applicable specifications dealing with manufacture of GFRC. The following publications are recommended for that minimum listing:

**ASTM International**
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
www.astm.org

The ASTM *Book of Standards* contains specifications and test methods for most of the materials and standard practices used in the production of GFRC. They also contain specifications and methods of tests for related materials. Some of the related standards are as follows:

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<th>ASTM Designation</th>
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<tr>
<td>A29/A29M</td>
<td>Standard Specification for Steel Bars, Carbon and Alloy, Hot-Wrought, General Requirements for</td>
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<tr>
<td>A36/A36M</td>
<td>Standard Specification for Carbon Structural Steel</td>
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<tr>
<td>A108</td>
<td>Standard Specification for Steel Bar, Carbon and Alloy, Cold-Finished</td>
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<tr>
<td>A143/A143M</td>
<td>Standard Practice for Safeguarding Against Embrittlement of Hot-Dip Galvanized Structural Steel Products and Procedure for Detecting Embrittlement</td>
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<tr>
<td>A153/A153M</td>
<td>Standard Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware</td>
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<tr>
<td>A276</td>
<td>Standard Specification for Stainless Steel Bars and Shapes</td>
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<tr>
<td>A283/A283M</td>
<td>Standard Specification for Low and Intermediate Tensile Strength Carbon Steel Plates</td>
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<td>A307</td>
<td>Standard Specification for Carbon Steel Bolts and Studs, 60,000 PSI Tensile Strength</td>
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<tr>
<td>A325</td>
<td>Standard Specification for Structural Bolts, Steel, Heat Treated, 120/105 ksi Minimum Tensile Strength</td>
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<tr>
<td>A370</td>
<td>Standard Test Methods and Definitions for Mechanical Testing of Steel Products</td>
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<td>A500</td>
<td>Standard Specification for Cold-Formed Welded and Seamless Carbon Steel Structural Tubing in Rounds and Shapes</td>
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<td>A513</td>
<td>Standard Specification for Electric Resistance Welded Carbon and Alloy Steel Mechanical Tubing</td>
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<tr>
<td>A572/A572M</td>
<td>Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel</td>
</tr>
<tr>
<td>A653/A653M</td>
<td>Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) or Zinc-Iron Alloy-Coated (Galvannealed) by the Hot-Dip Process</td>
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<tr>
<td>A666</td>
<td>Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel, Sheet, Strip, Plate, and Flat Bar</td>
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<tr>
<td>A675/A675M</td>
<td>Standard Specification for Steel Bars, Carbon, Hot-Wrought, Special Quality, Mechanical Properties</td>
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<tr>
<td>A780</td>
<td>Standard Practice for Repair of Damaged and Uncoated Areas of Hot-Dip Galvanized Coatings</td>
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<tr>
<td>A924/924M</td>
<td>Standard Specification for General Requirements for Steel Sheet, Metallic-Coated by the Hot-Dip Process</td>
</tr>
<tr>
<td>A1008/A1008M</td>
<td>Standard Specification for Steel, Sheet, Cold-Rolled, Carbon, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy with Improved Formability, Solution Hardened, and Bake Hardenable</td>
</tr>
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Reference Literature

A1011/A1011M  Standard Specification for Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy and High-Strength Low-Alloy with Improved Formability, and Ultra-High Strength

B633  Standard Specification for Electrodeposited Coatings of Zinc on Iron and Steel

B766  Standard Specification for Electrodeposited Coatings of Cadmium

C31/C31M  Standard Practice for Making and Curing Concrete Test Specimens in the Field

C33  Standard Specification for Concrete Aggregates

C39/C39M  Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens

C40  Standard Test Method for Organic Impurities in Fine Aggregates for Concrete

C88  Standard Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate


C117  Standard Test Method for Materials Finer than 75-µm (No. 200) Sieve in Mineral Aggregates by Washing

C127  Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate

C128  Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate

C136  Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates

C138/C138M  Standard Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

C144  Standard Specification for Aggregate for Masonry Mortar

C150  Standard Specification for Portland Cement

C173/C173M  Standard Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

C185  Standard Test Method for Air Content of Hydraulic Cement Mortar

C191  Standard Test Method for Time of Setting of Hydraulic Cement by Vicat Needle

C192/C192M  Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory


C231  Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

C260  Standard Specification for Air-Entraining Admixtures for Concrete

C289  Standard Test Method for Potential Reactivity of Aggregates (Chemical Method)

C295  Standard Guide for Petrographic Examination of Aggregates for Concrete

C494/C494M  Standard Specification for Chemical Admixtures for Concrete

C566  Standard Test Method for Total Evaporable Moisture Content of Aggregate by Drying

C567  Standard Test Method for Unit Weight of Structural Lightweight Concrete

C586  Standard Test Method for Potential Alkali Reactivity of Carbonate Rocks for Concrete Aggregates (Rock Cylinder Method)

C618  Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for use in Concrete

C641  Standard Test Method for Staining Materials in Lightweight Concrete Aggregates

C666/C666M  Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing

C947  Standard Test Method for Flexural Properties of Thin-Section Glass Fiber Reinforced Concrete (Using Simple Beam with Third-Point Loading)

C948  Standard Test Method for Dry and Wet Bulk Density, Water Absorption, and Apparent Porosity of Thin Sections of Glass Fiber Reinforced Concrete

C979  Standard Specification for Pigments for Integrally Colored Concrete
APPENDIX J

C1064/C1064M  Standard Test Method for Temperature of Freshly Mixed Hydraulic-Cement Concrete
C1077         Standard Practice for Laboratories Testing Concrete and Concrete Aggregates for Use in Construction and Criteria for Laboratory Evaluation
C1228         Standard Practice for Preparing Coupons for Flexural and Washout Tests on Glass Fiber Reinforced Concrete
C1229         Standard Test Method for Determination of Glass Fiber Content in Glass Fiber Reinforced Concrete (GFRC) (Wash-Out Test)
C1230         Standard Test Method for Performing Tension Tests on Glass Fiber Reinforced Concrete (GFRC) Bonding Pads
C1260         Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)
C1293         Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction
C1666/C1666M  Standard Specification for Alkali-Resistant (AR) Glass Fiber for GFRC and Fiber-Reinforced Concrete and Cement
D3800         Standard Test Method for Density of High-Modulus Fibers
E4           Standard Practices for Force Verification Testing Machines
E11           Standard Specification for Wire Cloth Sieves for Testing Purposes
E105          Standard Practice for Probability Sampling of Materials
E329          Standard Specification for Agencies Engaged in Construction Inspection or Testing

For all materials and equipment used in the manufacture of glass fiber reinforced concrete for which an appropriate ASTM designation has not been developed, manufacturer’s specifications and directions should be available. Such materials and equipment should be used only when they have been shown by tests to be adequate for the purpose intended and their use has been approved by the purchasing entity.

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333
www.concrete.org

1. SP-2: ACI Manual of Concrete Inspection
2. Manual of Concrete Practice

ACI Designation  Title
116R          Cement and Concrete Terminology
117          Specifications for Tolerances for Concrete Construction and Materials and Commentary
211.1         Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete
212.3R        Chemical Admixtures for Concrete
212.4         Guide for the Use of High-Range Water-Reducing Admixtures (Superplasticizers) in Concrete
214R          Evaluation of Strength Test Results of Concrete
214.3R        Simplified Version of the Recommended Practice for Evaluation of Strength Test Results of Concrete
221R          Guide for Use of Normal Weight and Heavyweight Aggregates in Concrete
304R          Guide for Measuring, Mixing, Transporting, and Placing Concrete
305R          Hot Weather Concreting
306R          Cold Weather Concreting
308.1         StandardSpecification for Curing Concrete
## Reference Literature

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<th>PCI Designation</th>
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<tr>
<td>MNL-117</td>
<td>Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products</td>
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<tr>
<td>MNL-119</td>
<td>PCI Drafting Handbook—Precast and Prestressed Concrete</td>
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<td>MNL-122</td>
<td>Architectural Precast Concrete</td>
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<tr>
<td>MNL-127</td>
<td>Erectors’ Manual: Standards and Guidelines for the Erection of Precast Concrete Products</td>
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<td>MNL-128</td>
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<td>SLP-100</td>
<td>PCI Safety and Loss-Prevention Manual</td>
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<tr>
<td>TN-3</td>
<td>Efflorescence on Precast Concrete</td>
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### Portland Cement Association

5420 Old Orchard Road  
Skokie, IL 60077  
www.cement.org

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<th>PCA Designation</th>
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<tr>
<td>EB001</td>
<td>Design and Control of Concrete Mixtures</td>
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<td>IS 214</td>
<td>Removing Stains and Cleaning Concrete Surfaces</td>
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### American Welding Society

550 N.W. LeJeune Rd.  
P.O. Box 351040  
Miami, FL 33135  
www.amweld.org

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<tr>
<th>AWS Designation</th>
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<tr>
<td>A5.1/A5.1M</td>
<td>Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding</td>
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<td>A5.4/A5.4M</td>
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<td>A5.5/A5.5M</td>
<td>Specification for Low-Alloy Steel Electrodes for Shielded Metal Arc Welding</td>
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<td>Specification for Carbon Steel Electrodes and Rods for Gas Shielded Arc Welding</td>
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<td>Carbon Steel Electrodes for Flux Cored Arc Welding</td>
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<td>B1.11</td>
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<td>Structural Welding Code Steel</td>
</tr>
<tr>
<td>D1.3</td>
<td>Standard Welding Code – Sheet Steel</td>
</tr>
</tbody>
</table>
APPENDIX J

Reference Literature

QC1 Standard for Certification of Welding Inspectors
Z49.1 Safety in Welding and Cutting, and Allied Processes

American Iron and Steel Institute
1140 Connecticut Ave., Ste. 705
Washington, DC 20036-4710
www.steel.org
  • Specification for the Design of Cold-Formed Steel Structural Members
  • Cold-Formed Steel Design Manual
  • Code of Standard Practice for Cold-Formed Steel Structural Framing

Steel Stud Manufacturers Association
800 Roosevelt Rd., Ste. 312, Bldg. C
Glen Ellyn, IL 60137
www.ssma.com

National Ready Mixed Concrete Association
900 Spring Street
Silver Spring, MD 20910
www.nrmca.org

Concrete Plant Manufacturers Bureau
  • Concrete Plant Standards
APPENDIX K

Erection Tolerances

Non-cumulative tolerances for the location of GFRC units are listed below.

\[ a = \text{Plan location from building grid datum}^* \quad \pm \frac{1}{2} \text{ in. (13 mm)} \]

\[ a_1 = \text{Plan location from centerline of steel}^* \quad \pm \frac{1}{2} \text{ in. (13 mm)} \]

\[ b = \text{Top elevation from nominal top elevation} \]

- Exposed individual panel \(\pm \frac{1}{4} \text{ in. (6 mm)}\)
- Nonexposed individual panel \(\pm \frac{1}{2} \text{ in. (13 mm)}\)
- Exposed relative to adjacent panel \(\pm \frac{1}{4} \text{ in. (6 mm)}\)
- Nonexposed relative to adjacent panel \(\pm \frac{1}{2} \text{ in. (13 mm)}\)

\[ c = \text{Support elevation from nominal elevation} \]

- Maximum low \(\frac{1}{2} \text{ in. (13 mm)}\)
- Maximum high \(\frac{1}{4} \text{ in. (6 mm)}\)

\[ d = \text{Maximum plumb variation over height of structure or 100 ft. (30 m), whichever is less}^* \quad 1 \text{ in. (25 mm)} \]

\[ e = \text{Plumb in any 10 ft. (3 m) of element height} \quad \frac{1}{4} \text{ in. (6 mm)} \]

\[ f = \text{Maximum jog in alignment of matching edges} \quad \frac{1}{4} \text{ in. (6 mm)} \]

\[ g = \text{Joint width (governs over joint taper)} \]

- Panel dimension less than 20 ft. (6 m) \(\pm \frac{1}{4} \text{ in. (6 mm)}\)
- Panel dimension over 20 ft. (6 m) \(\pm \frac{1}{8} \text{ in. (10 mm)}\)

\[ h = \text{Joint taper maximum} \quad \frac{1}{16} \text{ in. (10 mm)} \]

\[ h_{10} = \text{Joint taper in 10 ft. (3 m)} \quad \frac{1}{16} \text{ in. (10 mm)} \]

\[ i = \text{Maximum jog in alignment of matching faces} \quad \frac{1}{4} \text{ in. (6 mm)} \]

\[ j = \text{Differential bowing or camber as erected between adjacent members of the same design} \quad \frac{1}{4} \text{ in. (6 mm)} \]

A critical interface area is between the GFRC spandrel panel and the spandrel glazing system. Vertical dimensions between spandrels should be checked with a “story pole” or similar device to ensure that opening size is within allowable tolerances. The interface tolerance between these two systems is as shown in Fig. K.1.

* For precast concrete buildings in excess of 100 ft (30 m) tall, tolerances “a” and “d” can increase at the rate of \(\frac{1}{6} \text{ in. (3 mm)}\) per story over 100 ft to a maximum of 2 in. (50 mm).

† For GFRC elements erected on a steel frame, this tolerance takes precedence over tolerance on dimension “a”.

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PCI Manual for Quality Control for Plants and Production of Glass Fiber Reinforced Concrete Products, 2nd Edition
Figure K.1 Spandrel (Window) Rough Opening
Collection of Ideas on the Production of GFRC

Plant Safety

PCI encourages in-depth safety and loss-prevention programs. Such programs should outline general safety practices as they relate to the GFRC industry and existing federal regulations.

This section is intended to outline some of the more important safety practices for GFRC plants in a broad manner and cannot be considered to include every conceivable hazard that may be present in a GFRC plant. However, recognition of hazards, the establishment of good safety practices, and the requirement that all personnel abide by safety rules will result in more efficient and safer operation in any plant. The potential hazards discussed in this section are generally understood by producers and workers alike; however, it is human nature that people who are constantly exposed to potentially dangerous situations, over time, tend to lose their conscious fear unless they are constantly reminded of the dangers.

Housekeeping is the main consideration for a good, working safety program. Elimination of cluttered work areas, defective lighting, poor tool locations, and poorly protected equipment will improve safety.

It should be the responsibility of supervisory personnel to ensure that safety is never subordinated to production expediency. Any employee who will not abide by prescribed safety rules should not be permitted to work in the GFRC plant.

The details of a safety program should be carefully planned to ensure good safety practices, general housekeeping, and review of job-related accidents and injuries. As a guide, however, the following safety requirements, where applicable, should be covered:

1. All electrical wire and equipment in use should be of a type approved by the Underwriters Laboratories Inc. Installation and maintenance should comply with pertinent provisions of the National Electric Safety Code. All electrical circuits and equipment should be properly grounded in compliance with the code.
2. All personnel should be required to wear safety hats.
3. All personnel should be required to wear safety footwear.
4. All personnel should wear an appropriate face mask to avoid respiration of fine silica dust when cutting or grinding GFRC panels containing silica.
5. All personnel, when finishing by sandblasting, acid washing or etching, or any other operation that is apt to damage the eyes or be hazardous, should be required to wear safety glasses, respiratory protection, and appropriate protective clothing. If acid comes in contact with the skin, the affected area should be immediately flushed with large quantities of fresh water.
6. All debris should be removed from the vicinity of the work area not later than the end of each shift.
7. The proper type and amount of firefighting equipment (a fire extinguisher of the 5BC type or higher) in operating condition should be placed in accessible and well-marked locations, particularly in mold fabrication areas and burning and welding areas. Workers should be trained in their proper use.
8. Hazardous and flammable materials should be stored in separate areas or enclosures out of the immediate work area in accordance with the requirements of the authority having jurisdiction. Materials such as acids should be stored well protected from any production activities and such storage should be clearly screened or marked.
9. Hand tools should be kept in good condition: sharp, free of broken handles, free of mushroomed heads, etc.
10. Wire rope, slings, shackles, and other rigging equipment should be kept in good condition. Personnel should not be permitted beneath suspended loads. Handling equipment should be capable of safely moving units without endangering personnel.
11. Care should be exercised in the use of all cutting equipment. Saws and other equipment should be properly guarded to prevent accidents, contain sparks, and protect the worker in case of blade fracture.
12. Welding areas should be arranged and ventilated to protect workers from welding flashes and excessive welding fumes. Welding and/or flame cutting should not be allowed in the vicinity of sawdust or wood shaving accumulations.
13. Mold shops should have adequate ventilation and be kept clean and free of hazards.
14. All electrically powered mixers should be equipped with totally enclosed motors for safety and ease of maintenance, and should be fully grounded.
15. During sandblasting, dry or damp abrasive is propelled by air and static electricity may accumulate on the operator’s body. To control this problem, a properly grounded conductive hose should be used. Also, the hose line should have adequate strength for the pressure being used. The nozzle should be externally attached to the hose by a fitting that will positively prevent accidental disengagement. To enable the operator to have complete control over the equipment, the nozzle should be fitted with an automatic cutoff (dead man’s handle).

In abrasive blasting, dust is a serious hazard because sufficient silica dust breathed into the lungs can cause silicosis, which may cause total disablement. Only supplied-atmosphere (or air-fed) respiratory protective equipment approved by the Bureau of Mines should be used. Dust filter respirators should not be used for continuous protection where silica sand is used as the abrasive. The air supply for abrasive-blasting respirators should be free from harmful quantities of dust, mists, or noxious gases. Screens may be required to protect the surrounding work and personnel from flying grit. Blasting should not be done in windy conditions.

16. Portland cement dust is classified as a nuisance particulate by NIOSH and it is advisable to wear respiratory protection. Cement dust can be substantially reduced by using careful mixing procedures and by keeping spray atomization pressures as low as possible.

Portland cement slurry is a strong caustic (pH 12.4 to 13.4) and prolonged contact with the skin should be avoided. Eye protection should be worn at all times. Body parts exposed to the cement slurry should be flushed as soon as possible with fresh water or a milk/boric acid solution. Hands and feet should be protected by rubber gloves and boots, and care should be taken that no cement slurry finding its way inside a glove or a boot is allowed to remain there throughout the work period. Serious irritation and burns can result from prolonged contact with portland cement slurries. It should be noted that dry cement powder may absorb enough moisture from the skin to cause the same reaction as cement slurries.

17. Exposure to glass fibers sometimes causes irritation of the skin and, less frequently, irritation of the eyes, nose, or throat. This is not an allergic reaction, but simply a mechanical irritation. Skin irritation typically is experienced by individuals who are newly exposed to fibrous glass and it usually diminishes after several days of exposure. Good personal and industrial hygiene practices will minimize the amount of discomfort experienced. Specific recommendations are as follows:

a. Long-sleeved, loose-fitting clothing should be worn. Gloves and a cap are useful in some operations. Barrier creams are of limited value in protecting against mechanical irritants. Safety glasses or goggles should be worn in operations such as sanding and grinding where airborne particles may get into the eyes. Work clothes should be changed frequently and should be laundered separately to prevent glass fibers from getting into other clothing.

b. If particles accumulate on exposed skin areas, these areas should not be rubbed or scratched. The particles should be removed by washing thoroughly with soap and warm water. If water is not available, dry wash materials (waterless soap and paper towels) should be used.

c. A shower should be taken at the end of the workday. Some individuals find that using a washcloth assists the flowing water in rinsing the fibers from the skin. Following the shower, application of a good commercial skin cream or lotion may be helpful to some people.

d. Ventilation controls and good housekeeping practices should be employed to minimize exposure to airborne fibers. Personal respiratory protection is not required in most operations where fibrous glass materials are being used. However, in operations where an excessive dust level is not controlled by ventilation control, or where upper respiratory tract (nose and throat) irritation occurs, use of a respirator designed for nuisance-type dusts is advisable.

Stripping

The panel frame usually acts as a lifting frame for the panel during stripping, handling, and erection. Depending on the weight of the panel and the location of the pickup point inserts, the panel may be stripped with or without an auxiliary spreader beam by means of overhead cranes or lift trucks.

Difficult panel stripping may be accomplished by using small hydraulic jacks and/or multiple lines in order to minimize skin stress. Additional flex anchors may be installed at areas of potential high stress.

As a crane or hoist provides a means of applying force in one direction only, operators should receive instructions on this principle. The instructions should include established hand signals for the crane or hoist operator.

In some cases, special lifting frames can be built to facilitate removal of the unit from the mold and subsequent handling.
Maintenance and Cleaning

GFRC units require little maintenance to preserve their original appearance. By following a simple program of inspection and maintenance, GFRC can easily achieve the design service life of a building. To ensure proper performance or appearance, it is recommended that visual inspections be carried out yearly. Attention should be given to the caulked joints, surface appearance, and connections, if visible. Minor problems discovered and addressed in a timely manner will prevent expensive future repairs.

There are specific items that require periodic attention:

1. Window cleaning – clean every 90 to 180 days (based on dirt-accumulation effects of the environmental pollution).
2. Dirt and graffiti removal – the GFRC structure should be power washed as necessary (based on the effects of the environmental pollution). Buildup of dirt is usually a gradual process, and periodic flushing with plain water may be an adequate maintenance program.
3. Joint sealants – check all joint sealants for deterioration, and repair as required. Typical maintenance issues are water leakage through the joint, visible separation of the sealant from the GFRC, and cracking or tearing of the sealant. Sealants generally require recaulking only every 15 to 20 years.
4. Sealer – if methyl methacrylate sealer was applied, it should be reapplied every four to five years or as specified by manufacturer; if penetrating silane or siloxane sealer was applied, it may not be necessary to recoat. If desired to recoat, the minimum time would be seven to ten years.

Precautions should be taken to avoid damaging or staining GFRC units by:

1. Ensuring that access equipment does not scratch or chip GFRC surfaces.
2. Ensuring that window-cleaning solution (“runoff”) is cleaned from GFRC units to prevent staining.

All GFRC units should be furnished to the jobsite in a clean and acceptable condition. As erection of GFRC work progresses, all dirt, mortar, plaster, grout, stains, or other construction droppings should be removed by brushing or water washing. If required, the final cleaning of GFRC units should take place only after all installation procedures, including joint caulking, are completed. This cleaning should be done at least three to seven days after any repairs have been completed.

Removing stains from old GFRC sometimes leaves the area much lighter in color than the surrounding GFRC because surface dirt has been removed along with the stain or because the surface may have become slightly bleached. If at all possible, cleaning of the GFRC should be done when temperatures and humidity allow rapid drying. Slow drying increases the possibility of efflorescence and discoloration. There is no single prescription for the cleaning restoration of GFRC, as each building is exposed to a unique set of ambient conditions.

Because efflorescence often occurs during or immediately following construction, the first impulse is to immediately wash it off with water or an acid cleaning solution. This is not advisable, particularly in cool or damp weather when the primary result of such action will be to introduce more water into the GFRC. The water will wash some of the alkali salts from the surface but will also dissolve and carry the salts back into the GFRC, thus causing a recurrence of the efflorescence.

If it is possible to wait one or two years before doing anything to the building, 95% of the time the efflorescing salts will work themselves to the surface; thus the problem may solve itself by normal weathering. The water-soluble alkali salts will gradually weather away. Heavy calcium carbonate efflorescence, although less common, is extremely difficult to remove, as it forms a hard, white crust. After weathering to calcium hydrogen carbonate, it may be easily removed; otherwise, acidic cleaners may be necessary.

It is often helpful to determine the type of efflorescent salt, dirt, or stain so that a cleaning solution may be found that readily dissolves it without adversely affecting the surface finish.

Before cleaning, a small (at least a square yard), inconspicuous area should be cleaned and checked to be certain there are no adverse effects on the GFRC surface finish or adjacent corrodbile materials such as glass, metal, or wood before proceeding with the cleaning. A sprayed-on, strip-off masking can be used to protect glass and aluminum frames. The effectiveness of the cleaning method on the sample area should not be judged until the surface has dried for at least one week.
The key to successful cleaning is recognizing the advantages and limitations of each technique and designing a cleaning program around them (see ASTM E1857, “Guide for Selection of Cleaning Techniques for Masonry, Concrete and Stucco Surfaces”). A suggested order for testing appropriate cleaning procedures for removal of dirt, stains, and efflorescence from GFRC units (from least to most damaging) is:

1. Dry scrubbing with a stiff nylon-fiber brush, particularly if the surface is brushed shortly after the appearance of dirt or efflorescence.

2. Abrasive blasting with industrial baking soda. This abrasive will not affect the GFRC surface. Any residue on the surface should not be removed by water, as salts will be dissolved and carried into the GFRC, causing additional efflorescence. Residues should be blown, vacuumed, or brushed from the surface.

3. Wetting the surface with water and vigorous scrubbing of the finish with a stiff fiber brush followed by thorough rinsing of the surface with clean water. Low-pressure water (50 to 200 psi) spraying (water misting) or high-pressure water (400 to 800 psi) or steam cleaning at 10 to 80 psi may also be tried to assist in removing dirt. Steam cleaning is also done in conjunction with chemical cleaning. During disposal of runoff water from washing, consideration should be given to environmental compliance requirements.

4. Chemical cleaning compounds such as detergents, muriatic or phosphoric acid, or other commercial cleaners used in accordance with the manufacturer’s recommendation. If possible, a technical representative of the product manufacturer should be present for the initial test application to ensure its proper use. Consideration should be given to the chemical’s effect on the surface finish and adjacent materials.

Areas to be cleaned chemically should be thoroughly saturated with clean water prior to application of the cleaning material to prevent the chemicals from being absorbed deeply into the surface of the GFRC. Surfaces should also be thoroughly rinsed with clean water after application so that no trace chemicals remain in the surface layers of the GFRC. Cleaning solutions should not be allowed to dry on the GFRC finish. Residual salts can flake or spall the surface or leave difficult stains. Misapplication of hydrochloric acid can lead to corrosion of adjacent or embedded metals that have shallow cover. Care should be taken to protect all corrodiible materials, glass, or exposed parts of the building during acid washing.

Care should be taken to use dilute solutions of acid to prevent surface etching that may reveal the aggregate and slightly change surface color and texture of the GFRC unit and thus affect the appearance of the finish. The entire GFRC facade should be treated to avoid discoloration or a mottled effect. Application should be to small areas of not more than 4 ft² (0.4 m²) at a time, with a delay of about five minutes before scouring off the deposit with a stiff-bristle brush. Any of several diluted solutions of acids are effective ways to remove dirt, stains, and efflorescence.

   a. One part hydrochloric acid in nineteen parts water
   b. One part phosphoric acid in nine parts water
   c. One part phosphoric acid plus one part acetic acid (vinegar) in nineteen parts water
   d. One part acetic acid in five parts water

Hydrochloric (muriatic) acid may leave a yellow stain on white GFRC. Therefore, phosphoric or acetic acid should be used to clean white.

Rubber gloves, glasses, and other protective clothing must be worn by workers using acid solutions or strong detergents. Materials used for chemical cleaning can be highly corrosive and are frequently toxic. All precautions on labels should be observed because these cleaning agents can affect eyes, skin, and breathing. Materials that can produce noxious or flammable fumes should not be used in confined spaces unless adequate ventilation can be provided.

5. Dry or wet abrasive blasting using sand or other abrasives may be considered if this method was originally used in exposing the surface of the unit. Excessive abrasive blasting may change the color and texture of the finished unit and must be avoided. An experienced subcontractor or a GFRC producer should be engaged for sandblasting. A venturi-type nozzle should be used on the gun for its solid blast pattern, rather than a straight-bore nozzle that produces light fringe areas.

6. Stone veneer–faced GFRC units should be cleaned with stiff-bristle, stainless steel, or bronze wire brushes, a mild soap powder or detergent, and clean water using low or high pressure depending on stone type, if necessary. Acid or other strong chemicals that might damage or stain the stone veneer should not be used. Information should be obtained from stone suppliers on methods of removing oil, rust, and dirt stains from the stone.

7. For information on removing specific stains from GFRC, reference should be made to Removing Stains and Cleaning Concrete Surfaces, IS 214, published by the Portland Cement Association, Skokie, IL.
Loading

GFRC units should be loaded so the GFRC skin does not support the weight of the unit. This is generally achieved by blocking between the trailer bed and the GFRC panel frame. To minimize cyclic loading of the skin anchors, it may be advisable to provide additional blocking to the skin after the panel weight is supported on the panel frame. Since the trailer bed is flexible, two-point support is most desirable. Soft materials, such as high density polymer, polystyrene, or elastomeric materials, should be used to protect the panel edges during shipment. When tying down the GFRC units to the trailers, it is preferable to use nylon straps rather than chains. Special care is required to protect the panels at the binding points of the straps and to protect against the “slap” of a long reach strap. Over tightening of straps must be avoided, as this may result in cracking and permanent deformation of the panels. If panels are “nested” or stacked, consideration shall be given to transfer of vertical load in order to prevent progressive crushing or other damage. This can be prevented by blocking the panels from frame to frame. Special support frames may also be used to prevent damage from occurring. Attention should be given to adequately support any top or bottom returns at the strapping points in order to avoid cracking of the GFRC skin (see Fig. L.1).

Surface Finishes

General

One way to attach returns to a panel is to use a flex anchor at the back face corner at appropriate centers, using bonding pads for attachment. Longer rods can be used on larger returns. Care should be taken to ensure that the return is jigged and held securely at the appropriate angle during production of the base panel.

Form-finished units may appear less uniform in color than the same units subsequently given an exposed-aggregate finish. Uniformity in color, even within small units finished with black coloring, and for units using gray cement, may vary from unit to unit.

Daily variation in the water–cementitious ratio and curing conditions for the face mix will affect color. This is less pronounced in face mixes using white cement than those using gray cement. Additionally, this color variation will be less pronounced in finishes that have some degree of aggregate exposure.

When fabrication continues over extended periods, color can vary because of the changes in the physical characteristics of cement, coarse aggregates, and sands, even though they may be from the same sources.

Air entrainment should be incorporated into face mixes that will be exposed to freeze-thaw conditions. Finishing characteristics are usually not affected by addition of air in normal amounts. Air entrainment normally does not, but can, produce a slight color difference, and long-term weathering characteristics can be affected by the air content. For these reasons, it is important to be at a consistent percentage throughout the entire project.

Fine aggregates have a major effect on the color of white and light-colored face mixes, and can add color tones. Where the color depends primarily on the fine aggregates, gradation control is required, particularly where the color depends on the finer particles. Where fine aggregates are manufactured by crushing colored coarse aggregate and bagged by sizes directly from the screening operations, uniformity in gradation can be maintained from one batch to the next. For fine aggregates in bulk, and subject to several rehandling processes, this is not feasible. Consequently, it is recommended that for bulk material, the percentage of fine aggregate passing the No. 100 (150 µm) sieve should be no more than 5%. The GFRC manufacturer should verify that adequate supply from one source (pit or quarry) for each type of aggregate for the entire job is readily available.
Exposed aggregates can be brightened by washing with diluted muriatic acid. This removes the dull cement film that remains when exposure techniques, such as washing and brushing, are used. The acid solution shall not materially affect the remaining cement or aggregate. The acid is normally applied to a prewetted surface by brush or it can be sprayed. The surface shall be prewetted to reduce acid penetration. Immediately after each washing with the acid solution, the GFRC units shall be thoroughly rinsed with fresh, clean water to completely remove all traces of acid. Proper precautions shall be taken to protect all exposed hardware metal and the panel frame during cleaning operations.

The acid and brush shall be kept clean. When acid is brushed onto the surface, the brush may build up a concentration of insoluble silica gel in the bucket that may then be picked up by the brush and smeared over the surface. Hydrofluoric acid is effective in removing deposits but is extremely dangerous for inexperienced personnel. Such cleaning shall not be performed by plant employees unless they have been trained and properly protected.

Face mixes containing a polymer will exhibit finishing characteristics substantially different from those of face mixes without a polymer. Finishing times will be increased for retarded and acid-etched finishes. For this reason, it is desirable to use a face mix without a polymer for these finishes.

For finishes that do not involve removal of the matrix material, a face mix with a polymer may be advantageous because it is a denser mix and allows for a surface with fewer imperfections and reduced potential for surface crazing.

**Smooth**

The spray used to apply the mist coat should be well atomized to provide a spray of fine particles. Care should be taken to keep atomization pressure as low as possible so as not to “bounce” sand grains out of the slurry as it impacts on the mold. The initial spray-up coat should be applied immediately after spraying on the mist coat to prevent the mist coat from drying out.

For maximum economy, units with smooth surfaces should be produced without additional surface treatment after stripping. This, in turn, demands the following precautions:

1. Attention to detailing with provisions for ample draft, proper edges and corners, and suitable water drips and other weathering details.
2. Well-constructed molds, so that imperfections will not be mirrored in the units. The use of plastic molds or liners with a matte finish or fiberglass-overlaid plywood, which is smooth but not glassy, will help prevent crazing.
3. A mold release agent that is the same throughout production and is applied under as nearly identical conditions as possible each time. (Some release agents help reduce the crazing tendency by breaking the contact with glossy surface of the mold).
4. Mist coat or face-mix designs that combine a constant, low water–cement ratio, high density, and a polymer curing agent in order to minimize crazing, entrapped air voids, and color variations. The mix should be fully graded with aggregate fines below a No. 50 (300 µm) sieve not in excess of 5%.
5. Proper consolidation and curing to minimize non-uniformity that shows easily on such surfaces. Uniform curing with minimum loss of moisture from the smooth surface will help minimize crazing tendencies.
6. Minimization of chipping because smooth finish patches are difficult to perform in terms of texture and color match.

**Sand or Abrasive Blasting**

Materials used in the blasting operations are washed silica sand, certain hard angular sands, aluminum carbide, blasting grit such as power plant boiler slag, carbonized hydrocarbon, crushed chat (a waste material from lead mining), and various organic grits such as ground shells and corncobs.

For cleaning or light blasting of a surface, any of the abrasives will be adequate. For deep cutting, an abrasive grit should be used because of its speed of attack and cleaner surface appearance produced.

Some types of colored abrasives impart color to the surface of the concrete. With certain gradation combinations, pressure, and volume, impregnation of the abrasive in the surface can occur. If this happens, an abrasive of similar color to the matrix should be used. This can be minimized by a change in the volume of material, its gradation, and the pressure being applied.

Sandblasting may be done with dry abrasive in a stream of compressed air or water rings may be used to introduce water into the compressed air-sand stream at the nozzle. Sand also may be introduced into a high-pressure water washer.
APPENDIX L  Collection of Ideas on the Production of GFRC

The compressor characteristics will influence both the speed and quality of the work. Rotary or screw-type units deliver constant pressure, but piston units cause air flow to fluctuate and make it difficult for the nozzleman to produce a uniform surface. The longer the hose, the higher the pressure needed at the pot to overcome pressure losses in the line. In light blast finishes, 70 to 80 psi (0.48 to 0.55 MPa) pressure at the nozzle is usually sufficient. Heavy blast textures require up to 120 psi (0.83 MPa). The compressor should have a capacity of at least 200 ft³ (5.7 m³) per min.

The inside diameter of the hose should be no less than 1¼ in. (32 mm) or four to six times the diameter of the nozzle orifice in order to keep the sand in continuous suspension while traveling through the hoses.

The nozzle at the end of the system is the most important element. A venturi-type nozzle should be used to obtain a uniform blast pattern. Carbide or norbide nozzles should be selected for durability. Small and lightly blasted jobs require a minimum ⅛ in. (10 mm) orifice, while a ⅛ in. (19 mm) orifice can give considerably more production on a larger surface. Nozzle life depends on abrasive hardness and volume as well as pressure and generally varies from two to four months.

The sand pot should be of 300 to 500 lb (136 to 227 kg) capacity with properly functioning moisture separator and abrasive flow controls. The hose and pot internal tubing should be properly sized and balanced.

The time when sandblasting should take place is determined by scheduling, economics, visual appearance, and hardness of the aggregate. The timing of blasting is not as critical as for other finish methods. The face-mix matrix will be easier to cut in the first 72 hours after spray-up. As the face mix cures and gains strength, it becomes more difficult to blast to any appreciable depth, thus increasing the cost of the operation. Softer aggregates tend to abrade more when face-mix strengths are high and the surface will have a duller appearance. In some cases, the higher costs of deferred blasting may be justified by avoiding schedule problems. However, all surfaces should be blasted at approximately the same age or compressive strength for uniformity of appearance.

When blasting, the operator should hold the nozzle perpendicular to the surface being blasted. Some operators will deviate slightly from this position, as it seems to provide a better view of the work. The maximum deviation should be less than 15 degrees, as too much deviation from the 90-degree angle will result in undercutting of the course-aggregate particles. Best results are obtained with the nozzle positioned about 2 to 6 ft (0.6 to 1.8 m) from the element surface. The exact distance depends on the pressure used, the hardness of the face-mix matrix, and the cutting ability of the abrasive. An experienced operator can quickly determine the nozzle position to produce the specified surface finish.

When using wet sandblasting, the abraded mortar should be continually washed from previously sandblasted areas to prevent staining.

Retarded

Retarders are usually fast-drying, clear liquids with a dye added to facilitate even application. Dyes are also used for color coding to indicate retarders of varying strengths (degrees of penetration). Retarders possess various degrees of resistance to abrasion. This is important to prevent movement of the retarder when the face mix is sprayed into the mold. Retarders are formulated so that the retarded matrix either remains on the GFRC unit or stays on the mold. The choice depends on the particular operation under consideration.

The presence of an accelerator in a face mix or the heating of GFRC to accelerate strength gain will affect the depth of etch of the retarder. This can be compensated for by using a surface retarder with a concentration such that it would normally produce an etch deeper than that desired, or by using a specially formulated, heat-resistant retarder that has been thoroughly tested.

Unless desired, care also should be taken to avoid any one part of the mold inadvertently receiving a double coat of retarder, since this may give deeper retardation on light etches. Over- or under-retarded areas will stand out prominently, especially on large surfaces. There is often a tendency to coat excessively around details in an attempt to obtain complete coverage. This practice can result in a local weakening of the final detail, with the possibility that parts of the casting may become dislodged at the time of demolding. Corners and bottoms of any grooves require removal of any excess retarder that may have collected. A retarder applied only to a part of a mold face may not be successful because of the ragged effect produced at the edge of the treated area unless a demarcation feature is used. Sharp, crisp corners are achieved by putting a wax fillet over the retarder after it is sprayed or applied to the mold corner. This reduces the risk of the over-retarding effect on the corners.

Face mixes for exposed-aggregate panels are achievable on most sloped and/or sculptured configurations unless the slope becomes excessive. The degree of success on steeper slopes will depend on the mix design, steepness of slope, and placement and vibration techniques. When vertical returns are more than a few inches high, it is difficult to keep the face mix from sliding down. One method is to thicken the face mix near the bottom of the return. A more successful method is to cast the returns separately and match-cast them to the panel the following day, with attachment via flex anchors from return skin to panel skin.
Placement for exposed-aggregate mixes can be by hand, as with conventional concrete, or by spraying aggregate with a maximum size of 3/8 in. (10 mm). The density of rock obtained by spraying will typically not be as great as with hand placement methods. Spray methods will, however, have better success on steeper slopes because the mix is more cement rich and thus stickier. However, sprayed-up mixes have less aggregate to expose and exhibit a less dense finish when compared to conventional concrete mixes.

Vibration techniques for the face mix will depend on the type of panel. With large flat panels, external air vibrators, hand-held air vibrators, hand-held or vibrating jitterbug, hand tamping, or the drop-table process can be used. On sloped surfaces, hand methods are usually employed after the flat surfaces are complete.

It is advisable to vary the color or tone of the matrix wherever possible to match or blend in with the color of the aggregate. This match can be achieved by careful selection of cement and sand colors, and the use of coloring agents. A good matrix-to-aggregate match will prevent “patchy” effects (minor segregation of aggregate) from being noticeable.

Aggregates should be round or aggregate fracture should be conical and not slivered. Slivered coarse aggregate will tend to be dislodged during high-pressure washing and may not give a consistent appearance.

The retarded surface may be exposed by removing the matrix material by water blasting aided by use of brushes, or sandblasting.

After the aggregate is properly exposed and the panel is well cured, the exposed faces of the GFRC units and all edges where sealant material is to be applied may be given one or more washings with a 5% to 10% solution of muriatic acid to thoroughly clean the exposed aggregate and to remove any retarded cement paste and foreign material. See Article 2.8.6 for a further discussion on acid cleaning.

Formliners

Wood liners, either as boards, plywood panels, or nailed-on inserts, work well. Wood liner surfaces should be sealed to minimize surface discoloration of face mix caused by differential absorption of mix water by the liner. Then the liner should be lightly coated with form oil prior to placing facing mix. Sandblasted wood, textured plywood, and rough-sawn lumber are useful in creating rugged textures. Rough-sawn lumber is often used for board-surface-textured finishes where face-mix color variations are acceptable. Absorption can be minimized by coating the lumber with a wood sealer. To prevent bowing of the boards, all sides can be coated with wood sealer by painting or immersing. Even with a sealer, some types of lumber may absorb moisture from the face mix. In other cases, natural sugars found in the lumber, such as pine, may penetrate the sealer coating when the face mix is placed against the form, retard the set of the cement at the surface, and cause a dusty, dark, blotchy effect. Fir is the preferred choice for board-surface finishes due to its low sugar content.

An effective method of sealing wood to eliminate any moisture transfer is to spray a few light coats of surface resin onto the wood. Care must be taken not to apply the sealer too thickly or the wood-grain pattern will be lost. For molds with long casting duration, this process may need to be repeated every 7 to 14 days as required.

The weathering of the lumber can also affect the outcome of the face-mix finish. If rough-sawn lumber is being used, it is important to produce samples to determine the effect the lumber will produce. The lumber selected should be purchased at one time from one source to minimize the possibility of variations. Moisture leakage between pieces of lumber should be prevented or a dark line will result from the change in water–cement ratio. The joints may be sealed by using tongue-and-groove lumber. Closed-cell gasket material should be used at edges of mold to prevent leakage.

Metal liners are available in various textures that can be combined with different types of fasteners to achieve an architectural effect. Liner joints should be at rustication strips or mold edges since leakage is difficult to prevent at butt joints. An investigation should be made to determine whether staining may occur from the liner material or its fastenings.

Elastomeric material should have a Shore A-2 hardness of 50 to 60 and a minimum ultimate tensile strength of 600 psi (4.14 MPa). Elastomeric and rubber liners display gasketing characteristics and therefore achieve weep-free seamless joints. They also eliminate the need to cover the small slits cut in the liner for the fasteners. Elastomeric formliners may ripple unless there is a good bond to the base form. It may be desirable to have the product delivered with a plywood backing already attached. Edges of liners should be sealed to each other or to divider strips to prevent bleeding of slurry. The sealant used should be non-staining to the surface. Because of the difficulty in matching joints between formliners, this technique should be limited to widths less than the available width of the formliner, or joints should be detailed as an architectural feature in the form of a groove, recess, or rib.

Rubber/neoprene liners are useful for detailed textured surfaces and will greatly facilitate stripping, whereas other materials for such details would be virtually impossible to strip. The rubber/neoprene should be checked for resistance to deterioration by oils.
commonly used as parting agents and rigidity sufficient to resist wrinkling. The rubber/neoprene should also be checked for the possibility of staining or discoloring the face mix. Trials should also be made to determine the best time for stripping so the surface remains intact and the formliners can be reused.

Plastics can be obtained in sheet form with smooth or textured surfaces. These may be thermoformed or extruded ABS plastic, fiberglass-reinforced plastic, or polyvinyl chloride formliners. Sheet plastics may need appropriate backup to resist movement, particularly for wide portions of liners with deep indentations.

Foamed plastics create deeply revealed designs or blockouts. The preformed foam planks are easily cut to size, easily attached to the form, and are inexpensive enough not to require salvaging. It is necessary to use a low-solvent contact glue that should dry before contact with foam plastic is made, or the solvent will dissolve the plastic. Foam plastic is also used in backing for thick, vacuum-formed, plastic formliners where spray-up operation or application of a panel frame would cause deformation of otherwise-unsupported recess forms.

Combination finishes involving the use of more than one basic finishing method are almost infinite. One common example is the ribbed formliner and sandblasted finish.

Formliners can also be used as an aid for positioning of various veneer finishes.

GFRC can be used as a formliner material in some applications.

**Acid Etched**

Normally, a given amount of acid will react with a certain amount of cement no matter how much water is used to dilute it. A lot of water will reduce the reaction speed, although a small dilution might increase it slightly. The acid should be agitated and/or treated to improve its effectiveness. Application of acid without vigorous brushing is relatively ineffective due to the formation of a silica gel that prevents further etching regardless of the amount of acid applied. This gel, a residue of acid-and-cement reaction, usually forms within 30 minutes. It can be readily removed by brushing during the reaction, but if allowed to remain in place, it may clog some of the pores and be very difficult to remove. The rate of reaction will approximately double for each 20 °F (11 °C) increase in temperature. High temperature, however, causes hydrogen chloride to escape from solution more quickly, producing two undesirable effects: (1) loss of some of the acid that would otherwise be put to work and (2) contamination of the atmosphere. If adequate ventilation is available and if time is more important than material, these may not be serious objections.

Neutralizers are sometimes specified for use after application of acid to GFRC. They are not needed, as the GFRC matrix neutralizes the acid as effectively as any neutralizer, and thorough washing should be adequate. Disposal and neutralization of used acid should be carefully done to protect the environment and mechanical and electrical equipment. Soda ash can be used as a neutralizer.

The best results with acid etching of surfaces are obtained using low concentrations of solution after a two-week curing period, but often acid etching is done immediately after stripping to reduce handling operations. The surface should have at least three or four days of curing. Acid washing too soon contributes to formation of white silica gel deposits on units with a gray cement matrix or with dark-colored aggregates.

With the increasing concern for environmental considerations, the handling and disposal of acid can result in increased costs. Some states require complete containment of the acid residue runoff even though the parts per million is low enough to be insignificant. Most plants are required to provide enough dilution to bring the concentration to safe levels. This normally happens automatically because of the required prewetting water and rinsing water required to process the panel. It has also become increasingly difficult to perform any work requiring acid at jobsites due to potential liabilities.

There is a minimum depth of etch that is required to obtain a uniform panel surface. To attempt to go any lighter than this will result in a blotchy panel finish. This depth will expose sand and only the very tip of the coarse aggregate. It is difficult to achieve a totally uniform very light exposure on a panel that is highly sculptured. This is due to the acid spray being deflected to other areas of the panel, particularly at inside corners. This may be acceptable if the sculpturing creates differential shadowing.

If the face mix contains a polymer, the acid-etching time can increase by a factor of 3 to 8 depending on the depth of etch. For this reason, it is advisable not to include polymers in a face mix to be acid etched.
APPENDIX L          Collection of Ideas on the Production of GFRC

Veneer Facing Materials

Nominal thickness of the stone veneer will vary depending on the types of material being used—for example, granite, marble, limestone, or travertine. The range that is recommended for GFRC varies from \( \frac{7}{8} \) in. to \( 1 \frac{1}{4} \) in. (22 to 32 mm). Variation in thickness is not a problem except at the edge where a step in thickness occurs that may serve to lock the piece in. This can be alleviated by a piece of Styrofoam held in place at the step to allow movement. At corner butt joints, the finished edges should be within \( \pm \frac{1}{16} \) in. (\( \pm 2 \) mm) of specified thickness. Tolerance for overlength and overwidth should be \( +0 \) in. to \( -\frac{1}{6} \) in. (\( +0 \) to \( -3 \) mm), and should be \( \pm \frac{1}{16} \) in. (\( \pm 2 \) mm) for difference in diagonal measurements for out of square. Flatness tolerances for finished surface depend on the type of finish. For example, the granite-industry flatness tolerances vary from \( \frac{1}{64} \) in. (1 mm) for a polished surface to \( \frac{1}{16} \) in. (5 mm) for a flame (thermal) finish when measured with a 4 ft (1.2 m) straightedge.

There are several different style of stone-veneer anchors available. Three examples are shown in Figure L.2. The anchors are Type 302 or 304 stainless steel with a diameter of \( \frac{1}{8} \) in. (3 mm) or \( \frac{3}{16} \) in. (5 mm). They are commonly the same as those used in veneer-faced precast concrete, but may be modified to account for the thin section of GFRC. The spacing and quantity of anchors are dependent on many factors, including:

1. Flexural strength of the stone
2. Thickness of the stone
3. Strength of the GFRC composite
4. Strength of the anchor assembly

Figure L.2 Stone anchor details
**APPENDIX L  Collection of Ideas on the Production of GFRC**

The method of attaching facing materials such as natural stone veneer or other veneer products to GFRC panels should be thoroughly investigated because the differential volume-change characteristics of these materials compared to the GFRC backing may be significant. Tests for bowing, warping, and delamination should be conducted. The entire system should be tested and proven, both with respect to the suitability of the material and to the effect of its interrelationship with the GFRC backing. Differential moisture and/or thermal movements of facing mixes or veneers could subject the GFRC backing to stresses it may not tolerate in the aged condition.

A rule of thumb for anchor placement is a maximum spacing of 24 in. (0.61 m) on center or one anchor for every 4 ft² (0.37 m²) of stone veneer, with a minimum of two anchors per stone. However, placement can vary based on the results of the tests performed on the stone-and-anchor assembly. The minimum ratio of test load to service load should be five to one.

The GFRC and the stone veneer should be allowed to move independently from one another due to differential shrinkage. Spring clip anchors should be designed to flex. The designed flexibility on the anchor shown in Figure L.2(a) is the ability of the clip to move within a 1/16 in. (2 mm) oversize hole in the stone veneer. The designed flexibility in the anchor is shown in Figure L.2(b) is the addition of a rubber sleeve added to the spring clip. The clip is allowed to flex within the rubber sleeve space. An applied bondbreaker to the backside of the stone veneer and the flexibility of the spring clip anchor allow for adequate differential movement.

Holes are drilled in the stone veneer on a given angle from the horizontal and are preferably 3/4 in. to 1 1/4 in. (19 to 32 mm) deep but no closer than 1/4 in. (6 mm) from the face of the stone. The connectors should be oriented horizontally on vertical walls. Hole depths should be monitored to ensure adequate penetration. In some climates, epoxy is placed in the hole around the anchor to eliminate moisture condensation and consequent freeze-thaw degradation of the anchor hole. When using epoxy, the stone temperature should be high enough to allow epoxy to cure. If too cold, it will act as a negative heat sink, keeping the epoxy from curing.

Cracking in the veneer may occur if the bonding or anchoring details force the veneer pieces to follow the bowing. Furthermore, cracking can occur in the GFRC skin if the veneer provides restraint of bowing. This is particularly critical where the face materials are large (cut stone). The introduction of skin joints in the GFRC and/or the limitation of the size of the stone pieces may be necessary to provide a properly functioning system. Attention to detail during design and fabrication is critical to ensure that differential shrinkage is accounted for. Problems can occur if the characteristics of the veneer-GFRC backing system are not examined.

**Repairs**

Trial mixes are essential to determine exact quantities for the repair mix. This is best determined by applying trial repairs to the project mock-up or small sample panels. Selecting the appropriate mix should begin after the trial repairs have been allowed to cure a minimum of 7 days (preferably 14 days), followed by normal drying to 28 days. This is important because curing and ultraviolet bleaching of the cement skin have an effect on finished color.

GFRC bonding pads should be inspected for damage as well as for overall quality. Bonding pad damage can take on several different forms and is sometimes difficult to detect. Each bonding pad should be examined closely, since cracks cannot always be easily seen. Usually cracks are found in the interface between the bonding pad and the GFRC skin. However, there are several factors that could cause other failure modes to occur, as indicated in Figure C4.2.6(b). Panels with cracked bonding pads should be rejected until the pads have been repaired using approved and tested methods.

When minor delamination of a bonding pad is experienced, the crack can be epoxy injected to restore structural integrity of the pad. When a flex anchor has pulled through the pad or if a pad is totally delaminated, a bonding agent can be applied over the cured GFRC and fresh GFRC placed over the anchor to create a new bonding pad. These procedures should be tested and verified prior to use.

Panels that were found to have defects during the initial inspection must be rechecked to ensure that defects have been properly repaired. A simple recording system can help to verify that all original defects are repaired before the panels leave the yard. Compact yard storage may obscure panel markings that are usually on the inside surface of the panel. Therefore, during the initial inspection, all panels should receive an extra marking on the steel frame by the quality control inspector to aid in later identification.

When minor damage occurs to veneer stone, epoxy, stone dust, and a coloring agent, if necessary, can be used to repair small chips or spalls. These repairs can be finished to the same surface texture as the stone facing. If it is necessary to replace a stone
Face Mix Proportioning

One rule of thumb for compatibility is that if the backing has a 1:1 cementitious–sand ratio, the face mix can have a cementitious–aggregate ratio from 1:1 to 1:2.5, with coarser mixes at the leaner end of the range.

There has been some work that indicates that if the cementitious–aggregate ratio of the face mix is no less than half (as rich as) that of the backing, satisfactory performance may be anticipated. By this theory, if the cementitious–sand ratio of backing is 1:0.8 (= 1.25); the cementitious–(total) aggregate ratio of the face mix should be no less than 1:1.6 (= 0.625). There has been a limited amount of work done on this “ratio of ratios,” and it should not be expected to take the place of the more rigorous procedures discussed in Recommended Practice. It could, however, provide a good starting point.

High face-mix temperatures may cause flash-setting of the face mix or cause difficulty with pumping and spraying operations of the face mix. One common method of lowering the face-mix temperature is through the use of ice or ice water in the mix. However, the use of ice water may not be adequate to significantly reduce the temperature of the face mix during extremely long hot-climate cycles. Water is usually only about 15% of the volume of materials used in the face mix. Lowering the temperature of the sand, which is 45% of the mix volume, and/or the cement, which is 40% of the mix volume, will have more impact on the temperature of the mix. One method is to store bagged sand and cement in a refrigerated storage room, keeping the materials at 42 °F (5 °C). Pallets of sand and cement can be loaded into the storage room at the end of each day for overnight cooling of the next day’s production requirements. The best room should be large enough to hold several days’ production products.

Batching

The order in which the ingredients are added to a high-shear mixer is important.

1. Add mixing water (ice or cold water in hot weather), polymer, and liquid admixtures to the mixer. Start mixer.
2. Add cement and sand. Dry powder admixtures should be mixed with the dry sand prior to addition into the mixer. Mix for 1½ to 2 minutes and stop the mixer. Metakaolin should be added to the batch along with the cement or added after all other ingredients. Care should be taken when adding metakaolin after all other ingredients to ensure that the mixer is not overloaded.
3. A false set may occur. When this occurs, the mix should set for 1 to 3 minutes and then the mixer should be restarted for 30 additional seconds.

Placing and Consolidating

In general, mold oils used for GFRC are lacquer or emulsified stearates with a paraffinic or naphthoic crude base. Of the oils, the paraffinic type is preferred; it tends to be lighter in color although heavier in body. One nonproprietary material for experimentation is a 50-50 mixture of stearic acid and benzene or kerosene.

For steel molds, release agents should contain a rust inhibitor. Rough surfaces on steel molds may be conditioned against sticking by rubbing on a liquid solution of paraffin in kerosene, or the molds may be cleaned and oiled with a nondrying oil, and exposed to sunlight for a day or two.

To reduce color changes, a suitable release agent should be applied for the first and all subsequent uses of glass fiber reinforced plastic molds or plastic mold liners. An oil-phased emulsion or high-quality household wax are preferable. Unsaturated oils, ketones, esters, acids, toluol, toluenes, xylene, or halogenated solvents should be checked for compatibility with the plastic materials.

Concrete and GFRC molds will require a release agent. Light-colored petroleum oils or oil emulsions have been used successfully. The concrete surfaces may be coated with one or two coats of epoxy resin and then waxed. A saponifiable oil should not be used as a release agent.

Rubber liners generally require release agents. They may be coated with a thin film of castor oil, vegetable oil, lanolin, or water-emulsion wax. Mineral oil, oil solvent–based release agents, or paraffin wax should not be used as these will soften the rubber. The rubber supplier’s recommendation should be carefully followed.

Plastic foam molds are generally lightly sprayed with castor oil, petroleum jelly thinned with kerosene, or paraffin oil.
Sprayable face mixes should be applied in uniform layers. Flow rate and air pressure should be adjusted to provide an even rate of application. Proper uniform consolidation of the face mix will provide the best finish quality. Face mixes should generally be compacted carefully to remove excess air, especially on vertical shaped molds. All corners, recesses, and reveals should be compacted with special trowels and tools made for each condition to ensure that all areas of the face mix have been compacted. Care should be taken to prevent the trowel edge from touching the mold surface. This will cause blemishes in the finished surface. Mold vibration or the use of vibrating trowels are successful on the flat panels. This sometimes requires a two-step face-mix application on profile molds.

Comparing the water–cement ratio, compressive strength, drying shrinkage, and absorption values of facing and backing mixes is a good method to evaluate the compatibility between the mixes. The most compatible mixes will have very similar values. The question always is, “How close do the values have to be to be considered compatible?” The answer has to be gained from historical experience of successful and problem projects and application of some relative values. Drying-shrinkage test result comparisons are the most helpful. The percent of drying shrinkage for a typical GFRC backing mix could be approximately 0.100. Sand face mixes usually range from 0.095% to 0.110% and are known to be compatible with GFRC backing mixes and produce acceptable finishes. Currently, PCI recommends 3/8 in. (6 mm) as a maximum aggregate size for a face mix. Face mixes with 3/8 in. (10 mm) or larger aggregate will have much less drying shrinkage in the range of 0.050% to 0.080% and are considered noncompatible with a GFRC backing mix. The large difference in values using 3/8 in. (10 mm) and larger–aggregate face mixes have created bowing. Stresses between the outer and inner skin surface have been known to produce cracking on projects. These facts tend to set the lower and upper levels. Compatibility can also be visually evaluated through sample testing. The use of 2 ft × 10 ft (0.6 m × 3 m) test samples is a valuable visual confirmation of mix compatibility. The test board should have the face mix applied followed by the GFRC backing mix. No frame or ribs should be used that might restrain bowing. After one day of curing, the sample should be set on edge in an unrestrained fixture. The bowing is then visually measured at the center during a 28-day curing cycle. Compatible sand face mixes can be expected to bow between 3/4 in. (6 mm) and 3/8 in. (20 mm) after 28 days. Mixes with 3/8 in. (10 mm) aggregate are noncompatible and known to bow up to 1/2 in. (38 mm). The area between 3/8 in. (20 mm) and 1/2 in. (38 mm) bowing would be considered a zone for evaluation. Good practice would be to use face mixes that produce less than 1 in. (25 mm) bowing, although others with slightly higher bowing may produce acceptable results.

Spraying GFRC Backing
The sequence of spraying molds is important for a quality product and for ease of manufacturing. Perimeter vertical details and returns of flat panels should be sprayed first. Molds with high details in the center and flat perimeters should have the lower perimeter areas sprayed first.

It is important to pump the slurry at a flow rate that enables the spray operator to control the laydown of the composite flow rates of 15 to 50 lb (6.8 to 22.7 kg) of slurry per minute, depending on the number of strands that are typical. If the flow rate is too high, it will make it difficult to control thickness. Also, material will build up too quickly, particularly in corners and on reveals, which will reduce the effectiveness of rolling out. This could cause air pockets and/or dry glass fibers to be entrained, which could result in the panel face spalling or penetration of water through the panel.

Fibers that fall out of the spray pattern and collect in corners should be removed before these areas are sprayed; otherwise, these dry fibers will cause voids and weak sections.

Overspray should be cleaned off the mold before the cement sets. Edges should be trimmed with a knife and troweled level and smooth. Edges can also be turned back into the panel and rolled and troweled. This technique gives a good edge finish. Performing the trim and trowel operations on a unit before the cement sets minimizes mold cleaning and setup for the next unit. The finish of the back of the component depends upon customer specification. A roller finish may be all that is required. Trowel finishing should be done just as the cement sets to allow a smooth surface. Shaped trowels and rollers that fit contours of the mold are useful and can help speed up finishing.

The ideal composite is achieved when uniform mixing of the fiber and mortar occurs before depositing it on the surface, thus ensuring that no discrete lines of dry fiber or mortar are visible. Poor fiber wet-out reduces the area of the fibers available to the matrix for bonding and contributes to the formation of voids that reduce composite density. If fibers are not being wetted then the inclusion angle may require adjustment and the spray pattern may again require examination as before. The mortar pattern may also need alteration by either relocating the air nozzle (as is possible on some mortar spray heads) or by adjusting the air pressure to the mortar spray head.
The fiber may bounce out of the mortar spray pattern and this can be remedied by either lowering the air pressure to the mortar spray head, or increasing the air pressure to the chopper air mover. The inclusion angle should not require changing once an optimum setting has been found, and trimming air-pressure settings should enable the spray pattern to be finalized.

Distance and spraying at 90 degrees to mold face is not as critical with concentric spray guns compared with dual-head spray guns, but it is still important that spraying is smooth and even to obtain uniform buildup of the composite. A criss-cross spray pattern aids in obtaining uniform buildup of the composite (Fig. L.3). Typical distances of the spray gun to the mold surface are 12 to 48 in. (305 to 1220 mm) depending on the spray rate and the type of spray gun. The spray head is normally moved in straight lines, maintaining the correct distance and orientation. Spraying in an arc swinging from a fixed spray position results in poor glass fiber distribution and variable thickness (produces poor quality and gives excessive overspray). Spraying in strong air currents should be avoided to allow uniform material deposit in the mold.

The orientation of reinforcing fibers affects performance. Most GFRC spray-up composites have a two-dimensional random fiber orientation, but if care is not taken during production, fibers can be parallel oriented and the composite material will exhibit different properties when tested along different axes. A criss-cross spray pattern, as shown in Figure L.3, can be used to minimize the parallel orientation of the fiber.

The spray pump, mixer, and roving box should be positioned so that the operator has a minimum of discomfort in performing the spray-up process. This means that the slurry hose is either held by a boom or arranged so as to avoid continuous movement when traversing the mold with the spray head. The air hoses should be taped to the slurry hose to minimize discomfort. They should also be color coded to allow quick reassembly after maintenance during manufacture.

The fiber roving must be supported in such a manner as to facilitate “take-up” by the chopper gun and prevent contamination by overspray or dust en route. Similarly, the roving box requires storage in a suitable area away from moisture, overspray, and impact damage.

In order that the wound package forming the roving can be efficiently fed to the chopper head, a suitable path free from potential snags and abrasive surfaces has to be established. This has evolved to resemble the fishing-rod method of supporting a line—as a series of spaced eyes through which the line or roving is made to pass.

The vertical height between the roving bundle and the first support eye should be approximately 6 in. (150 mm). This enables the heavily coiled roving to open out easily on take-up and prevents snagging at the eye. The horizontal displacement of the guide eyes should be such as to avoid excessive over-run when the chopper drive is turned off. This over-run is also a function of the length of the drop from the last guide eye to the chopper head, and the distance of the horizontal run of eyes above the roving.

Scrim may be used to reinforce areas subjected to high stress loadings. For example, scrim may be used around large window openings, around door openings, in the area of gravity anchors where only two anchors are used in a panel, around transitions and shapes such as deep reveal lines, around window-washer tracks, and in any other area subjected to high localized stresses.

The scrim is usually placed in an area that is close to the outside face of the panel. For example, it is used on the back of a face mix to distribute localized stress and then the GFRC backing is sprayed directly on top. Also, scrim may be added to the rear surface of the GFRC backing by placing it between the second and third spray pass.
APPENDIX L  Collection of Ideas on the Production of GFRC

One of the major problems of a dual-head spray assembly is ensuring adequate fiber incorporation at the extremities of the unit being produced. There is a chopper gun (fiber) or spray head (slurry) lead depending on the direction of the spray head and this means overspray of either to ensure good distribution. The concentric gun eliminates this problem and reduces waste.

The following is a short summary of common problems and their solutions encountered in equipment used in the production of GFRC. It is also a guide for setting up a machine for initial use. Any equipment adjustments may cause a change in composite fiber content and necessitate re-running of bag and bucket tests. The first section contains short explanations of the different air supplies. The second section, pages L-17-18, is a table of problems, their causes, and corresponding potential solutions.

**Slurry Air:** The air supply atomizes the slurry at the nozzle of the gun. The line contains a pressure-drop-activated switch. This switch activates the pump and other spray unit controls. Desired changes in pressure setting must be accompanied by adjustment of the pressure-drop switch in order to maintain remote control of the spray unit. The pressures normally used are 45 to 65 psi (0.31 to 0.45 MPa) for the dual-head spray gun and 50 to 80 psi (0.35 to 0.55 MPa) for the concentric spray gun. Finer spray patterns can be achieved with higher pressure, but the pressure-drop switch will have to be changed for one with a higher upper limit. Adjustments can be made while spraying; however, due to the possible loss of remote control, the pump may have to be cut off manually.

**Chopper Air:** This air supply drives the air motor in the glass chopper. Regulating this air pressure gives control of the speed of the chopper. The concentric gun chopper comes with a 3000 RPM air motor. If greater output is needed, two strands of glass may be used or a higher RPM motor such as a 6000 RPM motor may be substituted.

**Air Mover:** It serves two functions: (1) to suck the fiber out of the chopper and (2) to widen the spray pattern. Normally, a pressure of 25 to 40 psi (0.17 to 0.28 MPa) is used. Care should be used in observing the spray due to the fact that excessive air pressure will propel the fibers in a stream directly in the center of the cement spray. Adjustments can be made while spraying.

A critical requirement for consistent spraying is a reliable supply of air. The air consumption of a spray unit is about 90 cfm (2.5 m³/min.). Allowances for other air equipment should be considered when choosing a compressor, as insufficient pressure could also cause the pump to activate when it is not supposed to, causing a hazardous situation. The spray unit should be turned off at the electrical disconnect at the end of the day. To be certain, the air supply line should be disconnected as well.

A common cause of stoppage in production is blockage of the pump or spray nozzle due to inadequate cleaning. Clean equipment is essential for the consistent production of good quality GFRC. Cleaning should be carried out at the end of the working day and when there is a long stoppage in production.

Mixing drums should be thoroughly scrubbed with a stiff-bristle brush to remove all traces of the slurry mix. No particles should be left in crevices or corners to harden. Seamless metal or plastic mixing drums are helpful. Hardened cement should be removed by chipping or application of an inhibited acid–type cleaner. All traces of the slurry should also be removed from the impeller by chipping or application of an inhibited acid–type cleaner. All traces of the slurry mix. No particles should be left in crevices or corners to harden. Seamless metal or plastic mixing drums are helpful. Hardened cement should be removed by chipping or application of an inhibited acid–type cleaner. All traces of the slurry should also be removed from the impeller.

1. **Hopper and Filter.** Pour clean water into the pump hopper and hose down the hopper sides while running the pump. The screen of the hopper should be cleaned at the same time. If the screen is not cleaned, it will cause the same problems it is designed to eliminate; for example, flakes or lumps of grout entering the delivery pipe and nozzle. The screen should be rinsed every time a mix is put through.

2. **Pump.** Use of a quick-release fitting on the pump foot enables the pump to be easily removed for thorough cleaning. Cleaning of the pump itself is important because particles of slurry can build up in the pump and begin to flake off after a day or so, thus blocking the spray nozzle.

   The flow from the pump to the supply line should not pass through abrupt changes in diameter such as those found at pipe fittings, etc. Dead spots in the flow occur at these points. The immobile slurry then hardens and breaks off, causing a plug in the nozzle.

3. **Hoses.** Hoses can be cleaned by passing a circular sponge of a diameter slightly larger than the hose diameter through the hose while running the pump. The sponge should be introduced at the end of the hose and not through the hopper.

4. **Nozzles.** Plug-ups that occur during operations can sometimes be cleared by removing the hose and blowing out or gently probing through the nozzle with a rod to dislodge the lump. In most cases, however, operation must be stopped and the retaining ring and nozzle removed and cleaned. Washing the nozzle with running water is not sufficient to remove debris. The nozzle should be cleaned with a “bottle” brush and thoroughly dried to reduce corrosion. Care must be taken during cleaning not to allow slurry to clog the air inlets or the annular passages in the head of the gun around the fluid tip. The outer nozzle (cap) ought to be checked at the same time for wear and rejected when this has increased in diameter by approximately 3/64 in. (1 mm) or the hole becomes misshapen.
APPENDIX L  Collection of Ideas on the Production of GFRC

The same procedure should be followed at the end of the day to clean the nozzle. The fluid tip should be removed and cleaned and the slurry passage through the head cleaned. Atomizing air passages through the head should be checked for plugs. Also at this time, the air fittings and the packing on the atomizing air control valve can be checked for air leakage and tightened or replaced.

If the glass output falls when using the same air pressure, then the air motor or the filter to the air motor requires maintenance, or the oil bottle feeding the air motor has run dry. The exhaust ports of the air mover can sometimes be blocked and should be kept clean.

At the end of each day, the chopper cover should be removed and the interior cleaned of fuzz, etc. If the cot is severely worn, or if it cannot be adjusted to just touch the body of the cutter head, it should be replaced. Worn cutter blades should be replaced. Chipped blades should also be replaced and the setting of the blades in the cutter head checked to see that the blades protrude 1.0 to 1.1 mm from the cutter head so that excessive pressure is not occurring between the blade and the cot (backing roller). The backing roller should also be checked for wear, and the pressure that it exerts on the cutting blades requires setting whenever the cutting blades or backing rollers are replaced. Special care should be taken during operations to keep the gun clean from slurry spray, dirt, etc.

When disassembling and cleaning air movers, great care must be taken not to burr or flatten the edge of the orifice. A small disturbance of this edge will cause a major change in the pattern of the fiber stream.

Installation of Panel Frame

When placing the frame, it is important that the GFRC is not damaged. Therefore, care must be taken not to drag the frame on the GFRC. The weight of the frame may cause damage to the unhardened GFRC.

The anchors connected to the GFRC backing are designed to impose minimal restraint to dimensional changes of the GFRC backing/face mix while still maintaining enough vertical and horizontal stiffness to transfer the panel service loads through the skin to the anchors and to the panel frame. The relatively thin skin responds quickly to changes in temperature and moisture. Fluctuations in temperature and moisture result in significant dimensional changes in the GFRC backing/face mix.

Panel skin loads are transferred to the panel frame through various types of flexible anchors. Each type of anchor functions to resist a specific type of panel loading. Panels should have flex anchors to resist wind loads and gravity anchors to support the dead weight (gravity load) of the panel skin. For some small panels, the flex anchors may be used to support the gravity load. Panels may also require seismic anchors to provide horizontal stiffness for earthquake loading. The overall stiffness of an anchor is a function of size, length, and orientation (Fig. L.4(a) and L.4(b)).

Flex anchors typically consist of L-shaped bars that are welded to the panel frame along one leg and connected to the GFRC backing using a GFRC bonding pad formed over the other leg (Fig. L.4(a)). Flex anchors are generally designed to have sufficient axial stiffness to transfer wind load to the frames without buckling. The length of the anchors should be sufficient to allow the anchor to flex and accommodate movement due to dimensional changes in the skin. If flex anchors are not flexible enough to accommodate this in-plane movement, restraint forces will be imposed upon the skin that may result in excessive stresses in the GFRC backing.
<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>CAUSE</th>
<th>SOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slurry not atomizing</td>
<td>1. Slurry air pressure too low</td>
<td>1. Increase slurry air pressure</td>
</tr>
<tr>
<td></td>
<td>2. Debris in nozzle of gun</td>
<td>2. Clean out nozzle</td>
</tr>
<tr>
<td>Glass jams in chopper</td>
<td>1. Air-mover pressure too low</td>
<td>1. Increase air-mover pressure</td>
</tr>
<tr>
<td></td>
<td>2. Fiber tube slots not properly aligned</td>
<td>2. Re-align slots</td>
</tr>
<tr>
<td></td>
<td>3. Broken or worn blades</td>
<td>3. Replace blades</td>
</tr>
<tr>
<td>Layering of glass and slurry</td>
<td>1. Misalignment of chopper and spray head (dual-head gun)</td>
<td>1. Re-aim chopper</td>
</tr>
<tr>
<td></td>
<td>2. Air-mover pressure too high (Concentric gun)</td>
<td>2. Decrease air-mover pressure</td>
</tr>
<tr>
<td>Pump does not cut on or off</td>
<td>1. Pressure drop switch not adjusted properly</td>
<td>1. Adjust switch to proper setting</td>
</tr>
<tr>
<td>properly</td>
<td>2. Pressure drop switch has inadequate range</td>
<td>2. Replace switch with one having proper range</td>
</tr>
<tr>
<td>Plug-up in slurry hose</td>
<td>1. Cement allowed to stand too long in hose</td>
<td>1. Flush out hose*</td>
</tr>
<tr>
<td></td>
<td>2. Sand separated from slurry and packed at constrictions (connection</td>
<td>2. Flush out hose*</td>
</tr>
<tr>
<td></td>
<td>fittings)</td>
<td></td>
</tr>
<tr>
<td>Blocked/intermittent</td>
<td>1. Dirt in nozzle or pump line or pump</td>
<td>1. Check and clean nozzle, then line, then pump</td>
</tr>
<tr>
<td>slurry spray</td>
<td>2. Mix false setting in pump hopper</td>
<td>2. Quickly dump mix</td>
</tr>
<tr>
<td></td>
<td>3. Mix too dry</td>
<td>3. Check water content, check mix design</td>
</tr>
<tr>
<td></td>
<td>4. Mix bridging in hopper</td>
<td>4. Ensure that mix enters pump, check vibrator</td>
</tr>
<tr>
<td>Chopper gun producing long</td>
<td>1. Worn blades</td>
<td>1. Renew blades</td>
</tr>
<tr>
<td>fibers</td>
<td>2. Worn backing roller (cot)</td>
<td>2. Reset/renew (skim flat) backing roller</td>
</tr>
<tr>
<td></td>
<td>3. Resistance generated before fiber fed into chopper gun</td>
<td>3. Check path of roving</td>
</tr>
<tr>
<td>Chopper gun producing short</td>
<td>1. Resistance generated before fiber fed into chopper gun</td>
<td>1. Check path of roving</td>
</tr>
<tr>
<td>fibers of varying lengths</td>
<td>2. Inadequate tension from backing roller spring</td>
<td>2. Adjust spring</td>
</tr>
<tr>
<td>Chopper gun blocking</td>
<td>1. Incorrect gap setting of air mover</td>
<td>1. Reset air mover</td>
</tr>
<tr>
<td></td>
<td>2. Lubricating oil in air-mover line</td>
<td>2. Check that compressed-air connections are</td>
</tr>
<tr>
<td></td>
<td>3. Slurry on roving</td>
<td>3. correct</td>
</tr>
<tr>
<td></td>
<td>4. Backing roller/chopper barrel incorrectly set</td>
<td>4. Keep roving package protected from slurry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4. Realign backing roller/chopper barrel</td>
</tr>
</tbody>
</table>

*CAUTION: When attempting to clear any blockage, always run pump in reverse in order to relieve pressure on hose. Never look directly into nozzle of gun. Always wear safety goggles when clearing a blockage.
<table>
<thead>
<tr>
<th>PROBLEM</th>
<th>CAUSE</th>
<th>SOLUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roving pulling out of chopper</td>
<td>1. Not enough pressure from backing roller retaining spring</td>
<td>1. Tighten spring</td>
</tr>
<tr>
<td></td>
<td>2. Drag from guide eyes</td>
<td>2. Check path of roving from the package to gun; remove rough patches on guide eyes</td>
</tr>
<tr>
<td>Inconsistency in sprayed material</td>
<td>1. Fluctuating output from pump due to restricted air supply</td>
<td>1. Check and clean air filters in line</td>
</tr>
<tr>
<td>Pinholes in surface</td>
<td>1. Poor atomization</td>
<td>1. Check gun type and settings</td>
</tr>
<tr>
<td></td>
<td>2. Inadequate rolling</td>
<td>2. Pay more attention to rolling</td>
</tr>
<tr>
<td></td>
<td>3. Excess release agent</td>
<td>3. Do not use too much release agent</td>
</tr>
<tr>
<td>Dry fiber in surface</td>
<td>1. Slurry too dry</td>
<td>1. Check water content</td>
</tr>
<tr>
<td></td>
<td>2. Inadequate rolling</td>
<td>2. Improve rolling</td>
</tr>
<tr>
<td></td>
<td>3. No mist coat</td>
<td>3. Check mist coat</td>
</tr>
<tr>
<td></td>
<td>4. Excess glass</td>
<td>4. Check glass content</td>
</tr>
<tr>
<td></td>
<td>5. Poor setting</td>
<td>5. Reset spray gun</td>
</tr>
<tr>
<td>Sprayed material dragged from mold surface</td>
<td>1. Dry or old compaction rollers</td>
<td>1. Keep rollers wet and spinning freely or replace</td>
</tr>
<tr>
<td></td>
<td>2. Rollers not spinning freely</td>
<td>2. Lubricate rollers</td>
</tr>
<tr>
<td></td>
<td>3. Excess pickup of material on rollers</td>
<td>3. Check time interval between spraying and rolling</td>
</tr>
<tr>
<td></td>
<td>4. Excess roller pressure</td>
<td>4. Use less pressure</td>
</tr>
<tr>
<td>Low glass output/high air consumption from air motor</td>
<td>1. Worn motor bearings and vanes</td>
<td>1. Replace</td>
</tr>
<tr>
<td></td>
<td>2. Air filter blocked</td>
<td>2. Clean and replace</td>
</tr>
<tr>
<td></td>
<td>3. Exhaust ports dirty</td>
<td>3. Clean</td>
</tr>
<tr>
<td></td>
<td>4. Oil bottle empty</td>
<td>4. Refill</td>
</tr>
<tr>
<td>“Ballooning” of roving input</td>
<td>1. Excessive tension on backing roller spring</td>
<td>1. Adjust</td>
</tr>
<tr>
<td></td>
<td>2. Worn or distorted backing roller</td>
<td>2. Replace</td>
</tr>
<tr>
<td></td>
<td>3. Worn spring</td>
<td>3. Replace</td>
</tr>
<tr>
<td>Variation of glass output</td>
<td>1. Variable air supply</td>
<td>1. Check adjustment</td>
</tr>
<tr>
<td></td>
<td>2. Misalignment of feeder tube affecting spring tension</td>
<td>2. Realign</td>
</tr>
</tbody>
</table>
In larger, heavier panels, if the skin is attached to the panel frame with only flex anchors, the flex anchors may provide excessive restraint and over stress the skin. If the dead load is carried separately by gravity anchors, the flex anchors can be made smaller and substantially reduce the in-plane restraint. Gravity anchors are designed to be stiff in the vertical direction and flexible in the horizontal direction. Gravity anchors provide restraint to vertical dimensional change movements of the skin. Therefore, gravity anchors should all be located along a single horizontal row, preferably near the bottom of the panel such that panel stresses are in compression due to the deadweight of the panel skin. Locating all the gravity anchors along one horizontal row creates a reference line. Vertical dimensional change movements of the skin occur relative to this line, which serves as a zero reference. A gravity anchor usually consists of two L-shaped bars (Figure L.4(b)) or a flat rectangular plate.
Seismic anchors are designed to be stiff in the horizontal direction and flexible in the vertical direction. Seismic anchors are sometimes necessary when earthquake loading must be considered in design and the flex anchors are not stiff enough to prevent significant horizontal displacement of the skin relative to the panel frame. Because seismic anchors will impose restraint to horizontal dimensional change movements of the skin, they should all be located along a single vertical row, preferably near the middle of the panel. Locating the seismic anchors along one vertical row creates a reference line. Horizontal volume-change movements of the skin occur relative to this line, which serves as a zero reference (Figure L.4(b)). A seismic anchor usually consists of an L-shaped circular bar that meets the GFRC skin at an angle with respect to horizontal. A flat rectangular bar may also be used to provide stiffness in the horizontal direction.

The farther an anchor is away from the zero reference, the more flexible that anchor must be to accommodate the dimensional change without inducing excessive restraint to the skin.

Anchors that are not oriented perpendicular to the skin tend to restrain skin movement. With respect to gravity anchors and seismic anchors, the restraint is intentional. However, if more than one zero reference line is created in a given direction due to an improperly oriented flex anchor or significantly bent flex anchor, panel-length changes between multiple reference lines may be great enough to cause the skin to crack. Therefore, it is important for the quality control inspector to identify the zero reference lines for each panel during inspection and verify that there is, in fact, only one reference line for each direction of expected dimensional change (horizontal and vertical).
Figure L.4(c) Flex Anchor Placement Considerations

Early-drying-shrinkage-related length changes start taking place immediately after fabrication and are the first dimensional changes that the panel skin will experience. A significant amount of the length change that occurs as a result of early drying shrinkage is irreversible. That is, the panel skin will not return to its original dimensions even when exposed to a wet environment. Anchors should generally be oriented on the side of the frame member that corresponds to the direction of anticipated length-change movement due to early drying shrinkage. Also, flex anchor feet should be oriented such that toes point toward the zero reference line to allow for early-drying-shrinkage length changes of the skin. This allows the anchors to bend away from the frame in response to length change associated with early drying shrinkage. If panel anchors are oriented appropriately, horizontal dimensional changes in the skin resulting from early drying shrinkage will take place independent of the anchor if slip sleeves are used, or will tend to bend the anchor away from the frame. Since most of this initial displacement is irreversible, the anchors will be “set up” for subsequent dimensional changes in either direction.

It may not always be possible to orient the anchors appropriately with respect to the zero reference. When such situations arise, the anchor can be pre-bent slightly so that the anchor will not bear against the frame member [Figure L.4(c)]. However, bending the anchor should not be allowed after the bonding pad has been applied. Therefore, if an anchor is identified as being mispositioned after application of the bonding pad, the panel should not be approved until the anchor is repaired to provide the necessary function.

Often special anchors are required at returns in order to provide sufficient support for the return without restraining skin dimensional change movements. Returns add a third dimension to the panel skin, which means that the anchors that support the return must accommodate volume-change movements in two different planes.

Application of Bonding Pads

The bonding pad, where the flex anchor is attached to the GFRC backing, is usually manufactured in one of two different ways: (1) the hand pack method and (2) the green sheet overlay process. Both methods require the operator to actually hand apply the bonding pads and knead them into the GFRC backing.

The hand pack method is accomplished by the operator spraying the GFRC composite into a suitable container or premixing the composite. This material is then deposited by hand over the flex anchor contact foot. This bonding pad is worked by hand into the GFRC backing.
For the green sheet overlay process, GFRC is sprayed and rolled onto a flat mold similar to the GFRC backing. As soon as the sheet has been sprayed to the required thickness and compacted, it is then cut into pads. These pads are then placed over the flex anchor contact foot and fully worked into the fresh backing, using care not to reduce the thickness over the anchor foot.

When GFRC backing containing no polymer has become dry, it can be reworked with rubber float trowels. A slight fog mist of water should be applied. GFRC backing containing polymer should be worked with an additional GFRC mix and hard rolling. Bonding pads applied too early on green GFRC may cause disturbance of face mix and result in finish blemishes.

**Repair of Bonding Pads**

Broken bonding pads sometimes need to be repaired in the plant or in the field. In order to repair a broken bonding pad, the surface of the GFRC skin should be roughened, and some glass fibers exposed. This area then should be cleaned of any loose debris. A latex (acrylic copolymer)–portland cement paste or epoxy bonding agent should then be applied to the area and a fresh bonding pad attached to the GFRC skin. As with standard flex anchors, each manufacturer should test the bonding pad repair procedures to establish data for use in design. Due to creep considerations, the aforementioned repair technique is limited to repairing not more than 10% of the total anchors on a panel.

**Integral Ribs**

The incorporation of stiffening ribs by placing shaped blocks of foam or hollow sections and overspraying are ways to support GFRC. However, these areas often show as shadows on the finished face. They affect the mass and rate of curing in the area where applied due to differential moisture content caused by heat flow differences or slower moisture loss. Standing ribs can be formed by spraying against a removable mold.

**Curing**

Controlled moist curing of GFRC is as important as spraying it up properly. Not only does the cure schedule affect strength gain, but improper curing can cause warpage due to variations in moisture content and affect surface appearance (porosity, staining, efflorescence). The thin panel skin allows rapid loss of water from the composite if the units are exposed to dry conditions. Incomplete strength development (lower physical properties) will occur when panels are cured in normal atmospheric conditions. Therefore, moist curing is necessary in order to develop adequate strengths.

A minimum adequate wet cure may be obtained by keeping all surfaces continuously wet to the touch at a temperature above 60 °F (16 °C) for 7 days. This can be accomplished in several ways:

1. A simple fog room built of lumber and polyethylene sheet in which a continuous water mist spray maintains relative humidity at 95% to 100%
2. Covering surfaces with burlap which is kept continuously wet by soaker hoses
3. Storing units under water
4. Wrapping panels in soaked burlap or rags and totally sealing in polyethylene film

GFRC units should be cured as long as possible past the minimum seven days. At no time after spray-up and before the end of the seven-day-minimum wet cure should any portion of the unit be allowed to dry. GFRC panels are usually thin, and are susceptible to rapid drying. Curing materials or methods that allow one portion of a unit to cure or dry out faster than other portions may produce color variations in the finished product and differential shrinkage, which can lead to warping or cracking of the unit.

Water supplies should be checked for staining materials. Water containing iron will cause rust stains. A water-conditioning filter system can be installed where it is judged that the finish to be applied will not sufficiently remove the stain.

**Batching and Mixing Facilities**

Other items to consider when storing alkali-resistant (AR) glass:

1. Open packages should be protected from dust, dirt, and cement splash or spray and be resealed or completely covered with plastic sheets between uses.
2. If the boxes are palletized, warehouse pallet racks should be used to prevent overloading of the lower layers of packages.
3. Packages of AR glass roving should not be stored where there is likelihood of physical damage. Impact damage or crushing will result in problems in feeding roving from the package.
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Collection of Ideas on the Production of GFRC

4. To use AR glass fiber roving, the top of the package should be carefully opened without damaging the roving package. The package is protected with a polyethylene film bag, which should be opened and pulled back over the top. The roving may be gently pulled from the package from inside the cylinder. The end of the roving should be kept knotted when not in use to prevent splitting or raveling.

5. Stacking of the roving package with the axis horizontal can lead to severe crushing of the roving package.

Production Testing – Wet

A good starting level for the fiber chopping rate is an excess of 0.3 to 0.5% of the required fiber content. The fiber roving chopping rate for a 21-lb-per-minute (9.5 kg) slurry flow rate would then be $21 \times 0.054 = 1.134$ lb (0.5 kg) per minute for a required 5% fiber content. The air line pressure to the chopper should be adjusted until the desired chopping rate is achieved. Three measurements of chopping rate should be made and the mean calculated. In the event of a gross variation between measurements (for example, greater than +5% of the mean value) the air line pressure may be varying and the regulator should be checked.

After determining the glass fiber content by the wash-out test, the required level (5% in the above example) should be compared to the actual fiber content. If adjustments are required, the new chopping rate is determined by multiplying the old rate by the ratio between the required level and the measured level.

   Old chopping rate setting: 1.134 lb per minute
   Wash-out test results: 4.3%
   Required fiber content: 5.0%
   New chopping rate: $(1.134) \times 5.0/4.3 = 1.319$ lb per minute

The new settings should be checked by another determination of glass content shortly after resuming spray-up operations.

If the operator set the slurry flow rate up to a high level in order to accelerate the spraying time, the wash-out tests may show fiber contents that are lower than required. Adjustment to the slurry flow rate may be necessary.

Good record keeping will soon allow slurry flow rates and fiber roving chopping rates to be set accurately at the beginning of each day’s operations. Only one measurement of these rates should then be necessary.

If the limits on fiber length are exceeded, the glass fiber length should be adjusted as follows:

   1. Check cutting blades and replace any found to have a less-than-acceptable cutting edge.
   2. Check whether extra resistance is generated before the glass fiber is fed into the chopper gun.
   3. Check the degree of contact of the rubber roller with the blade. (The chopper blade must sink into the rubber roller above $\frac{1}{64}$ in. (0.5 mm) deep.)
This appendix is intended to provide information concerning premix glass fiber reinforced concrete and indicate where it differs from spray-up GFRC, which is the primary material discussed in this manual. Appendix M covers only those sections presented within the body of the manual that require revision to address the differences between premix glass fiber reinforced concrete and spray-up GFRC. For sections not covered, it is intended that the main body of the manual be referred to unless indicated otherwise in this appendix.

For example, Section 4.1.2 means that text is being added to Division 4, Section 1.2. In each section, some of the text immediately prior to where the addition or modification is being made is given to help clarify how the section is being changed.

**General Description**

Premix glass fiber reinforced concrete is the term applied to a cement/sand slurry and chopped strands of alkali-resistant glass fiber mixed together before transport to the mold. The slurry is cast usually with vibration into a mold, similarly to precast concrete products, or may be sprayed. Typically, premix products contain less than 4% AR glass fiber by weight of the total mix.

Premix is used in products where strength is not the prime requirement. Premix is not recommended for the type of thin-wall architectural panels covered by the main body of the manual. It is used for smaller, highly sculptured architectural units and mass-produced standard products.

As a general rule, premix with the same fiber content and fiber length will have lower strengths than spray-up GFRC. Reasons for this are:

1. Premixing may entrap more air, thereby reducing the density of the composite. Strengths of premix are density sensitive.
2. The mixing action may cause filamentizing and reduce tensile strength of strand.
3. The spray-up process lays the fibers down with almost perfect random planar orientation or two-dimensional orientation, whereas premix will have a three-dimensional orientation. This reduces the effective fiber content in the plane of the composite, thereby reducing the inherent strength of those planar-related strengths such as flexural and tensile strength.

**2.2 Production and Curing Facilities**

These are the same as discussed in the manual, except for the following:

1. Equipment for mixing the cement/sand slurry at high speed and the ability to blend the chopped strands on a slower speed setting to avoid fiber damage. Alternatively, proprietary mixers designed specifically for premix can be used.
2. Means of vibrating the cast item at frequencies from 3000 to 9000 vibrations per minute with a high amplitude or correct equipment to spray the fibrous premix into a mold.

**2.4 Molds**

Molds for premix manufacture are essentially the same as for spray-up GFRC manufacture. The principal difference is that premix allows the use not only of open molds but also back-formed (inner core) molds, similar to precast concrete molds, which cannot be used in spray-up.

**2.7.1 Stripping**

In the case of a mold with a back form, it is useful to remove the core as soon as possible after casting. This prevents the premix from shrinking onto the core and making demolding difficult.

If a product is overstressed on demolding, it may crack at a later date.
APPENDIX M  

4.1.2 Batching and Mixing

When the components are batched by weight, the following tolerances should be followed:

1. Cement and other cementitious materials:
   \[ \pm 1\% \text{ of the required weight of material being weighed, or } \pm 0.3\% \text{ of scale capacity, whichever is greater.} \]
2. Aggregates:
   \[ \pm 2\% \text{ of the required weight of material being weighed, or } \pm 0.3\% \text{ of scale capacity, whichever is greater.} \]
3. Water:
   \[ \pm 1\% \text{ of the required weight of material being weighed, or } \pm 0.3\% \text{ of scale capacity, whichever is greater.} \]
4. Admixtures:
   \[ \pm 3\% \text{ of the required weight of material being weighed, or } \pm 0.3\% \text{ of scale capacity, or } \pm \text{ the minimum dosage rate for 94 lb (43 kg) bag of cement, whichever is greater.} \]
5. AR glass fibers (premix manufacture):
   \[ \pm 1\% \text{ of the required weight of material being weighed, or } \pm 0.3\% \text{ of scale capacity, whichever is greater.} \]

4.2 Premix Backing

4.2.1 Mix Proportioning

Records should be kept of actual mixes used to enable comparison of cured products to the specified requirements. New mix designs should have trial batches run and physical property tests evaluated prior to their use.

Variations in mix composition can result in variations in composite physical properties. Gradation of sand used for slurry mixes is also not standardized. Performance of ordinary portland cements typically used can vary from one source of supply to another. Several different polymer curing admixtures are currently available and in use. Therefore, composite mix proportions, constituents, and physical properties can vary from one manufacturer’s plant to another. Manufacturers should be aware of the potential variations in the physical properties of premix resulting from changes or modifications in the mix composition.

The following factors should be considered in preparing the mix design:

1. Fiber content, absolute minimum 2.5% by weight of total mix. Typically, the fiber content will be 3.5% by weight of total mix.
2. Fiber length (1/2 to 1 1/2 in.) (13 to 40 mm).
3. Desired physical properties.
5. Water–cementitious ratio, maximum 0.35. Workability adjustments should be made with the use of water reducers or superplasticizers.
6. Polymer content, minimum 6% polymer solids by weight of cement.
7. Admixtures.

The principal factors affecting the properties of the premix backing are fiber content, water–cementitious ratio, porosity, composite density, sand content, fiber orientation, fiber length, and type of cure. Density and porosity are also functions of the degree of compaction.

Fiber content, length, and orientation primary affect early tensile ultimate strength (ETU), early flexural strength (EFU), and impact strength. Fiber content has little effect on the modulus of elasticity. A glass fiber content of 3.5% by weight is usually optimum for premix mix designs.

Fiber contents greater than 4% tend to have poor workability and entrapped air, which causes reduced density. A minimum fiber content of 2.5% by weight is recommended to ensure adequate ultimate strengths. Although certain fibers may appear to process satisfactorily at fiber contents above 3.5, flexural strengths and density should be checked to make sure that the higher fiber content is not having any deleterious effects on composite properties.

Higher fiber contents than 4% can be achieved with special mixers. One such mixer has a flexible base, which is undulated by the action of an eccentric shaft projecting into the center of the mixing vessel. This undulating action causes the material to be turned
over on itself, thereby mixing the fibers into the slurry. This mixing action enables the mixer to be capable of mixing higher fiber contents than conventional mixers.

Fiber lengths also affect composite ultimate strengths. In premix production, glass fiber lengths of $\frac{1}{2}$ or $\frac{3}{4}$ in. (13 or 19 mm) are usually used. In certain products, lengths of 1 or 1½ in. (25 or 40 mm) may provide beneficial results. In general, shorter fibers give better workability but longer fibers will give higher strengths. In some cases, blends of short and long fibers can be beneficial.

The primary property of premix is flexural strength. Yield strengths are primarily influenced by the matrix, water–sand and cement–sand ratios, density, and degree of cure. The ultimate strengths are affected primarily by glass fiber content, fiber length and orientation, and composite density. Premix has lower fiber content, uses shorter fiber length, and usually has a more three-dimensional fiber orientation than GFRC. This typically results in premix having an initial EFU that is lower than GFRC, whereas EFY should be similar to that of GFRC. With 3.5% by weight of fiber, a factor of about 1.5 to 2 between EFY and EFU is available during the early life of the product, when it must withstand loads associated with handling, shipping, and installation. This factor changes over the life of the product as the ultimate strength decreases.

Premix also tends to exhibit a lower early strain to failure than does GFRC.

The flexural strengths of composites can be increased by incorporating scrim in the tensile surface of the composite. The bi-directional construction of the scrim provides more directional reinforcement than random chopped strand. In general, a fiber content of 3.5% by weight of total mix using $\frac{1}{2}$ to $\frac{3}{8}$ in. (12 to 38 mm) or blends of lengths within this range, cementitious–sand ratios of approximately 1:1, and typically 6% to 7% by weight of polymer solids to dry cement of an acrylic thermoplastic copolymer dispersion used as a curing admixture, provide a blend of acceptable composite properties and processability. Although, as with GFRC, the target cementitious–sand ratio should be 1:1, satisfactory processing may require slightly higher cement content; for example, a 1:0.85 cementitious–sand ratio may be necessary.

**Premix Production**

All the foregoing standard and commentary in Division 4 apply also to premix production, with the exception that Section 4.2.3, *Spraying*, does not apply, and Section 4.2.4, *Compaction*, only partly applies. The differences are covered in the following sections.

**Type of Premix**

Premix products are manufactured either by casting, usually with vibration, or by spraying.

**4.2.2 Batching and Mixing**

All materials should be accurately batched by weight or volume (see Article 4.1.2 for tolerances).

The composite is prepared in the same way for both methods of manufacturing. First, the slurry should be prepared exactly as for GFRC spray-up as described in Section 4.2.2.

The chopped glass fiber strands should be of the specified length or lengths where a blend of fiber lengths is to be used. The fiber strand should be weighed accurately (see Section 4.1.2 for tolerances) to give the specified fiber content.

The mixing process should create a thoroughly mixed slurry, while at the same time causing minimal strand breakdown, fiber damage, or entangling of the strands (fiber balling). This requires that the mixing process be capable of incorporating the fibers quickly and uniformly.

The mixing processes use either the special mixer described or the two-stage process in which the slurry is prepared in a high-shear mixer followed by a slow blending phase in which the fibers are incorporated.

The fiber should be added last, over a period not exceeding two minutes, and the mixer should only be allowed to run for a time sufficient to fully incorporate the fiber, normally only a few seconds. It should be added gradually in such a way as to avoid balling of the fibers and should be mixed until the fibers have been dispersed into the mix (no dry fibers). The total time to mix the fibers should be kept to less than two minutes to avoid filamentization of the strands.
APPENDIX M

Premix Casting

A premix composite should be charged into the mold in a manner to minimize the possibility of fiber alignment, particularly with strand lengths over 1 in. (25 mm), and cold joints or knit lines where material flows meet. Where possible, vibration should be used to facilitate flow of the composite in the mold and also to expel entrapped air and compact the composite.

The cast premix will have more three-dimensional fiber orientation, as compared to sprayed premix, which will have more two-dimensional orientation as a result of the spray process.

When casting, the molds should be filled in a way that avoids two or more material charges. Flow lines can be created where flows meet and the fibers may not bridge the flow lines. This will create a weak point in the product, which may result in a crack.

The mold must be filled in a manner that avoids pockets of air being trapped between the premix and the mold surface. Whenever possible, the mold should be filled from one point only.

If the premix is pumped from the mixer to the mold using a peristaltic-action pump, the mix must be designed to avoid separation of the mix components. A thixotropic or pumping aid can help avoid separation.

Because it is not usually possible to build up cast premix in layers as is done in spray-up (the total thickness being placed in one casting), rolling out is usually not effective with premix. However, the mixing process inevitably incorporates some air into the mix, and as the composite properties are density dependent, premix castings should involve vibration of the mix at some point, in order to expel as much as possible of this entrapped air. The vibration can be applied during the transfer of the premix to the mold and/or when the material is filling the mold. Excessive vibration must be avoided, as it can cause separation of the mix components. Where vibration cannot be used, the composite should be placed and compacted either by hand or by rollers.

4.2.3 Premix Spraying

In premix, the fibers are thoroughly wetted by the slurry in the mixing process, so roller compaction is not required to achieve this effect as it is in GFRC. Although the force of the spray should make the amount of entrapped air minimal, roller compaction of each layer can still be beneficial to expel any entrapped air that may occasionally occur. Also, roller compaction can help merge one layer into another and eliminate any possible cold joints between layers. If roller compaction is used with spray premix, then the commentary in Section C4.2.4 should be applied.

Premix composites are generally sprayed using peristaltic pumps, as shown in Figure M4.2.3(a), paired with a premix gun, as shown in Figure M4.2.3(b).

![Figure 4.2.3(a) Peristaltic Pump](image-url)
Spray operators should be trained personnel with a record of satisfactory performance based on results of flexural tests.

Spray of premix should begin before any face mix or mist coat has set. The spray nozzle should be aimed at 90° (± 20°) to the mold surface. The spray nozzle should always be kept the same distance from the mold surface. The spray nozzle should be moved back and forth, covering the entire mold surface. Figure 4.2.3(c) shows typical spray premix operation.

Where premix spraying is done in layers, each layer should be sprayed onto the preceding layer while the preceding layer is still wet and plastic (before initial set). Spraying should be continued until the design thickness is achieved. The design thickness should not be less than 3/4 in. The final thickness should be checked in accordance with Section 5.2.4.

4.3 Curing

The curing requirements in the manual regarding moist curing and curing of mixes with polymer admixtures apply to premix.

5.0 Quality Control

With the exception of those procedures designed to check spray gun settings, such as a bag and bucket test, all quality control procedures recommended for spray-up GFRC are applicable to premix. Premix properties are highly dependent on density and glass content and these should be checked.