Polyester and Vinyl Ester Coatings

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Polyester and vinyl ester resin-based linings are known for their solvent and chemical resistance. The different resins in these linings have broad resistance ranges, with acid resistance being a major strength. Some of the specific resins resist 1 or more chemicals or types of chemicals better than other resins, so systems often are fine-tuned by the choice of resin for a particular chemical environment.

Esters are the reaction product of an organic acid and an alcohol. Polymers used in this class of materials are the unsaturated polyesters formed by reaction of unsaturated dibasic acids and dihydric alcohols. Styrene or a similar vinyl-type monomer is used to cross-link the resin and form the film. The polymerization is initiated by a catalyst, with the reaction by free radical addition, which is a chemical reaction mechanism unique to this class of coatings.

The word "lining" in the coatings industry is commonly defined as a material used to protect the inside surface of a tank, vessel, or similar structure from highly corrosive or potentially highly corrosive exposures. Linings can be monolithic systems or built-up systems. Because of their typically thick application and use in severe chemical conditions, polyesters and vinyl esters normally are referred to as linings. They offer good adhesion to most substrates, although most applications are on steel or concrete.

These linings include several systems varying in thickness, type of fillers and reinforcement, and application method. For each lining system, various polyester and vinyl ester resin bases are used to achieve the desired chemical resistance.

Table 1
Properties of Lining Fillers and Reinforcements

Silica Fillers	Most used, good permeation resistance, low cost
Carbon Fillers	Electrical conductivity or fluoride resistance
Hard Mineral Fillers	Increased abrasion resistance
Fiberglass Chopped Mat	Good chemical resistance
Fiberglass Woven Cloth	Strong, bidirectional reinforcement
Fiberglass "C" Grade Veil	Best chemical resistance
Synthetic Reinforcements	Where fluorides would attack glass
Glass Flakes	Best permeation resistance when aligned
Mica Flakes	Good permeation and chemical resistance

Tables courtesy of the author

History of Development

Since the 1960s, polyester and vinyl ester linings have been used extensively for their high chemical resistance. They previously had been used in mortars for chemical-resistant brick linings and fiberglass-reinforced plastic (FRP) structures such as tanks, pipes, and ducts, so their use in protective linings is a natural extension of their broad chemical resistance properties.

Early linings were reinforced with chopped fiberglass strands or woven fiberglass cloth (woven roving). Silica and other particulate fillers were incorporated to enhance physical properties and minimize curing shrinkage, the release of heat after mixing, and a high coefficient of thermal expansion compared to the substrate. These linings were applied by trowel and roller up to ¼ in. (6 mm) thick.

As these linings were developed, flake fillers were added to increase resistance to permeation by water vapor. This property is important for immersion or wet service at elevated temperatures. Glass and mica flakes were used to extend the service temperatures of the linings in hot, aqueous environments. This type of lining can withstand immersion temperatures of 180 to 212 F (82 to 100 C) at thicknesses of 60 to 150 mils (1.5 to 3.8 mm).

Thinner, spray-applied systems were formulated to reduce material cost and increase application rate.

Spray-applied systems of 2 coats, 15 to 20 mils (375 to 500 micrometers) each, proved to be useful for more economical chemical-resistant applications at temperatures up to 130 F (55 C). Eight to 10 mils (200 to 250 micrometers) per coat appears to be the practical minimum thickness for polyester- and vinyl ester-based coatings.

General Chemical Characteristics and Variations

This group of linings is based on unsaturated thermosetting resins (as prepolymers) that are dissolved in an unsaturated monomer (usually styrene) to form the resin component. By addition of a peroxide catalyst, a free radical addition reaction occurs that transforms the liquid resin into an infusible solid film. A free radical is a species that has an unpaired electron and is so reactive that it only has a transient existence. The free radical polymerization reaction occurs at the carbon-carbon double bonds (C=C) of the unsaturated moieties. Although the monomer may be volatile in its liquid state, it is the cross-linking agent, and it is incorporated into the film. Thus, these systems theoretically are 100 percent solids formulations. Evaporation is not required as in solvent-borne systems.

Table 2
Chemical Resistance Ratings for Polyester and Vinyl Ester Linings

	Generic Resin Type				
Chemical	**ISO**	**BIS-A**	**CHLOR**	**VINYL-E**	**NOV-VE**
Acetic Acid–10%	D1	C1	C1	C1	A1
Acetic Acid–100%	E2	D2	D2	D2	D1
Acetone	N	N	N	N	C2
Ammonium Hydroxide–20%	N	E1	N	E1	E1
Ammonium Nitrate	A1	A1	A1	A1	A1
Benzene	D2	D1	D1	E2	D1
Chromic Acid–10%	N	E1	C1	N	E1
Formaldehyde	A1	A1	A1	A1	A1
Formic Acid	E2	D1	D1	E1	D1
Gasoline–Unleaded	A1	A1	A1	A1	A1
Hydrochloric Acid–10%	E1	A1	A1	A1	A1
Hydrochloric Acid–37%	E2	D2	D2	D1	D1
Hydrofluoric Acid–10% *	E1	D1	D1	D1	D1
Kerosene	A1	A1	A1	A1	A1
Methylene Chloride	N	N	N	N	E2
Methyl Ethyl Ketone	E2	E2	E2	E2	D2
Nitric Acid–10%	D2	B1	A1	C1	A1
Nitric Acid–60%	N	D1	D1	N	D1
Oils	A1	A1	A1	A1	A1
Phosphoric Acid–85%	A1	A1	A1	A1	A1
Sodium Chlorate	B1	A1	A1	A1	A1
Sodium Hydroxide–10% *	N	D1	N	D1	D1
Sodium Hydroxide–50% *	N	C1	N	C1	C1
Sulfuric Acid–50%	B2	B1	A1	B1	A1
Sulfuric Acid–75%	E2	E1	E1	E1	E1
Toluene	N	E2	E2	E2	E1
Trichloroethylene	N	E2	E2	E2	E1
Vinegar (Acetic Acid–3%)	A1	A1	A1	A1	A1

These ratings are typical for polyester and vinyl ester linings and reflect the maximum recommended temperatures. Maximum temperature for any given lining type may be lower depending on lining thickness and permeation resistance. See Table 3.

Resin Abbreviations

ISO	Isophthalic
BIS-A	Bisphenol-A Fumarate
CHLOR	Chlorinated
VINYL-E	Vinyl Ester
NOV-VE	Novolac Vinyl Ester

Ratings

1	Good for immersion or constant flow
2	Limited to spillage or secondary containment
A	Good to 200 F (93 C)
B	Good to 180 F (82 C)
C	Good to 140 F (60 C)
D	Good to 120 F (49 C)
E	Good to 100 F (38 C)
N	Not Recommended

**Exposed lining surface requires carbon filler or synthetic veil*

Polyester prepolymers are produced by a condensation reaction of organic acids and polyols. The choice of reactants will establish the resulting polymer properties—mechanical properties, thermal stability, and chemical resistance. Commonly used polyols include bisphenol A, neopentyl glycol, and propylene glycol. The most common organic acid reactants are isophthalic acid, orthophthalic anhydride, terephthalic acid, fumaric acid, and maleic anhydride.

Vinyl ester resins are a type or subset of polyester resin. Vinyl ester prepolymers are formed by reaction of epoxy resin (polyol) with acrylic or methacrylic acid, which contains the vinyl group. Bisphenol A and novolac epoxies generally are used. Novolac-based vinyl esters are more reactive than bisphenol A and produce polymers with greater thermal stability and chemical resistance.

General Performance Properties

Strengths of Polyesters and Vinyl Esters

These resins generally are low in viscosity and cure quickly at ambi-

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ent temperatures without post curing. They offer excellent adhesion and high strength.

Polyesters and vinyl esters are known for their chemical resistance, although most are better in acidic environments than in strong alkaline conditions. (Alkaline solutions attack the ester linkage, reforming the polyol and a salt of the carboxylic acid.) They are resistant to organics, including solvents, as well.

Polyesters and vinyl esters are used in applications that require resistance to aggressive chemicals and elevated temperatures as high as 212 F (100 C) wet or 350 F (177 C) dry.

Uses include tank linings; floor linings; secondary containment linings; and coatings for structural steel, walls, and ceilings.

Limitations of Polyesters and Vinyl Esters

These resins undergo high shrinkage and give off heat during cure. The heat and the shrinkage produce a trapped tensile strain (pre-stress) that can lead to cracking or disbondment, especially at very low operating temperatures. If not reinforced, the resins are brittle.

Modification by addition of fillers or reinforcement to increase flexibility usually reduces resistance to chemicals and decreases thermal stability. The resins have a high coefficient of thermal expansion, so reinforcement is critical.

The resins generally are inhibited by contact with oxygen during cure. This inhibits surface cure, and the top (air-exposed) surface does not cross-link completely, significantly reducing chemical resistance. For thick linings, this usually is not a critical factor. However, for thin coatings (less than 40 mils or 1 mm), and for maximum chemical resistance, it may be critical. The tendency and degree of sensitivity to air inhibition vary greatly among the different resins in this group. Paraffinic additives often are incorporated in lining topcoats to reduce air inhibition by forming a film over the surface before cure.

Proper formulation is required to take advantage of the chemical resistance properties of these materials while minimizing potential pitfalls.

Lining Types and Components

Unreinforced Filled Systems

These products use a particulate filler to extend the base resin. Silica fillers, including graded, washed, and dried sands, along with crushed or fumed silica flour and other mineral fillers, are used. The preblended fillers usually are furnished

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as a separate component referred to as an aggregate.

At the time of application, the hardener (or activator) is first added to the resin component, and the 2 are mixed thoroughly. Next, the aggregate or filler is added and mixed until uniform. The compound is spread on the substrate, such as a floor, and troweled to the designated thickness. A typical thickness is ¼ in. (6 mm).

A high fill ratio (5 to 10 parts filler to 1 part resin by weight) is used to reduce cost, minimize curing shrinkage, and reduce the coefficient of thermal expansion of the film. Because this combination tends to be very rigid and brittle, flexibilizers may be added to the resin, reducing the chemical resistance. Use of these products generally is limited to concrete floors. They have high resistance to abrasion damage. They are relatively rigid, however, and will crack over moving cracks in the concrete.

Alternatively, this type of product may be installed by the broadcast system. There are several variations, but the most common method involves application of the resin/hardener mix, which is poured directly onto the concrete surface and spread by squeegee or roller.

Immediately, a filler is broadcast onto the surface by hand or mechanical means. It usually is applied to excess, until it no longer sinks into the resin and no resin is visible. After the resin cures, the surface is swept to remove the unbonded, excess filler.

This process may be repeated several times, depending on the thickness desired. Finally, 1 or more additional coats of the resin are applied to smooth and seal the surface. This system is generally ¹⁄₁₆ to ¼ in. (1½ to 6 mm) thick.

Reinforced Composite Linings

Fiberglass reinforcements are used extensively to add strength to a lining. In addition to increasing strength and resistance to cracking, they greatly reduce curing shrinkage and coefficient of thermal expansion. The relatively high modulus of elasticity of fiberglass and its ability to be bonded by the resin make it very effective for linings.

In addition to fiberglass reinforcement, one or more layers contain fillers such as silica, carbon, or hard mineral particles. These fillers are especially necessary for elevated temperature service in aqueous environments. Typical system construction for several lining types is shown in Figs. 1 and 2. Thickness generally ranges from ⅛ to ¼ in. (3 to 6 mm).

Most systems use preformed layers of chopped fiberglass strands or woven fiberglass "cloth." During lining installation, the fiberglass is saturated with catalyzed resin and rolled thoroughly to fully wet the individual glass strands and remove air bubbles.

A combination of chopped fiberglass strands and catalyzed resin also can be spray-applied using a chopper gun. Continuous strands of fiberglass called roving are chopped into short strands, typically 1 to 2 in. (25 to 50 mm), and injected into the catalyzed resin stream exiting the gun. Though effective for some applications, this method relies heavily on operator expertise to maintain reasonable control of thickness.

Chemical-grade fiberglass veil called "C" veil is more resistant to attack and normally is used as a top reinforcement layer. However, synthetic fiber reinforcements (e.g., polyester) are used on the top surface instead of the fiberglass veil for environments such as hydrofluoric acid or hot caustic that would attack glass.

Flake-Reinforced Linings and Coatings

Flake reinforcement is most effective at providing a barrier to permeation of the lining. The aligned flakes make the path of water or other contaminants through the resin much longer. Since the flakes are not permeable, water molecules must travel a much greater distance, and the resistance of the composite is greatly increased. This barrier effect is important for high temperature immersion service.

Trowel-applied glass flake-reinforced systems provide the highest permeation resistance since large glass flakes up to ⅛ in. (3 mm) in diameter can be incorporated (Fig. 3). These linings are rolled after application to minimize trapped air and assist in flake alignment. These systems normally are applied in 2 or more layers. Thickness ranges from 60 to 160 mils (1½

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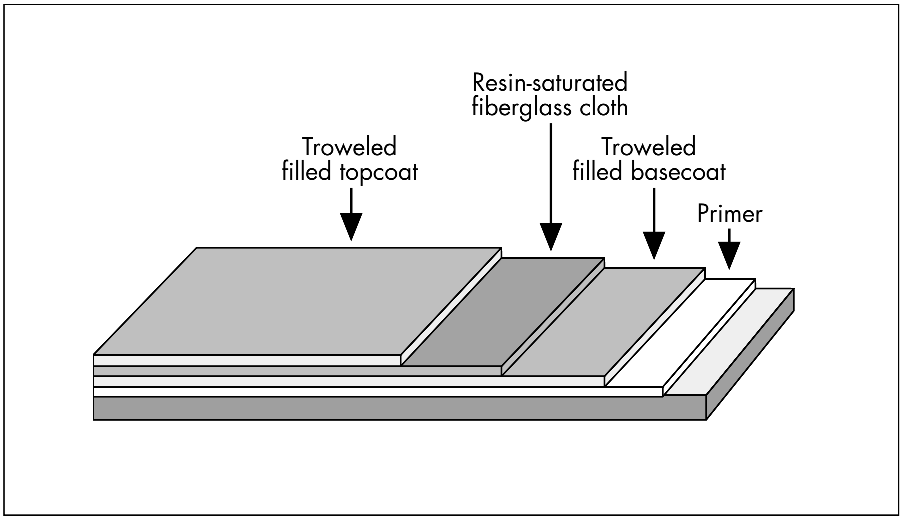

Fig. 1 - Fiberglass cloth-reinforced lining with filled basecoat and topcoat

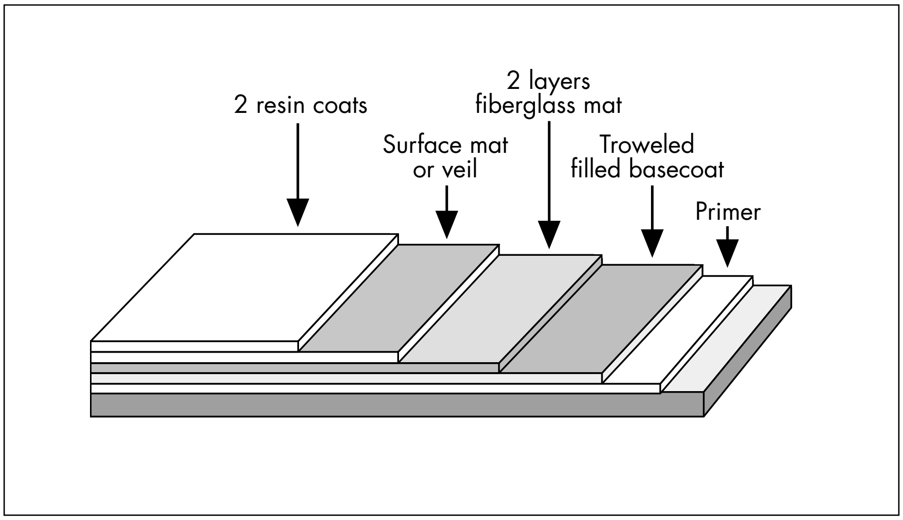

Fig. 2 - Fiberglass mat-reinforced lining with silica-filled basecoat

to 4 mm) for temperature service up to 200 F (93 C).

Smaller glass or mica flakes are used in spray-applied systems. The flakes, though not as well aligned, still provide a high degree of reinforcement and increased permeation resistance. Spray application reduces applied cost. Spray-applied systems typically withstand immersion temperatures of 130 to 150 F (54 to 66 C) when applied in 2 to 3 coats at 30 to 80 mils (¾ to 2 mm). In nonimmersion conditions, flake-reinforced polyester linings can withstand temperatures of 300 to 350 F (149 to 177 C), while vinyl esters can withstand 350 to 400 F (177 to 204 C). Thinner systems of 2 coats at 20 mils (½ mm) normally are recommended for mild, nonimmersion applications (Fig. 4).

Crack-Bridging Linings

Chemical-resistant polyester and vinyl ester linings are somewhat rigid but function well on steel substrates. However, they have very little, if any, ability to remain continuous without cracking or to bridge cracks in concrete substrates that open after the lining is installed. That is because the localized strain over the crack (the change in width divided by the original width) is ex-

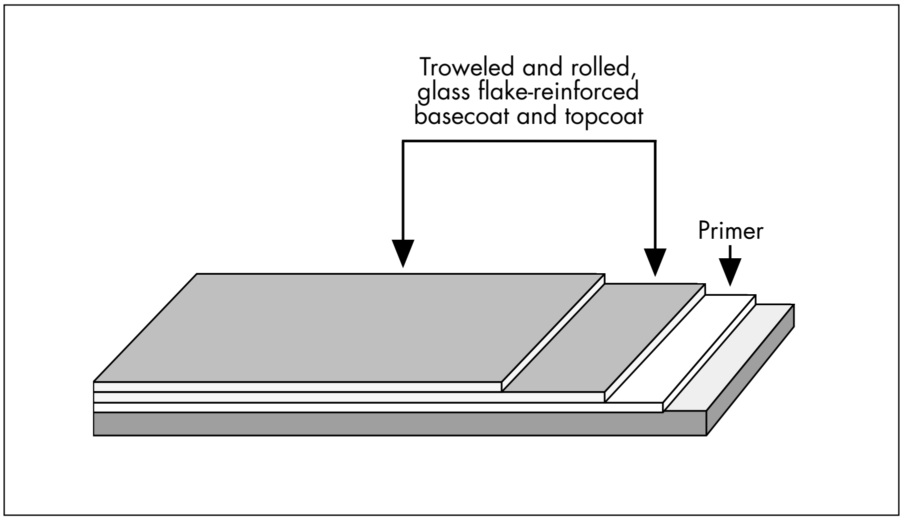

Fig. 3 - Troweled glass flake lining

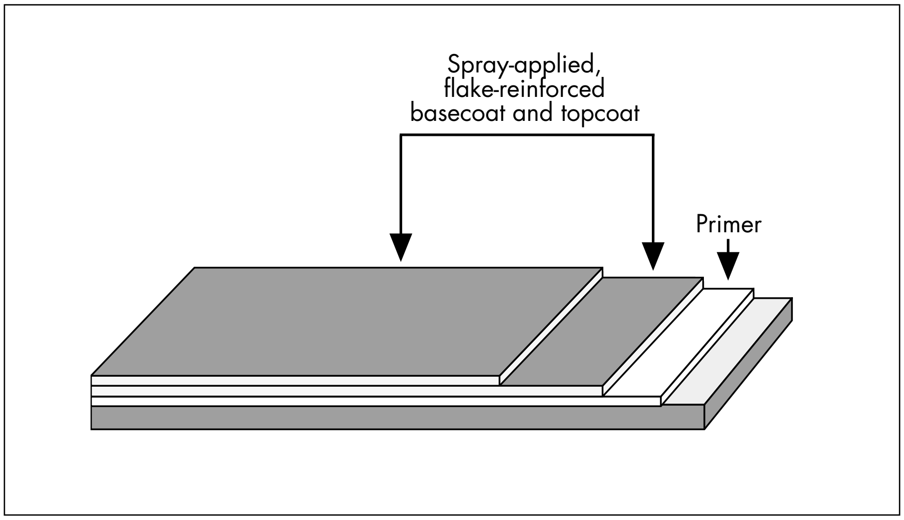

Fig. 4 - Spray-applied, flake-reinforced lining

tremely high and can cause a crack to propagate through the lining.

Making the resin more flexible is not a valid option, since that would reduce the chemical resistance. To provide the high chemical resistance of these linings and bridge crack movements in concrete substrates caused by shrinkage or thermal movement, special engineered composite linings have been developed.

These systems incorporate a very low modulus (soft) basecoat or membrane with a tough, high modulus, fiberglass-reinforced layer to "disengage" the lining from the substrate in areas of high strain, such as over moving cracks. The basecoat may be neoprene, urethane, or heavily flexibilized epoxy. In this way, the localized crack movement results in high shear deformation in the soft basecoat, and the high modulus spreads the strain over a wide area (4 to 20 in. or 102 to 508 mm) of the chemical-resistant top layers. The desired, highly resistant lining layer is applied over this decoupling system (Fig. 5). Essentially, the crack displacement is spread over a 6- to 12-inch (152- to 305-mm) width of lining so that the strain can be tolerated without cracking.

Other linings or lining systems, even fiberglass-reinforced linings, will crack when substrate cracks open as little as 2 mils (50 micrometers). Composite crack-bridging systems can accept crack movement up to 120 mils (3 mm) without cracking.

Lining Formulation

Even though the lining formats (reinforcement types and application steps) and the base resins of polyester and vinyl ester linings from different manufacturers may be the same, individual lining ingredients and performance may vary. This is because of the many interactive elements that make up the final lining or coating.

The resin and monomer combination must contain promoters to help initiate the reaction when the catalyst is added. Inhibitors are necessary to maintain a useful shelf life without pre-hardening or gelation of the resin. Flexibilizers may reduce brittleness, and pigments may provide color for appearance or to distinguish between coats during application.

Thixotropic agents and polar agents are combined to build the sag resistance necessary to hold thick layers on vertical or overhead surfaces before curing. Fillers, flakes, or reinforcements are essential to establish needed physical properties and reduce permeability. Wetting and coupling agents are used to maintain adhesion between the resin and the surfaces of the fillers. Leveling or flow agents may be added to provide smoother surfaces. Properties of key fillers and reinforcements are shown in Table 1.

Silica filler blends are the most cost-effective for building thickness for durability, permeation resistance, and reduced shrinkage and coefficient of expansion.

Carbon fillers and synthetic fiber reinforcements are used where silica

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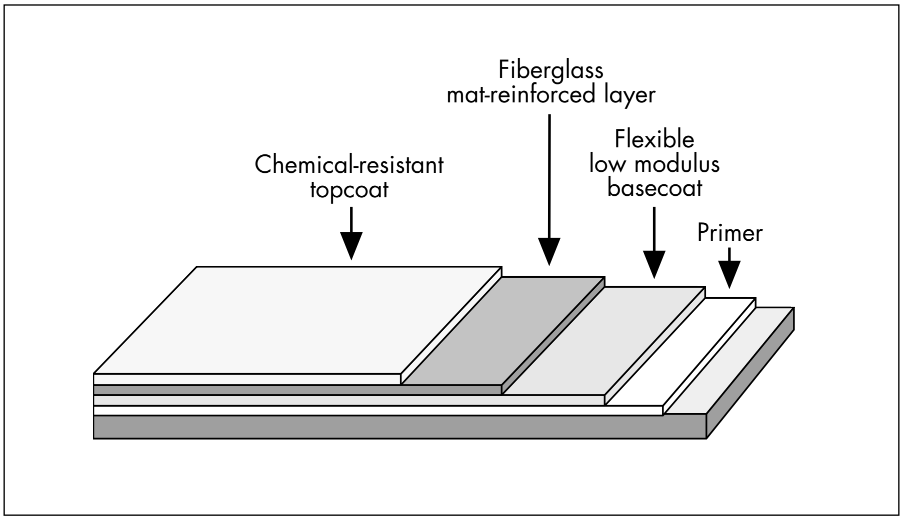

Fig. 5 - Crack-bridging lining system

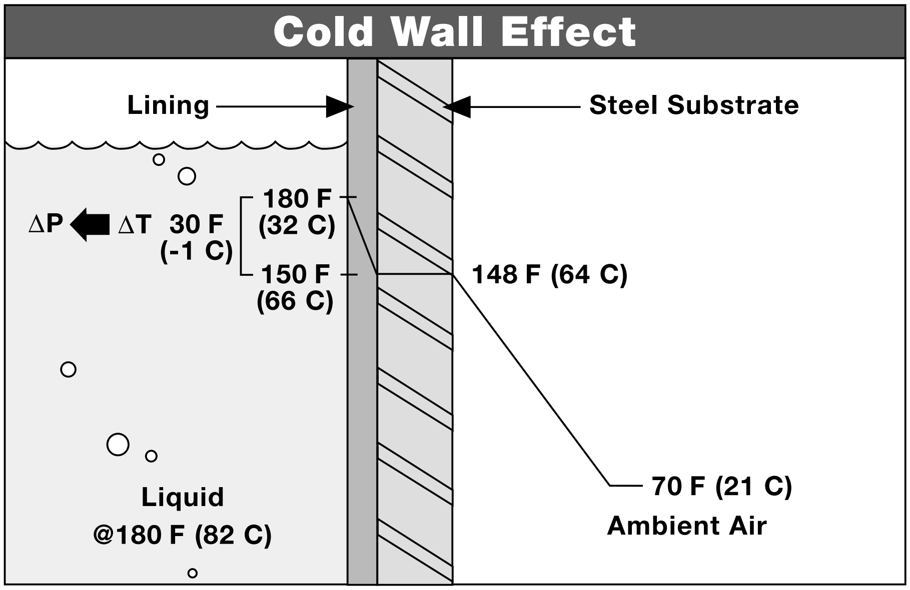

Fig. 6 - Greater water pressure at liquid-lining interface than at lining-steel interfaces drives water to lining-steel interface, possibly resulting in delamination.

would be chemically attacked. Carbon also is used to produce electrical conductivity on lining and flooring surfaces to discharge static electricity.

To increase abrasion resistance, hard mineral fillers such as aluminum oxide are incorporated. Glass fibers are most often used in thick lining systems in the form of chopped strand mat, woven cloth, and chemical grade surface veil. Flake fillers are most efficient in reducing permeation.

Physical And Performance Properties

Shrinkage and Coefficient of Thermal Expansion

Polyester and vinyl ester resins exhibit relatively high shrinkage during cure. On a volumetric basis, 8 to 10 percent shrinkage during cure is typical for the neat resin with no fillers, additives, or reinforcements. The coefficient of thermal expansion is 20 to 40 x 10^{-6} in./in./F (36 to 72 x 10^{-6}mm/mm/C). Because the linings

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are applied to rigid steel and concrete substrates, which have coefficients of thermal expansion of about 6 x 10^{-6} in./in./F (11 x 10^{-6}mm/ mm/C), fillers and reinforcements are important to minimize the stresses developed in the lining during cure and created by changes in temperature.

Given the thickness and rigidity of the substrates, the lining must accommodate thermal expansion and contraction of the surface to which it is applied. The lining must undergo the imposed strain and resulting stress without cracking, delaminating, or shearing from the substrate. The coefficient of thermal expansion for complete linings ranges from 12 to 15 x 10^{-6} in./in./F (22 to 27 x 10^{-6}mm/mm/C) for filled, reinforced systems and large glass flake-reinforced systems to more than 20 x 10^{-6} in./in./F (36 x 10^{-6} mm/mm/C) for spray-applied, mica-filled systems. Fortunately, these systems normally have enough flexibility to accommodate the thermal strains.

Adhesion

These systems have good adhesion to carbon steel, many other metals, and concrete. However, a coarse, angular abrasive blast profile is imperative on metallic substrates to help mechanically lock the coating into the surface so that it will withstand the stresses caused by curing and temperature changes.

Flexibility

The chemical-resistant base resins used to produce these linings are relatively rigid, with maximum elongation of 2 to 5 percent. Some specialty resins have higher elongation, up to 10 percent, but, generally, as elongation and flexibility go up, chemical resistance and thermal stability are reduced.

Adding fillers and reinforcements to strengthen and increase permeation resistance greatly reduces the elongation capability of the lining system. The amount of elongation or imposed strain that will crack these linings is typically from 0.25 to 0.5 percent. Manufacturers provide recommendations for the design of equipment to be lined with regard to the maximum strain or amount of flexing that their linings can reliably tolerate. Normal design for most carbon steel substrates, however, usually will be rigid enough, with maximum surface strains of 0.07 to 0.1 percent. Special emphasis should be placed on areas of high local strain or bending. These include floor-to-wall junctions of tanks and bottom areas with poor support. Certain types of storage tanks with lap-weld-

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ed bottoms require special attention in designing and applying the lining. Where tank bottom support is incomplete, grouting may be recommended to minimize flexing. Concrete, as a substrate, is much less flexible. Aside from crack movements, concrete strain will never exceed 0.01 to 0.02 percent.

Chemical Resistance

As previously stated, polyester and vinyl ester linings are used widely for their resistance to a broad range of chemicals. Isophthalic polyesters generally have poorer chemical resistance than vinyl esters and more chemical-resistant polyesters. However, isophthalic polyesters are less expensive than vinyl esters and other polyesters and may give adequate performance in a specific exposure environment.[1] Bisphenol A fumarate resins have the advantage of very broad resistance, including strong alkaline environments. Chlorinated polyesters, while not good in alkaline conditions, excel in strong mineral and oxidizing acids. Chlorinated polyesters are the best choice for strong chromic acid. Vinyl esters also offer resistance to a wide pH range and high temperatures. Novolac and other high molecular weight vinyl ester resins offer better stability in high temperatures and improved resistance to sulfuric acid.

Table 2 shows typical chemical resistance capabilities for a range of chemicals and resin types. The temperatures shown are maximums, and the type (thickness and construction) of lining may reduce the maximum temperature capability of the lining. Even though generalizations can be made for these linings based on the type of resin and reinforcement, performance will not be uniform because each product is a proprietary formulation. Consult the lining manufacturer for specific recommendations, and perform in-service coupon tests, if possible. When elevated temperature service is involved, the best test method is an application directly to the vessel wall so that the effect of the thermal gradient on permeation is evaluated.

Permeation Resistance

Because polyester and vinyl ester linings may be placed in immersion at elevated temperatures, high permeation resistance is necessary to avoid failure by blistering or loss of adhesion. Permeability is reduced by addition of reinforcements and fillers. The type and amount of filler are important to the lining's permeability. Large glass flakes, troweled and rolled for orientation parallel to

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Table 3
Permeability of Various Polyester and Vinyl Ester Linings

Lining Type			Permeability perm in. (g/Pa•s•m)	Thickness mils (mm)	Permeance perms* (g/Pa•s•m^2)	Relative permeance	Max. wet service F (C)
Resin	Filler/ Reinforcement	Application					
Novolac Vinyl Ester	1/8 in. (3 mm) Flake glass	Trowel & roll 2 coats	0.00011 (160E-15)	70 (1.8)	0.0016 (9.15E-11)	1	200+ (93+)
Bisphenol A Polyester	1/8 in. (3 mm) Flake glass	Trowel & roll 2 coats	0.00022 (319E-15)	70 (1.8)	0.0031 (1.77E-10)	2	200+ (93+)
Novolac Vinyl Ester	1/64 in. (0.4 mm) Flake glass	Spray 3 coats	0.00100 (1.4 E-12)	54 (1.4)	0.0185 (1.06E-09)	12	150 (66)
Bisphenol A Polyester	Silica filler fiberglass cloth	Trowel/roll & trowel topcoat	0.00310 (4E-12)	150 (3.8)	0.0207 (1.18E-09)	13	160 (71)
Bisphenol A Polyester	Silica filler fiberglass mat	Trowel basecoat mat/resin coats	0.00440 (6E-12)	125 (3.2)	0.0352 (2.01E-09)	22	160 (71)
Bisphenol A Polyester	Mica flake	Spray 2 coats	0.00160 (2E-12)	35 (0.9)	0.0457 (2.61E-09)	29	130 (54)
Bisphenol A Polyester	Fiberglass mat	Roller-applied fiberglass mat	0.00780 (11E-12)	60 (1.5)	0.1300 (7.44E-09)	81	120 (49)
Isophthalic Polyester	Mica flake	Spray 2 coats	0.00300 (4E-12)	18 (0.46)	0.1667 (9.54E-09)	104	120 (49)

** Perm = Grains of moisture/hr/ft^2/in. Hg (g/Pa•s•m^2)*

NOTE: "E" in the metric conversions for perms and perm inches stands for exponent (e.g., 9.15E-11 is the same as 9.15×10^{-11}).

the substrate, are most effective in reducing permeability. Silica, carbon, and other particulate fillers are effective because of the large amount that can be added to the resin, resulting in the ability to build a thicker layer. Fiberglass, in various forms, though very effective for reinforcement, does little to reduce permeation because of the small amount that can be used (5 to 20 percent by volume).

Permeability and lining permeance for various lining types are shown in Table 3. Permeability is the property of the material regardless of thickness, and permeance (permeability divided by thickness) is the property of a lining at a given thickness. These properties are measured using the procedure outlined in ASTM E 96, Test Methods for Water Vapor Transmission of Materials.

Note the great difference in permeability using different fillers. Aligned glass flake fillers are by far the most effective in reducing permeability and, in turn, increasing ability to withstand higher temperature immersion service.

The maximum wet service temperature tends to follow the lining permeance. This temperature is best established by testing the lining in accordance with ASTM C 868, Test Method for Chemical Resistance of Protective Linings. This method is for testing by the one-sided immersion or Atlas cell test. It is an important laboratory test for evaluation of linings to be used in aqueous environments at elevated temperatures because of the "driving force" created by the temperature gradient within the lining—cooler at the substrate than at the immersed surface (Fig. 6). Commonly referred to as the "cold wall effect," this can cause condensation of water at the substrate surface, resulting in corrosion and blistering.

Uses of Polyesters and Vinyl Esters

Polyester and vinyl ester lining systems are used for top to bottom protection of industrial plants and equipment, especially where acid or organic chemicals are present. These uses include protective, spray-applied coatings for ceilings, walls, hoods, ducts, and tank exteriors; interior tank linings; reinforced flooring for process spillage areas; and trenches, sumps, and secondary containment surfaces.

There are many applications for these products throughout the

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chemical process industry and in a variety of other industries that handle corrosive chemicals. Examples are given below.

- In primary metals plants, these products may serve as reinforced linings to protect concrete floors, foundations, and trenches from acids used for pickling.
- The pharmaceutical industry uses reinforced vinyl ester for sanitary protection of process floors exposed to acid and organic solvent spills. Special crack-bridging versions are used for truck unloading areas and secondary containment basins.
- For more than 25 years, the power industry has used flake-reinforced and fiberglass-reinforced linings for scrubbers, tanks, ducts, and stacks to protect critical flue gas desulfurization (FGD) equipment for long-term service.
- The waste treatment industry continues to use these systems for storage and neutralization tanks, unloading areas, and secondary containment basins.
- Chlorine producers use flake-reinforced linings for elevated temperature brine storage tanks.
- Municipal sanitation facilities use fiberglass- and flake-reinforced linings and coatings for grit chambers, sumps, and wet wells.
- Glass flake-reinforced polyester linings are used in food-related applications such as starch tanks.

Application Considerations

Environment

Temperature of the surface and the adjacent air typically should be between 45 and 120 F (7 and 49 C) during product application to provide proper cure. Excessive temperature can cause bubbling, pinholing, or high thermal stress in the finished lining. Consult the manufacturer's literature for the exact temperature range.

The surface temperature should be at least 5 F (3 C) above the dew point of the air in the work area to avoid condensation or application on a wet surface.

Surface Preparation

Because of the generally high thickness of these systems and their use at elevated temperatures, proper surface preparation is essential to product performance.

Concrete surfaces should be abrasive blasted and have sufficient tensile strength for the system being applied. Minimum acceptable tensile strength is about 200 to 300 psi (1.4 to 2.1 MPa), which is the maximum tensile strength achieved by portland cement concrete. Surface tensile strength can be determined in accordance with ASTM D 4541, Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Testers.

Steel should be blasted with a coarse, angular abrasive to produce a minimum profile of 3 mils (75 micrometers). Shot blasting produces a peened surface, so grit blasting is required.

Stainless steel and alloys may require harder or larger blast media or higher blast pressures to achieve the desired profile. Surface cleanliness in accordance with SSPC-SP 5, White Metal Blast Cleaning, is almost always required.

Product Application

Application procedures for these thick-film lining systems include troweling, rolling, and spraying. Applicators should have special training and experience with the method being used, and they should closely follow the recommendations of the lining manufacturer for equipment and procedures.

Components of the material should be mixed in strict accordance with published procedures. Thickness and time between coats should be within allowable limits.

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Quality Control Procedures

Quality control procedures should verify environmental conditions during surface preparation and application, proper mixing, applied thickness, and continuity of the lining.

Since lining thickness is important to establish a barrier to chemical attack and permeation, it should be checked at pre-established spacing or locations to ensure that the minimum allowable thickness has been applied.

Excessive thickness may detract from lining performance by causing cracking, so a maximum thickness is usually established. Dry film thickness is checked using various magnetic gauges on steel substrates and eddy current gauges on other metallic substrates. Coating thickness on concrete is checked with wet film gauges during application.

Lining continuity—the absence of holes through the lining—is important so that corrosive material does not have a path to attack the substrate. For these thick linings, the only practical method of inspection is with a high voltage holiday detector.

NACE RP 01-88, Standard Recommended Practice for Discontinuity (Holiday) Testing of Protective Coatings, presents the method for high voltage spark testing. Consult the lining manufacturer for the maximum voltage to use. Where a hole in the lining exists, the high voltage will cause a spark to jump through to the substrate. Using too high a voltage may produce a holiday in the film.

Steel substrates are, of course, very conductive. Concrete substrates usually require special conductive primers for reliable testing. The method recommended for testing on concrete surfaces is ASTM D 4787, Standard Practice for Continuity Verification of Liquid or Sheet Linings Applied to Concrete Substrates.

Health and Safety Precautions

Procedures for protecting workers' safety and health are contained in the lining manufacturers' published installation instructions and Material Safety Data Sheets. Worker protection procedures should be followed carefully. Following are some general comments about exposure levels and the risks of styrene.

The American Conference of Governmental Industrial Hygienists has determined that styrene monomer has a threshold limit value (TLV) of 50 ppm as an eight-hour, time-weighted average (TWA). Areas where styrene is used should be well ventilated to avoid buildup of fumes.

Overexposure to styrene is reported to have adverse health effects on workers. Proper skin protection should be worn, and appropriate respiratory protection should be used, especially if styrene vapors exceed 50 ppm. Among the observed effects are skin irritations; eye, nose, and throat irritations; depression of the central nervous system; damage to the peripheral nervous system; and chromosomal changes. Although styrene has been classified as a possible human carcinogen, studies have not followed enough workers long enough to accurately assess the cancer risks of occupational exposure.[2]

Uncured resins are flammable, so no welding or open flames should be allowed in or near the work area.

Conclusion

A wide range of polyester and vinyl ester lining products is being used for high performance, cost-effective protection of steel and concrete surfaces subject to chemical environments. Other advantages of these systems include their adhesion, strength, flexibility, solvent resistance, and heat resistance.

However, chemical resistance may be reduced by the addition of fillers or reinforcements and by contact with oxygen during cure. Also, they usually perform better in acidic than in alkaline environments. Particulate filler or aggregate is added to some polyester and vinyl ester lining systems to extend the base resin.

In other cases, they are reinforced with various kinds of fiberglass or with glass or mica flakes. These thick-film lining systems typically are applied by trowel, roller, or spray equipment. Proper lining thickness is essential to provide effective protection in a myriad of industrial uses. ***JPCL***

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