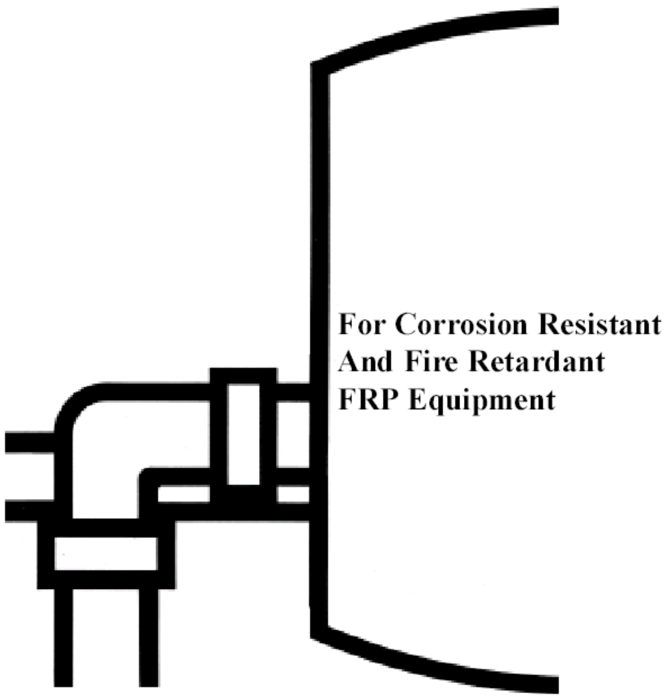
PENN
Specialty Chemicals, Inc.

Chemicals from Renewable Resources

QuaCorr® Resin

Properties and Applications



Contact Information
United States:
3324 Chelsea Avenue
Memphis, TN 38108
Phone: 901-320-4028
Fax: 901-320-4002
www.pschem.com
Email: PennUSA@pschem.com

Customer Service
(For orders or product inquires)
Phone: 1-877-952-3594
Fax: 901-320-4013

INTRODUCTION

QuaCorr® is the trademark for furfuryl alcohol based resin/catalyst systems developed by Penn Specialty Chemicals for the manufacture of fiberglass reinforced plastic (FRP) equipment. QuaCorr laminates exhibit a broad range of solvent and chemical resistance combined with excellent physical, flame spread, and smoke development properties that are unique among FRP systems.

Comparable corrosion resistance generally can be found only in much more expensive materials of construction such as specialty metals, alloys, and fluorocarbon polymer or glass-lined steels.

The QuaCorr systems provide the fabrication characteristics and physical properties needed to make durable, reliable, high performance equipment. More and more corrosion engineers are finding that QuaCorr FRP equipment is cost effective in providing corrosion control in a broad spectrum of corrosive media.

This brochure provides material specifiers and/or potential users of FRP equipment with a guide to the basics of when, where, why, and how to utilize the QuaCorr systems. Substantial cost savings and many other benefits can be realized when QuaCorr equipment is specified for you plant including:

1. Excellent resistance to most chemical media including solvents, acids, bases, and their various combinations.
2. Resistance to chemical attack at elevated temperatures.
3. Excellent retention of physical properties at upset temperatures to 400°F.
4. Resistance to a broad spectrum of chemical media combined with stability at elevated temperatures provide versatility to accommodate process changes, unanticipated spills, and thermal upsets.
5. Outstanding flame spread and smoke development properties for ducting, stacks, scrubbers, and other related applications.
6. Ease of fabrication by any of three commonly used techniques: hand lay-up, spray-up, or filament winding.
7. Suitability for large structures and pressure vessels.

QuaCorr FRP equipment is often specified for handling liquid or gaseous effluents where aggressive combinations of acids or bases and strong solvents such as ketones, ethers, or chlorinated organic types are present. Typical equipment includes: tanks, reactors, pressure vessels, distillation columns, piping, scrubbers, ductwork, hoods, stacks, fans, and sumps.

Engineers in many industries have utilized the benefits of QuaCorr FRP equipment. Among the processes employing QuaCorr equipment are those manufacturing pesticides and other agricultural chemicals, vinyl chloride monomer, other chlorinated organics, isocyanates, rayon, cellulosic fibers and films, dye-stuffs, and esters such as acrylates. QuaCorr equipment is also used widely throughout the chemical processing industry for the recovery of solvents, for waste effluent systems and in metal treatment.

CORROSION RESISTENT PROPERTIES

When buying corrosion resistant equipment for your process or plant, several key factors determine if QuaCorr equipment should be specified. They include:

1. The presence of solvent in combination with acids or bases
2. Temperatures of 160°F (71°C) or greater for either operating or upset conditions
3. As an alternative to specialty metals, alloys, and lining based on cost/performance.
4. The need for low flame spread, low smoke development, corrosion resistant material.

These and other factors are discussed more fully in the following sections.

Media Considerations

Media composition is a complex and extremely critical aspect of material selections. Changes in the process stream and the presence of trace amounts of material can greatly alter the performance and life expectancy of equipment. Therefore, all present and potential corrosion problems should be considered before specifying material of construction for replacement structures, expansion programs, and new installations. In many instances, the ability of QuaCorr equipment to handle solvents in combination with acids and bases may circumvent the need for new equipment if process changes occur.

A general comparison of the corrosion resistant properties of QuaCorr laminates and other typical materials of construction is given in Table 1.

Table 1 Comparative Corrosive-Resistant Properties

	Acids				Bases	
Materials of Construction	H_2SO_4 Dil	H_2SO_4 conc	HCL Dil	HCL conc	NaOH Dil	NaOH Conc
Carbon Steel	A	R (above 85%)	A	A	R	R
Stainless Steel	R below 10%	R above 90%	A	A	R	A
Hastelloy C®	R	R	R	R	R	R
Aluminum	A	A	A	A	A	A
Premium Polyester Laminates	R	R to 60%	R	R	R	A
QuaCorr Laminates	R	R to 60%	R	R	R	R to 50%

	Salts	Solvents				
Materials of Construction	CaCl Sat	CS_2	Toluene	MEK	Chloro Benzene	Ethylene Dichloride
Carbon Steel	A	R	R	R	R	R
Stainless Steel	A	R	R	R	R	R
Hastelloy C®	R	R	R	R	R	R
Aluminum	A	R	R	R	R	R
Premium Polyester Laminates	R	A	R	A	A	A
QuaCorr Laminates	R	R	R	R	R	R

* A = attacled, R = resistant

QuaCorr FRP equipment is resistant to attack by the following general types of media, including mixtures of these: acids (strong and weak), bases (strong and weak), aggressive Solvents including Ketone, Chlorinated Types, Ethers, Esters, Aromatics, Carbon Disulfide, Furfural, and Furfuryl Alcohol.

Frequently in choosing the material of construction for equipment, specifying engineers are faced with media and/or conditions for which they do not have historical evidence of satisfactory performance for one or more of the candidate materials. If there is any question of suitability, corrosion testing is recommended. Verification of performance by exposure of spool pieces or laminate test coupons to actual process media operating conditions assures that properly fabricated equipment will perform satisfactorily in the designated service.

TYPICAL ACCEPTABLE MEDIA

Following is a partial listing of some chemicals handled satisfactorily by properly constructed QuaCorr Equipment. These chemicals alone or in admixtures are corrosive to many other materials. Because performance may be affected by media combinations, concentrations, and temperatures, testing of QuaCorr laminates in the proposed environments is advised where prior knowledge is not available.

Acetic Acid	Methanol	Acetone
MethylEthyl Ketone	Acrylic Acid	Monochlorobenzene
Acrylonitrile	Nitrobenzene	Allyl Chloride
Perchloroethylene	Aniline	Phosphorous Oxychloride
Benzaldehyde	Potassium Pyrophosphate	Benzene
Quaternary Ammonium Salts	Pulp Mill Liquors	Benzyl Chloride
Sodium Hydroxide	Carbon Disulfide	Carbon Tetrachloride
Chlorophenol	Chloroisobutane	Sulfur Dioxide
Sulfuric Acid	Sulfur Monochloride	Cyclohexanone
Dichlorophenol	Dichloroethane	Tall Oil
Tetrahydrofurfuryl Alcohol	Tetrahydrofuran	Dimethyl Propanolamine
Ethyl Acetate	Thionyl Chloride	Ethanol Toluene
Trichloroethylene	Toluene Diisocyanate	Formalin
Glyoxal	Furfural	Vinyl Chloride
Zinc Chloride	Xylene	Hydrochloric Acid
	Methylallyl Chloride	Zirconium Oxychloride

Media Not Recommended

Ammonia Gas	Oleum	Aqua Regia
Piperidine (100%)	Bromine (free)	Phenol (100%)
Calcium Hypochlorite	Phosphorous Bromide	Chlorine (free)
Potassium Peroxide	Chlorosulfonic acid	Pyridine (100%)
Dimethyl Formamide	Sodium Hypochlorite (100%)	Sulfur Trioxide
Hydrogen Peroxide	Nitric Acid	Sulfuric Acid
Hypochlorous Acid (over 60%)		

FIRE AND SMOKE PROPERTIES*

QuaCorr 1001 laminates, in addition to outstanding corrosion resistance, have inherent low flame spread/low smoke development properties. This is due to the highly cross-linked nature of cured furan resin coupled with a high char yield. Typical ASTM E-84 indices for QuaCorr 1001 laminates are Flame Spread 70, Smoke Development 120.

*The fire test data set forth herein are used solely to measure and describe the properties of these materials, products, or systems in response to heat and flame under controlled laboratory conditions and should not be considered or used to predict the fire hazard of materials under actual fire conditions.

Table II. Typical Fire and Smoke Test Results †

Test	Quacorr 1001 Laminate
Flame Spread (ASTM E-84)………….	70
Smoke Development (ASTM E-84)….	120
Radiant Panel Test (ASTM E-162)…..	61
NBS Smoke Density, D_s Max. (ASTM E-662)……………………	62
Limited Oxygen Index (ASTM D-2863)…………………	25

† Pr

TEMPERATURE CONSIDERATIONS

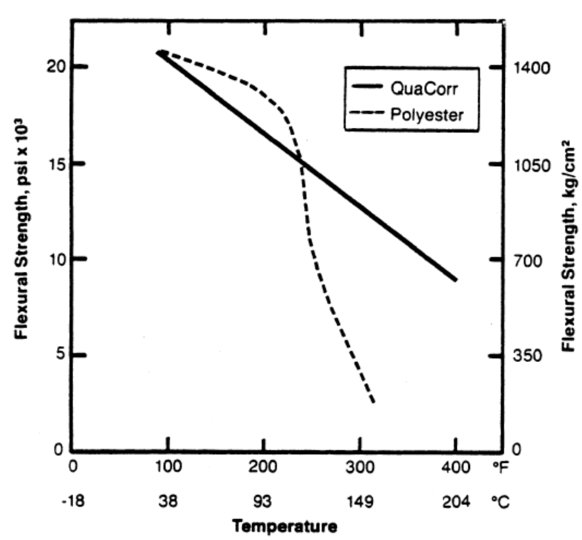
Temperature is an important consideration when selecting the materials of construction for equipment. Frequently, materials which will handle the media at ambient temperature are less suitable for elevated temperature service.

Strength Retention vs. Temperature

Physical property retention of QuaCorr laminates at elevated temperature is a very important feature. Typical of most polymeric materials, strength decreases as temperature increases. However between –50°F (-46°C) and 450°F (232°C), the decrease in strength of well post-cured QuaCorr laminates is essentially linear (see Figures 2-5) and does not show the sharp, rapid loss in properties exhibited by styrenated polyester laminates. This capability of QuaCorr laminates to retain significant strength over and extended temperature range provides design engineers with a margin of safety in designing structures where a process upset may result in a high temperature for a period of time. Specifying QuaCorr equipment thus reduces the risk of a catastrophic failure due to a sudden temperature change. Figure 1 compares the strength retention of QuaCorr laminates at elevated temperatures to a premium polyester laminate.

Figure 1

Flexural Strength vs. Temperature



Continuous Service Temperature

A second aspect of elevated Temperature performance is the temperature acceptable for prolonged exposure. Studies have shown the maximum recommended continuous service temperature for QuaCorr laminates in the presence of air is about 265°F (130°C). At higher temperatures, QuaCorr laminates undergo slow surface oxidation and lose strength over a period of months. Where oxygen and other oxidizing media are absent, it is anticipated QuaCorr laminates can withstand continuous temperatures of at least 300°F (149°C) for prolonged periods.

Media/Temperature Effects

A third aspect of elevated temperature performance is the effect of the media on the laminate at the elevated temperature. Well-cured QuaCorr laminates have a very highly cross-linked structure which results in good resistance to many solvents. Thus in the temperature range of 150°F (66°C) to 265°F (130°C), QuaCorr laminates will handle many solvents which rapidly destroy polyesters, vinyl esters, or epoxy laminates. However, it is difficult to predict accurately the effect of a solvent or mixture of solvents on a laminate. **Coupon or spool piece testing is recommended where there is a lack of case history or suitable test data.**

COST/PERFORMANCE ADVANTAGES OF QUACORR EQUIPMENT

QuaCorr equipment often provides a cost/performance benefit for the specifying or design engineer who has responsibility for materials selection. However, realization of maximum cost/performance benefit with QuaCorr equipment requires both proper design and fabrication.

Resistance of QuaCorr resin based laminates to organic chemicals and solvents is unique among resins used for contact molded FRP equipment. Consequently, many applications requiring corrosion resistance to combinations of organic materials with aqueous acids, bases, or salts can be specified QuaCorr FRP. In many instances QuaCorr equipment provides a significant savings in capital investment compared to alternative materials of construction such as Hastelloy®[1], Monel®[2], Inconel®[2], tantalum, titanium, 316 stainless steel and rubber, glass, or thermoplastic lined steel.

QuaCorr equipment also offers a significant advantage in versatility of application. The broad spectrum corrosion resistance of QuaCorr laminates provides insurance against the need to purchase new equipment if process changes occur. Likewise, the excellent strength retention properties of QuaCorr laminates at elevated temperatures can be of benefit in applications where thermal upsets are concern. As a result the use of QuaCorr equipment may eliminate expenditures for replacement equipment associated with process changes.

The outstanding fire and smoke properties of QuaCorr laminates compared to FRP equipment made with other commonly available resins provides and addition al measure of safety as well as corrosion resistance. Thus, QuaCorr equipment is often indicated for ducting, hoods, scrubbers, and related items. In such applications, QuaCorr equipment can have a favorable effect on property loss in case of fire.

1. Trademark of Haynes International, Inc.
2. Trademark of Huntington Alloys Corp.

PHYSICAL PROPERTIES OF QUACORR LAMINATES

The data included in this section are intended to provide a physical property profile of typical QuaCorr laminates prepared in the Penn Chemicals laboratories using contact molding techniques common in the industry. The values are intended as guidelines only. It is our recommendation that final design be based on physical properties determined on laminates manufactured with the reinforcement, resin, and fabrication techniques to be employed in the construction of the proposed equipment.

Table III. Typical QuaCorr Laminate Properties[1]

Property (ASTM Test Method)	A[2]	B[3]	C[4]
Laminate Thickness, inches	0.15	0.32	0.43
Glass Content, % (D-2584)	26	32	33
Flexural Strength, psi (D-790)	18000	20000	22000
Flexural Modulus, psi (D-790)	700000	800000	900000
Tensile Strength, psi (D-638)	10000	12000	14000
Tensile Modulus, psi (D-638)	800000	1000000	1200000

	All Mat Laminate	*Mat and Woven Roving Laminate*
Compressive Strength, psi [5]	25300	17200
Poisson's Ratio	0.358	0.264
Hardness, Barcol (D-2583)	40 Minimum	
Izod Impact Strength, ft. lbs./in. of notch (D-256)	14	
Elongation, % (D-638)	1	
Density, g/cc (D-792)	1.4-1.6	
Coefficient of thermal expansion, in./in./°F (E-228)	1.16x10-5	
Coefficient of thermal conductivity, in./in./°F (K-factor), BTU/ft2/hr./F/in[6]	1.8	
Maximum Continuous Temperature °F (°C)	265 (103)	
Maximum Upset Temperature °F (°C)	400 (204)	
Heat Distortion Temperature (HDT)[7] @ 264 psi (D-648)	Above 340°F (171°C)	
Corrosion Resistance	See Technical Bulletin 405	
Fire Resistance	See Technical Bulletin 4000 & 402	

1. Post-cure: 1 hr. @ 140F (60C), 2 hrs @ 180F (82C), 1 hr. @ 200F (93C)
2. Construction: V-3M-V
3. Construction: V-3M-WR-M-V
4. Construction: V-3M-WR-M-WR-M-V
5. Determined by IITRI Compression Fixture Method
6. Determined by Comparative (a proposed ASTM procedure)
7. HDT will increase with increased post-cured of laminate.

V="C" glass surfacing mat
M=1 ½ oz. Chopped strand mat
WR=24 oz. Woven roving

Flexural Properties of QuaCorr Laminates as a Function of Temperature

Figures 2 through 5 depict the flexural properties of QuaCorr laminates at various temperatures. Results for laminates containing woven roving (Figure 3 and 5) as well as those constructed entirely of chopped strand mat (Figure 2 and 4) are included. The laminates were subject to two levels of post-cure prior to being brought to thermal equilibrium for testing. (See footnote below Figures 2-5 for fabrication and post-cured details).

In addition to illustrating the excellent strength retention characteristics of QuaCorr laminates, these data indicate the following:

a. Actual strength and modulus values for laminates containing woven roving generally are slightly higher than for those having all chopped strand mat reinforcement.
b. Flexural property reduction with increasing temperature is relatively linear for laminates cured at 250°F (121°C)
c. Properties of laminates post-cured at 180°F (82°C) plateau at higher test temperatures because of continued cure taking place during the testing operating.

Figure 2

Flexural Strength of QuaCorr Laminates Reinforced With Chopped Strand Mat

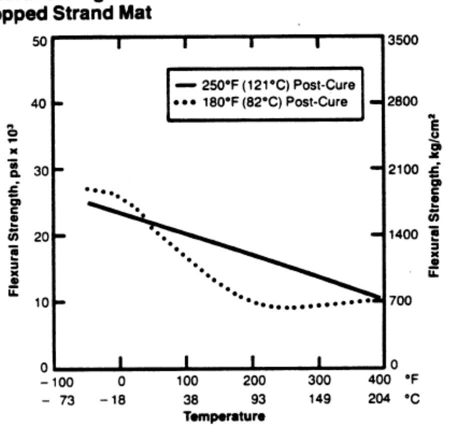


Figure 3

Flexural Strength of QuaCorr Laminates Containing Woven Roving Reinforcement

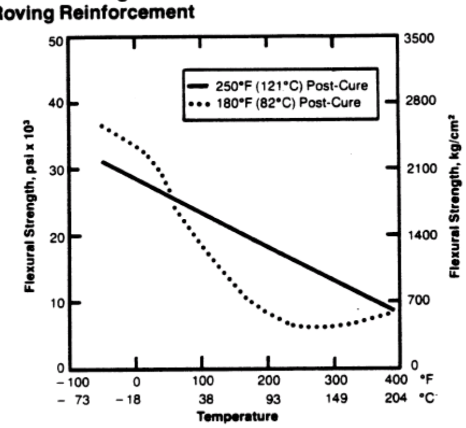


Figure 4

Flexural Modulus of QuaCorr Laminates Reinforced With Chopped Strand Mat

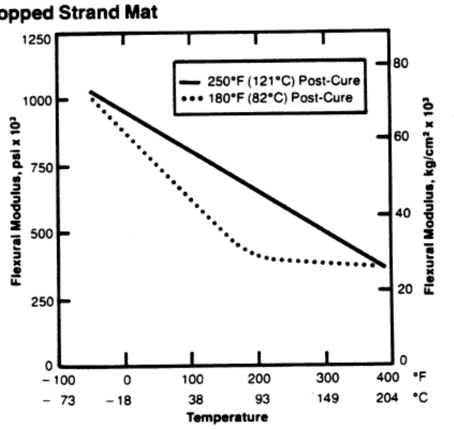
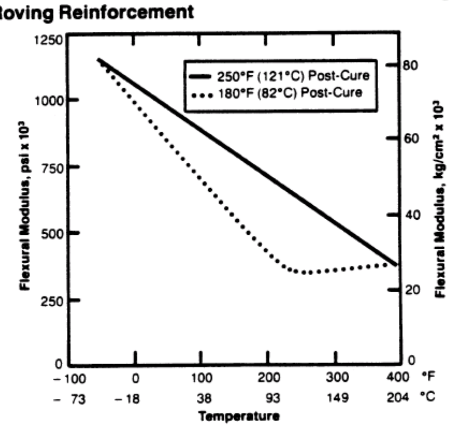


Figure 5

Flexural Modulus of QuaCorr Laminates Containing Woven Roving Reinforcement



Glass Reinforcement:
V = "C" glass surfacing mat
M = 1½ oz. chopped strand mat
WR = 24 oz. woven roving

All mat laminate:
Construction = V-6M-V
Average thickness = 0.264 inches
Glass content = 29.5%

Mat and woven roving laminate:
Construction = V-3M-WR-M-WR-M-V
Average thickness = 0.294 inches
Glass content = 33.9%

Post-cure:
180°F post-cure = 1 hour @ 140°F, 2 hours @ 180°F.
250°F post-cure = 1 hour @ 140°F, 2 hours @ 180°F, 1 hour @ 200°F, 2 hours @ 225°F, 2 hours @ 250°F.

Flexural and Tensile Properties of QuaCorr
Laminates Reinforced with Chopped Strand Mat

Table IV 180°F Post-Curve			*Table V 250° Post-Curve*		
Flexural Properties, psi (ASTM D-790)			Flexural Properties, psi (ASTM D-790)		
Test Temperature, °F*	Strength	Modulus	Test Temperature, °F*	Strength	Modulus
-50	27,200	1,012,000	-50	25,300	1,056,000
0	26,000	1,004,000	0	23,800	1,028,000
75	19,900	762,000	75	20,400	810,000
150	13,200	520,000	150	18,000	635,000
200	10,400	435,000	200	17,900	619,000
250	8,400	391,000	250	15,400	560,000
300	8,700	387,000	300	12,900	479,000
350	10,200	391,000	350	10,200	391,000
400	10,200	386,000	400	10,100	367,000
Tensile Properties, psi (ASTM D-638)			Tensile Properties, psi (ASTM D-638)		
Test Temperature, °F*	Strength	Modulus	Test Temperature, °F*	Strength	Modulus
-50	14,800	--	-50	--	--
0	12,700	--	0	--	--
75	12,800	984,000	75	10,800	1,079,000
150	12,200	783,000	150	11,200	773,000
200	10,800	608,000	200	12,300	761,000
250	10,500	613,000	250	10,800	692,000
300	10,700	699,000	300	10,100	635,000
350	10,800	667,000	350	10,800	704,000
400	10,300	665,000	400	10,000	597,000

*Specimens tested immediately upon equilibration at test temperature.

Flexural and Tensile Properties of QuaCorr
Laminates Reinforced with Chopped Strand Mat

Table VI 180° Post-Curve			*Table VII 250° Post-Curve*		
Flexural Properties, psi (ASTM D-790)			Flexural Properties, psi (ASTM D-790)		
Test Temperature, °F*	Strength	Modulus	Test Temperature, °F*	Strength	Modulus
-50	37,200	1,151,000	-50	31,800	1,149,000
0	34,600	1,003,000	0	28,600	1,035,000
75	19,900	834,000	75	23,300	906,000
150	12,800	575,000	150	24,500	793,000
200	10,200	466,000	200	20,100	707,000
250	6,300	339,000	250	16,900	644,000
300	7,100	364,000	300	13,400	539,000
350	9,500	465,000	350	10,200	420,000
400	8,600	400,000	400	8,900	382,000
Tensile Properties, psi (ASTM D-638)			Tensile Properties, psi (ASTM D-638)		
Test Temperature, °F*	Strength	Modulus	Test Temperature, °F*	Strength	Modulus
-50	18,600	--	-50	13,800	--
0	15,800	--	0	11,800	--
75	14,700	1,188,000	75	11,900	1,224,000
150	14,600	979,000	150	13,500	1,085,000
200	13,200	875,000	200	13,400	977,000
250	12,000	869,000	250	13,100	938,000
300	11,100	880,000	300	11,500	830,000
350	11,000	936,000	350	10,700	839,000
400	10,100	861,000	400	10,100	758,000

*Specimens tested immediately upon equilibration at test temperature.

FABRICATION CONSIDERATIONS
Good fabrication is very important in manufacturing equipment which will provide optimum performance. Both physical and corrosion resistant properties are affected by the quality of fabrication.

QuaCorr FRP equipment may be fabricated by hand lay-up, spray-up, and filament winding techniques.

Characteristics important in the fabrication to ensure quality laminates include:

1. Laminate construction should consist of both a corrosion barrier and a structural section. The corrosion barrier should be a minimum of 100 mils with a glass content of 25-29%. In addition to a thin gel coat containing a suitable glass surfacing mat, the corrosion layer should consist of at least three layers of resin impregnated 1.5 oz./sq. ft. chopped strand mat. The structural portion of the laminate may be constructed with all chopped strand mat, alternate layers of chopped strand mat and woven roving, or by filament winding.
2. While Barcol hardness is an indication of surface cure, it is important the laminate exhibit an equivalent degree of cure throughout.
3. Post-cure to 180°F (82°C) is recommended for all QuaCorr equipment to ensure adequate through cure. Equipment intended for elevated temperature use should have a maximum cure near the use temperature, but the post-cure should not exceed 250°F (121°C).

Handling of QuaCorr Resin/Catalyst Systems
Before working with the QuaCorr resin/catalyst systems, the “Storage and Handling” section and the material safety data sheets should be studied carefully and the safety procedures contained therein should be followed strictly.

Inspection and Quality Assurance
Quality fabrication is very important to performance of equipment. It is recommended that the end-user inspect the equipment during the course of fabrication and installation of the equipment.

All major components should be inspected after fabrication but prior to assembly. At this stage, laminate quality can be determined, and parts can be reworked or rejected with minimal costs.

Cut-outs should be obtained from all man-ways, etc. and inspected for void and delaminations. These cut-outs also should be used for confirmation of physical properties, glass content, and reinforcement sequence. Cut-outs must undergo the same post-cure as proposed for the equipment before undergoing testing for physical properties.

Careful inspection upon delivery is also required to determine if any damage has occurred during shipment.

In instances where an installation requires field assembly, care should be taken to assure that fabrication quality and post-cure during field assembly are equal to that performed in the shop.

Additional Information:
For technical service and other information or assistance, contact:

Penn Specialty Chemicals, Inc.
3324 Chelsea Avenue
Memphis, TN 38108
USA
Phone: 901-320-4028
Fax: 901-320-4007

Customer Service
(For orders or product inquiries)
Telephone: 1-877-952-3594
Fax: 901-320-4013

Additional Data

The following additional data is available upon request:

Material Safety Data Sheet – QuaCorr 1001 Resin
Material Safety Data Sheet – QuaCorr 2001 Catalyst