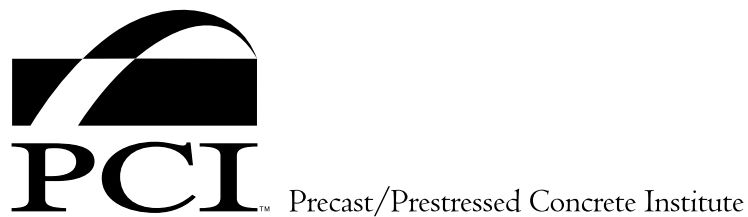


Manual for
QUALITY CONTROL
for Plants and Production of
GLASS FIBER REINFORCED
CONCRETE PRODUCTS

SECOND EDITION

MNL-130-09



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First Edition, 1991
Second Edition, 2009

ISBN 0-937040-82-7

Every effort has been made to ensure the accuracy of the information presented in this manual. However, PCI cannot accept responsibility for errors, oversights, or the misuse of the information contained herein. The user must recognize that no manual or regulation can substitute for experience and sound judgment. This publication is intended for use by personnel competent to evaluate the significance and limitation of the information it contains, and accept responsibility for its proper interpretation and application.

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.

TABLE OF CONTENTS

Foreword	iii
Introduction	v
Definitions	xi

DIVISION 1 – QUALITY CONTROL

1.1 Objective	1-1
1.2 Plant Quality Assurance Program	
1.2.1 General.....	1-1
1.2.2 Documented Procedures.....	1-2
1.2.3 Management Responsibilities	1-3
1.3 Personnel	
1.3.1 General.....	1-3
1.3.2 Engineering	1-4
1.3.3 Drafting	1-4
1.3.4 Production	1-4
1.3.5 Quality Control.....	1-4
1.4 Design Responsibilities	
1.4.1 General	1-5
1.4.2 Shop Drawings	1-6
1.5 Project Samples	
1.5.1 General.....	1-6
1.5.2 Size and Shape	1-6
1.5.3 Identification	1-6
1.5.4 Visual Samples and Initial Production Approval of Architectural Finishes.....	1-7

DIVISION 2 – PRODUCTION PRACTICES

2.1 General Objectives and Safety	
2.1.1 General	2-1
2.1.2 Plant Safety	2-1
2.2 Production and Curing Facilities	
2.2.1 Area Requirements.....	2-1
2.2.2 Mold Fabrication.....	2-2
2.2.3 Storage of Release Agents and Retarders.....	2-2
2.2.4 Steel Fabrication and Storage	2-2
2.2.5 Production Area and Equipment.....	2-3
2.2.6 Curing and Finishing Areas	2-5
2.2.7 Handling Equipment	2-6
2.2.8 Storage Area for Finished Products	2-6
2.3 Panel Frame	
2.3.1 Fabrication.....	2-7
2.3.2 Verification.....	2-8
2.4 Molds	
2.4.1 Materials and Construction.....	2-9
2.4.2 Verification and Maintenance	2-12
2.5 Anchors, Inserts, and Hardware	
2.5.1 Installation	2-13
2.6 Product Identification.....	2-14
2.7 Product Handling	
2.7.1 Stripping	2-14
2.7.2 Handling	2-15
2.7.3 Yard Storage	2-15

2.7.4	Cleaning	2-16
2.7.5	Loading.....	2-17
2.8	Face Mix / Veneer Finishes	
2.8.1	General.....	2-17
2.8.2	Smooth	2-19
2.8.3	Sand or Abrasive Blast Finish	2-20
2.8.4	Retarded Finish	2-20
2.8.5	Formliners.....	2-21
2.8.6	Acid-Etched Finish.....	2-22
2.8.7	Veneer Facing Materials.....	2-23
2.8.8	Applied Coatings	2-24
2.9	Repairs	2-25
2.10	Acceptability of Appearance	2-26
2.11	Sealers or Clear Surface Coatings.....	2-29
DIVISION 3 – RAW MATERIALS AND ACCESSORIES		
3.1	Face Mix and GFRC Backing Matrix Materials	
3.1.1	General.....	3-1
3.1.2	Cement.....	3-1
3.1.3	Facing Materials	3-2
	3.1.3.1 Fine Aggregate	3-2
	3.1.3.2 Coarse Aggregate	3-3
3.1.4	Sand for GFRC Backing	3-4
3.1.5	Mixing Water.....	3-5
3.1.6	Admixtures.....	3-6
3.2	Reinforcement	
3.2.1	Alkali-Resistant Glass Fibers.....	3-9
3.3	Panel Frame and Hardware	
3.3.1	Panel Frame	3-9
3.3.2	Anchors and Inserts.....	3-10
3.3.3	Handling and Lifting Devices	3-10
3.3.4	Connection Hardware.....	3-11
3.4	Integral Rib Formers	
3.4.1	Rib Former Materials	3-11
3.5	Welding	
3.5.1	Materials	3-11
DIVISION 4 – PRODUCTION		
4.1	Face Mix	
4.1.1	Mix Proportioning.....	4-1
4.1.2	Batching and Mixing	4-1
4.1.3	Placing and Consolidating.....	4-3
4.2	GFRC Backing	
4.2.1	Mix Proportioning.....	4-5
4.2.2	Batching and Mixing	4-7
4.2.3	Spraying	4-8
4.2.4	Compaction	4-9
4.2.5	Installation of Panel Frame.....	4-12
4.2.6	Application of Bonding Pads.....	4-12
4.2.7	Integral Ribs	4-14
4.2.8	Inserts and Embedments.....	4-14
4.3	Curing	4-15
4.4	Batching and Mixing Facilities	
4.4.1	General Requirements for Batching and Mixing Plants.....	4-16
4.4.2	Storage of AR Glass.....	4-16

4.4.3	Storage and Handling of Aggregates	4-17
4.4.4	Storage of Cement	4-17
4.4.5	Storage of Admixtures, Pigments, and Curing Admixtures	4-18
4.4.6	Measuring Equipment.....	4-18

DIVISION 5 – QUALITY CONTROL

5.1 Inspection

5.1.1	Necessity for Inspection	5-1
5.1.2	Scope of Inspection	5-1

5.2 Testing

5.2.1	General.....	5-2
5.2.2	Acceptance Testing of Materials and Preproduction Testing	5-3
5.2.3	Production Testing of Aggregates	5-10
5.2.4	Production Testing—Wet.....	5-10
5.2.5	Production Testing—After Curing.....	5-14

5.3 Records

5.3.1	Record Keeping.....	5-16
5.3.2	Suppliers' Test Reports	5-16
5.3.3	GFRC Records	5-17
5.3.4	Calibration Records for Equipment.....	5-17

5.4 Laboratory Facilities

5.4.1	General.....	5-18
5.4.2	Quality Control Testing Equipment.....	5-18
5.4.3	Test Equipment Operating Instructions	5-19
5.4.4	Welding.....	5-19

DIVISION 6 – PRODUCT TOLERANCES

6.1 Requirements for Finished Product

6.1.1	Product Tolerances—General	6-1
-------	----------------------------------	-----

6.2 Measurement

6-2

6.3 Product Tolerances.....

6-3

APPENDICES

Appendix A

Guidelines for Developing the Plant Quality System Manual	A-2
---	-----

Appendix B

Considerations for the Architect/Engineer in Preparing Plans and Specifications	B-1
---	-----

Appendix C

Product Dimensional Tolerances.....	C-1
-------------------------------------	-----

Appendix D

Finish Samples	D-1
----------------------	-----

Appendix E

Sample Record Forms.....	E-1
--------------------------	-----

Appendix F

Specification for Alkali-Resistant Glass Fiber	F-1
--	-----

Appendix G

Specification for Polymer Curing Admixture	G-1
--	-----

Appendix H

Test Procedures	H-1
-----------------------	-----

Appendix I

PCI Plant Certification Program.....	I-1
--------------------------------------	-----

Appendix J

Reference Literature.....	J-1
---------------------------	-----

Appendix K

Erection Tolerances..... K-1

Appendix L

Collection of Ideas on the Production of GFRC..... L-1

Appendix M

Premix M-1

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 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.

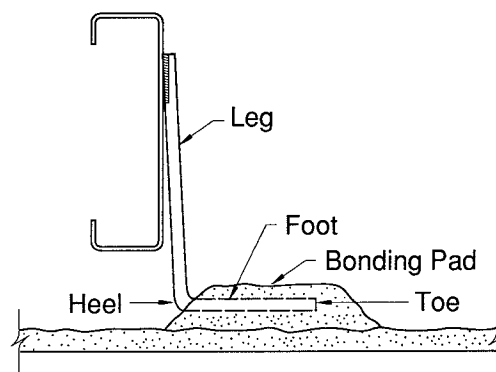
Facing Aggregate – An aggregate complying with ASTM C33, except for gradation, predominantly retained on the No. 20 (850 µm) sieve with a 1/4 in. (6 mm) maximum size.

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 mm) 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 μ m) 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 cm²) 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

Commentary

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.

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.

1.2 Plant Quality Assurance Program

C1.2 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.

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

DIVISION 1 – QUALITY CONTROL

Standard

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.

Commentary

employees. See Appendix A for developmental guidelines for a plant quality system manual.

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.

DIVISION 1 – QUALITY CONTROL

Standard

Commentary

7. Inspection of the placement and quality of panel frames, cast-in appurtenances, ribs, and block-outs.
8. Mix design preparation and evaluation.
9. Inspection of test board preparation.
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.

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.

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.

C1.3 Personnel

C1.3.1 General

In this section, the functional responsibilities of certain basic positions are outlined. Whether one or more of these functions is assigned to one person, or several persons are assigned to a specific function, is the prerogative of management. This is normally dependent on the intended use of the product and the size of the plant.



DIVISION 1 – QUALITY CONTROL

Standard

At least one individual in the plant organization shall be certified as a GFRC Technician/Inspector in the PCI Quality Control Personnel Certification Program.

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.

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.

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.

DIVISION 1 – QUALITY CONTROL

Standard

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.

1.4 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.

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

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.

C1.4 Design Responsibilities

C1.4.1 General

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.

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.

DIVISION 1 – QUALITY CONTROL

Standard

Commentary

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.

DIVISION 1 – QUALITY CONTROL

Standard

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.

The samples shall be stored outdoors and positioned to allow comparison with production units. They shall be stored to allow proper lighting (sun and shade) for daily comparisons of the production units for finish and exposure.

Commentary

C1.5.4 Visual Samples and Initial Production Approval of Architectural Finishes

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

Commentary

2.1 General Objectives and Safety

C2.1 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.

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.

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.

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 GRFC 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

C2.2 Production and Curing Facilities

2.2.1 Area Requirements

The production and curing area(s) shall be designed for controlled production of GRFC 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.

C2.2.1 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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

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-

To meet the provisions of Division 4, it may be necessary to provide heating and/or proper ventilation for the casting area and the forms depending on the geographic location of the plant.

C2.2.2 Mold Fabrication

Mold fabrication facilities should be capable of maintaining constant working temperatures above the minimum required for specific raw materials and processes used. Resins, catalysts, accelerators and acetone, etc., for plastic molds should be stored within the manufacturer's recommended temperature range and away from the production areas.

Storage for special molds, special patterns, or other items that are very expensive should be considered when the project may be expanded in the future or where they may be reused in some form at a later date.

C2.2.3 Storage of Release Agents and Retarders

Release agents and retarders generally have a reasonably long and stable storage life. However, such materials may be susceptible to damage from extreme temperature changes.

Certain weather conditions can affect the performance of water-based release agents or retarders. Generally, they can't be used in cold weather because they might freeze. Even at temperatures slightly above freezing, some water-based products thicken enough to produce more bug holes and/or reduce performance.

The oils in some release agents have a critical emulsifier content. Dilution makes the emulsion unstable and causes poor performance.

C2.2.4 Steel Fabrication and Storage

It may be desirable to protect steel without corrosion protection from the weather.

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

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.

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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

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 $\frac{1}{8}$ 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.

Commentary

The hose diameter of the slurry-handling equipment should be large enough to avoid blockages. The equipment should have a variable output that allows optimization of the flow rates to match production rates and be capable of being easily cleaned. Use of the equipment should create a minimum amount of discomfort to the operator performing the spray-up process.

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.

Flow rates of 15 to 50 lb (6.8 to 22.7 kg) of slurry per minute depending on the number of strands are typical.

Air pressure is a critical item in the spray-up procedure. A well-atomized spray depends on a constant supply of dry air at the pressure required.

The air pressure at the spray head should be regularly checked, either by installing an ordinary dial gauge in the line, or by inserting a needle gauge in the air hose. Air hoses should be blown clean before connecting to spray heads.

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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary



Figure C2.2.5 Concentric spray gun.

The proper finishing tools shall be available to compact the GFRC composite in the mold.

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.

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,

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.

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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

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 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.

C2.3 Panel Frame

C2.3.1 Fabrication

Most GFRC panels are fabricated using a panel frame to provide dimensional stability and structural support. The frame is generally made using light-gauge steel or a combination of structural shapes and light-gauge steel.

The quality control inspector should realize that the location and orientation of all framing members should not deviate from the shop drawings in order for the panel frame to function as designed. Variations in location and orientation of frame members can result in excessive restraint of the skin that could be detrimental to the long-term serviceability of the completed panel.

Loads from the panel skin are transferred to the panel frame through flex, gravity, and, in some cases, seismic anchors. These anchors are designed and welded to the frame to accommodate moisture and thermal movement of the skin without imposing excessive restraint. Oversized, incorrectly welded, incorrectly positioned, or embedded anchors can cause undue restraint resulting in stresses sufficient to crack the skin.

Anchors are welded at the top of the flex anchor leg for flexibility with flare bevel groove welds. Excessively long or mislocated welds of the flex anchors to the studs can shorten the intended design length. AWS D1.1 covers structural steel welding such as tubes or angles used in fabricating the panel frame. AWS D1.3 covers sheet steel, such as stud framing members used in the panel frame. Arc welding methods, as outlined in AWS D1.3, are most often employed for connection of light-gauge steel shapes.

If thick hardware, such as plates or angles for bearing connections, is required, supplementary thin plates or angles should first be welded to the studs as a base for welding the thick hardware to the panel frame.

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

DIVISION 2 – PRODUCTION PRACTICES

Standard

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

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.

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.

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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

4. Checking storage of filler material.
5. Checking equipment to be used.
6. Checking weld joint preparations.
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.

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.

C2.4 Molds

C2.4.1 Materials and Construction

The overall quality of the project starts with molds capable of allowing the production personnel to make units that meet all the specifications.

The appearance of the finished surface is directly related to the choice of mold material and the quality of the mold itself. The in-service life of a mold is also a function of the choice of mold material, which must therefore be selected with care. Molds for GFRP can be made of various materials such as plywood, concrete, steel, plastics, polyester resins reinforced with glass fibers, plaster, or a combination of these materials. For complicated details, molds of plaster, elastomeric rubber, or foam plastic may be used. These molds are often combined or reinforced with wood or steel depending on the size and complexity of the unit to be produced.

Ideally, all corners should have a radius or have fillets. Chamfers, rounded corners with a minimum $\frac{1}{8}$ 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 $\pm \frac{1}{8}$ in. (± 3 mm). Window openings require that a high degree of accuracy be maintained for sealing.

DIVISION 2 – PRODUCTION PRACTICES

Standard

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.

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.

Commentary

of windows to GFRC. The plane of the opening should be held to close tolerances.

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.
6. Uniformity of performance.
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.

Mold seams as well as welds on steel molds should be checked daily during the mold preparation stage. Mold seams resulting from jointing of loose parts, such as bulkheads, side molds, or any mold modification pieces should be minimized to the extent required by the finished surface, well fitted, secured, and sealed to prevent leakage. Molds should have high rigidity, minimum deflection, and minimum movement of the mold material between the stiffeners.

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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

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.

Molds shall permit controlled, fixed positioning or jiggling 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.

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.

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

Commentary

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 should include a system for supporting the panel frame in the correct position. Prepositioned stops and fixtures are recommended.

Various edge conditions should be oversprayed and then hand-troweled or cut and trimmed to dimension during production. The mold should contain control points and templates for production finishing.

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.

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.

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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

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.

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.

Commentary

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, block-outs, 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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

2.5 Anchors, Inserts, and Hardware

C2.5 Anchors, Inserts, and Hardware

2.5.1 Installation

C2.5.1 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.

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.

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.

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.

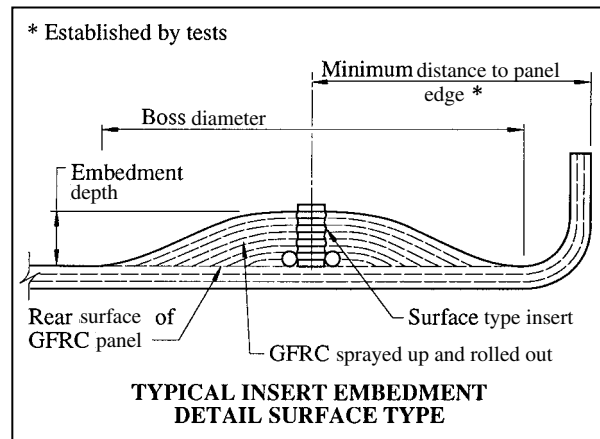


Figure C2.5.1 Insert Connection Details for Panels without Panel Frame

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.

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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

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 over-stressing 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.

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

C.2.7.1 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 over-stressing.

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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

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.

Veneered units should be lifted cleanly to prevent chipping or spalling of the veneer edges. Uniformity of stripping age from unit to unit should be maintained to GFRC color differences.

C2.7.2 Handling

Where handling stresses are determined by structural analysis, positions for support and handling may be varied subject to limiting of stresses within applicable design values. For most GFRC units, vertical handling and two-point support should be the rule. However, many units are of a size or shape for which alternate methods may have to be applied.

Each plant should develop specific unit-handling procedures. These should include demolding, lifting, storage, preparations for transport, and tie-down of panels during transportation.

C2.7.3 Yard Storage

A general rule of thumb regarding panel storage and transport preparation procedures is to not subject the GFRC backing/face mix to any loads. Panels should be supported and tied down by the panel frame and should not be stacked.

Panel-handling procedures should also consider maintaining the clean architectural surface of the panel. The need for protection will depend on the configuration of the panels, the length of storage time, and local environmental conditions.

Proper panel support during storage will minimize warping and bowing.

Panel supports should be made of nonstaining materials, such as plastic. A plastic cap or foam should be inserted in pockets or recesses of embedded items that could fill with water and freeze or produce rust staining on the panel finish.

DIVISION 2 – PRODUCTION PRACTICES

Standard

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 alkalis 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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

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.

Workers using cleaning compounds or acid solutions should be thoroughly trained in their use. The use of proper protective wear should be strictly enforced.

C2.7.5 Loading

The manufacturer should ensure that units are ready for delivery before loading. This may necessitate a lead time for final checking, possible cleaning, and minor repairing that may be required as a result of damage or accumulation of dirt in storage. Units should not be shipped to jobsites until they have reached sufficient strength to withstand the effects of the particular shipping and handling methods used.

Factors such as the size, shape, type of finish, method of transportation, type of vehicle, weather and road conditions, and distance of haul enter into determining the necessity of wrapping or protecting the GFRC units during shipment.

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

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

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.

uniform than those containing materials of similar colors. Consistency in apparent color of all finishes can be enhanced by color compatibility of materials. If the coarse aggregate, fine aggregate, and cement paste are similar in color, the depth of exposure and “patchy” effects (minor segregation of aggregate) will not be as noticeable in maintaining color consistency. In contrast, if material colors are quite different, products may appear blotchy for the same reason.

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.

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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

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, $\frac{1}{8}$ to $\frac{1}{4}$ 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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

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.

Sand used for blasting operations shall be free of deleterious substances such as fine clay particles. The type of abrasive shall not cause undesirable color contamination of the surface.

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.

C2.8.3 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.

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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

When using a retarder, the manufacturer's recommendations shall be followed. Surface retarders shall be uniformly applied by roller, brush, or spray.

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

The retarded surface shall be exposed by removing the cement paste to a level that matches the approved sample.

2.8.5 Formliners

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.

Commentary

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 activates the retarder.

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.

C2.8.5 Formliners

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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

An investigation shall be made to determine whether staining or discoloration may occur from the liner material, its fastenings, or joint sealers. Care shall be taken to use mold release agents and retarders that are compatible with the liner and the liner shall not be subjected to temperatures in excess of those recommended by the manufacturer.

2.8.6 Acid-Etched Finish

In cases where aggregate is to be exposed to a considerable depth, acid-resistive 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.

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.

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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

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.

2.8.7 Veneer Facing Materials

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

Particular attention shall be paid to the compatibility of materials with respect to differential expansion and contraction caused by thermal and moisture changes; and also the differential volume change (shrinkage) between the veneer facings and GFRC backing. If the materials do not have similar physical properties, the final design shall include compensation for some interaction of the different materials.

Natural stone. 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.

Commentary

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.

C2.8.7 Veneer Facing Materials

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.

Care should be taken so that differential stone thickness does not constrain the GFRC skin.

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

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 hardness 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.

Anchor 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.

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.

DIVISION 2 – PRODUCTION PRACTICES

Standard

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.

Commentary

Paint and stains are formulated to provide certain performance characteristics under specific conditions and may be used for purely decorative reasons. See Article 2.11 for information on both clear and pigmented sealers. There are significant differences among paint or stain types, brands, and performances. Knowledge of the service conditions and performance is necessary for selecting an appropriate paint or stain.

A clear coating of silane or siloxane may be applied to the face and back surfaces of a panel to reduce moisture absorption (moisture movement) and efflorescence. In most cases, except for the silanes or siloxanes, it will be necessary to adequately roughen the surface in order to obtain good adhesion of the coating.

C2.9 Repairs

A certain amount of repair work can be expected. Written repair procedures should clearly define when quality control is required to consult with the design engineer to determine an appropriate remedial action.

To match specified architectural finishes, repair mixes should be developed early, following approval of initial sample. A trial-and-error process is normally required for each newly developed face mix to effectively match color and texture.

Because the techniques and procedures of repairing GFRC are affected by a variety of factors including mix ingredients, final finish, size and location of damaged area, temperature conditions, age of panel, surface texture, etc., precise methods of repairing cannot be detailed in this manual.

Temperature limitations for proper curing of repair materials should be considered.

Repair work requires experienced craftsmanship and careful selection and mixing of materials.

The GFRC backing and the facing should be thoroughly inspected. Cracks discovered in the GFRC backing or facing may result in the withholding of panel approval until proper evaluation is complete. Surface cracking of the face mix or GFRC backing may be an indication of hidden damage that could lead to through-cracking as the panel ages. Every effort should be made to prevent cracking from occurring. Whenever cracking is detected, manufacturing procedures, handling, mix design, and panel design should be reviewed to determine the cause of the cracking and to prevent further occurrence. Any panel with visible cracks should be carefully evaluated. Many surface cracks are the result of plastic shrinkage of the face mix and may cause no distress. Any panel with through-cracking should be structurally evaluated.

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

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.

for acceptance. This evaluation should establish if the panel can be successfully repaired.

Repair methods should ensure that the repaired area will conform to the balance of the work with respect to applicable requirements for appearance, structural adequacy, serviceability, and durability. Repairs should be made at the plant well in advance of shipping to allow for proper curing of the repaired area. Color variations can be expected between the repaired area and the original surface due to the different age and curing conditions of the repair. The repair will generally become less noticeable over time with exposure to the environment.

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 $\frac{3}{8}$ 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, $\frac{1}{8}$ to $\frac{1}{4}$ 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

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

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.

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

DIVISION 2 – PRODUCTION PRACTICES

Standard

Commentary

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.

8. Blocking stains evident on the exposed surface.

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.

9. Areas of GFRC backing, exposed glass fibers, or exposed anchors or embedments showing through the face mix.

10. Foreign material embedded in the face.

11. Repairs visible from a viewing distance of 20 ft (6 m).

12. Shadow lines.

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.

13. Cracks visible at 20 feet (3m) viewing distance.

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 concentration of