PCI

Precast/Prestressed Concrete Institute

Manual for Quality Control for Plants and Production of

Glass Fiber Reinforced Concrete Panels

MNL-130-09

Second Edition

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

SECOND EDITION

MNL-130-09

Precast/Prestressed Concrete Institute

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First Edition, 1991
Second Edition, 2009

ISBN 0-937040-82-7

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Printed in the U.S.A.

FOREWORD

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.

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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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.

Backing – 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 m^3).

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.

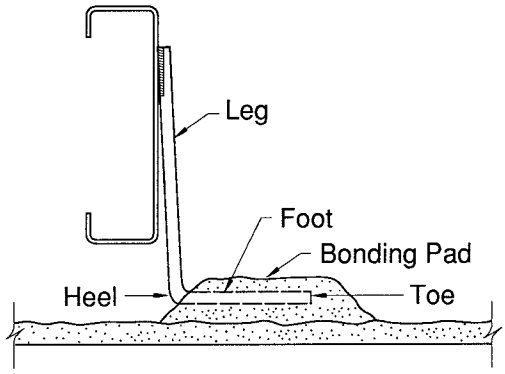
Facing Aggregate – An aggregate complying with ASTM C33, except for gradation, predominantly retained on the No. 20 (850 µm) sieve with a 1/4 in. (6 mm) maximum size.

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 connec tions 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 (Tensile)* – Tensile strength at either yield (Y) or ultimate (U). A uniform stress as contrasted to flexural stress (herein usually, but not always, modified by A or E and Y or U).

Test Board – A test sample produced by spraying up simultaneously with and alongside the production panel from which coupons are cut for testing.

Thermal Movement – Volume change of the skin due to temperature change of the skin. Volume change may be contraction or expansion.

Tolerance – Specified permissible variation from stated requirements such as dimensions and strength.

Trowel Surface – The surface of a panel away from the form or mold made by smoothing with a trowel or roller.

U (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).

DIVISION 1 – QUALITY CONTROL

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.

1.2 Plant Quality Assurance Program

1.2.1 General

The plant shall implement and maintain a documented quality assurance program in addition to this manual. Each plant shall have a unique plant quality system manual based on operations at that facility.

The plant quality system manual shall, as a minimum, cover the following:

1. Management commitment to quality.

Commentary

C1.1 Objective

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.

C1.2 Plant Quality Assurance Program

C1.2.1 General

The use of a written plant quality system manual requires an initial effort by plant management for development of the document. It further requires periodic updating to establish new practice guidelines for addressing the changes in products, procedures, and facilities.

Plant procedures should be documented as specific instructions to operating personnel. This will help to ensure uniformity in daily operations and the training of present and new