66

USING PLASTICS, ELASTOMERS, AND COMPOSITES FOR CORROSION CONTROL

P. R. Khaladkar
E. I. DuPont de Nemours & Co. Inc., Wilmington, Delaware

A. INTRODUCTION

This chapter provides a broad overview of the application of polymers used for corrosion control in the chemical processing industry. The generalizations offered about polymer performance might suggest possible approaches, but they should not be considered as recommendations owing to the complexity of equipment design and the many variables of chemical processing. Consultations with experts, analyses of case histories, and testing are essential to the success of these materials.

Although a great deal of information regarding chemical resistance is available, much of it is not directly useful in selecting an appropriate construction material. It does, however, serve as a first step in determining likely candidates.

Polymer-based materials are attractive candidates due to their chemical resistance and favorable strength/weight ratio. Their use, however, is limited due to their viscoelastic nature and inability to withstand high temperatures. An overview of

Uhlig's Corrosion Handbook, Third Edition, Edited by R. Winston Revie

the use of polymer-based materials for corrosion control is presented in this chapter. All the same, these materials are used very cost effectively in many corrosive and hazardous applications.

B. OVERVIEW OF PLASTICS, ELASTOMERS, AND COMPOSITE MATERIALS

In their final useful form, plastics, elastomers, and composites are polymers made from organic chemicals. Polymers are long-chain molecules consisting of repeating units called monomers. Monomers are predominately manufactured from oil and natural gas, although exceptions exist in naturally occurring rubber and wood. A process of polymerization converts these monomers into polymers. Figure 66.1. illustrates different polymer structures. The polymers are then shaped into final forms using one of several molding processes, such as injection molding, extrusion, transfer molding, and so on. Appropriate fillers can be added during these processes to achieve certain desirable properties such as chemical resistance, strength, and processability. The end results of polymer processing are shapes and forms, which are referred to as plastics, elastomers, and composites. There is a great deal of overlap in these materials and the use of these terms has more to do with the evolution of the terminology than technical accuracy.

To describe polymeric materials more accurately, the following three distinct classifications are used:

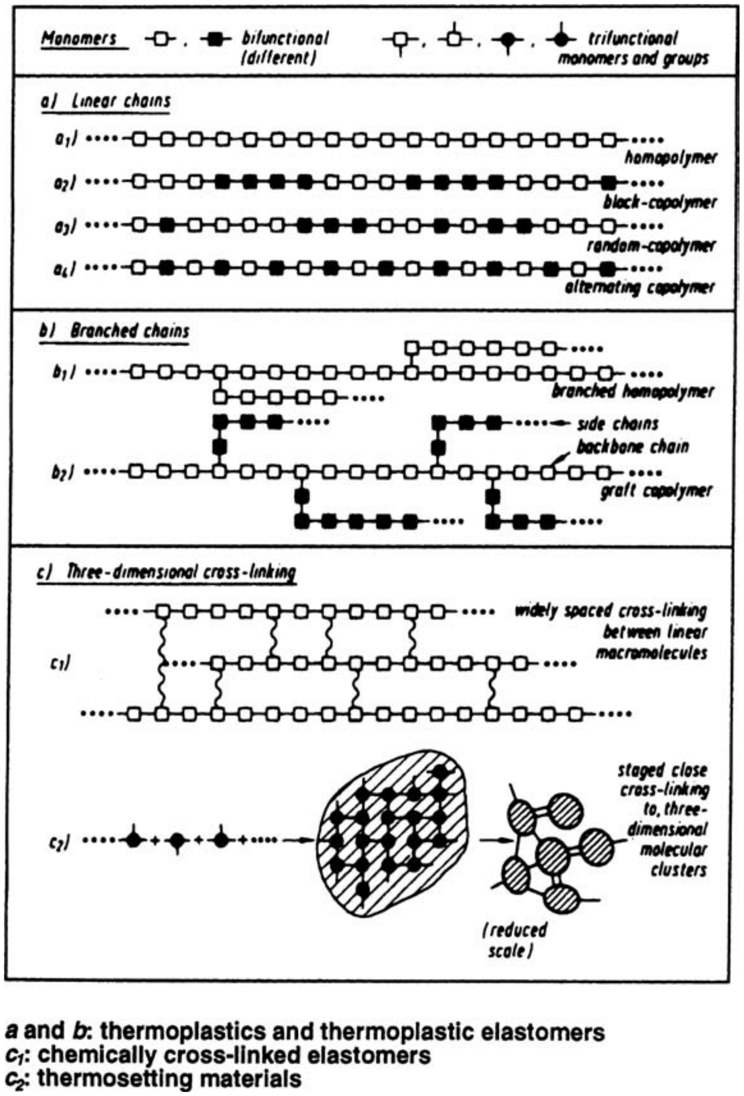


FIGURE 66.1. Bi- and trifunctional polymer structures. (Reprinted with permission from the International Plastics Handbook, Hanser Gardner Publishers.)

- Generic nature
- Thermal processing behavior
- Mechanical behavior

Polymers are classified by generic nature according to the organic family to which it belongs. Examples are polystyrene, vinyls, fluoropolymers, and so on. These polymer families typically have several members.

Polymers are also classified by their *thermal processing characteristics* (i.e., thermoplastics or thermosetting). Thermoplastics can be remelted and reprocessed somewhat like ice cubes can be melted and refrozen into new shapes. These materials can be welded and are soluble in certain solvents. Thermoplastics are either amorphous or semicrystalline. Thermosetting materials cannot be remelted or reprocessed and heating them to high temperatures will result in their thermal decomposition and charring. Thermosetting properties are due to their cross-linked structures, which are achieved by the cure process (For elastomers, this process is known as vulcanization). Certain solvents can swell thermosetting materials. Figure 66.2 schematically illustrates thermoplastic and thermosetting materials.

Examples of thermoplastic polymers are:

Acrylics
Fluoropolymers
Vinyls
Polystyrenes
Polyphenelyne oxide
Polysulfones
Polypropylenes
Polybutylenes

Examples of thermosetting materials are:

Epoxies
Melamines
Phenolics
Polyesters
Urethanes (rigid)

The chemical structures of thermoplastic polymers commonly used for corrosion control are shown in Figure 66.3. Polymers can also be classified by their *mechanical properties* as

1. Rigid plastics, elastic modulus > 100,000 psi (7031 kg/cm^2)
2. Semirigid plastics, modulus between 10,000 and 100,000 psi (703 and 7031 kg/cm^2)
3. Nonrigid plastics, modulus < 10,000 psi (703 kg/cm^2)

If semirigid or nonrigid plastics additionally possess properties of high elongation and high recovery, they are known as elastomers or rubbers. Elastomers are defined by the American Society for Testing and Materials (ASTM) as "a macromolecular material that returns rapidly at room temperature to approximately its initial dimensions and shape after substantial deformation by a weak stress and the subsequent release of the stress." Elongation at the breaking point is known to be as high as 900% for many elastomers. Most commonly used elastomers are thermosetting in nature, that is, they are crosslinked. There are a few elastomers which are thermoplastic in nature. They are known as thermoplastic elastomers (TPEs). These, however, do not have applications in chemical handling.

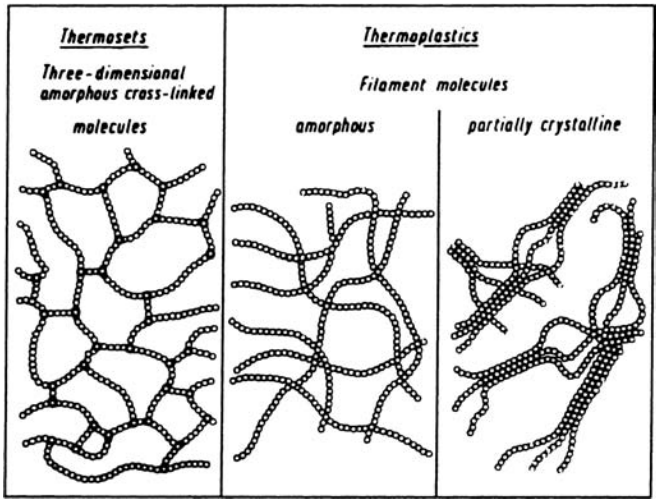
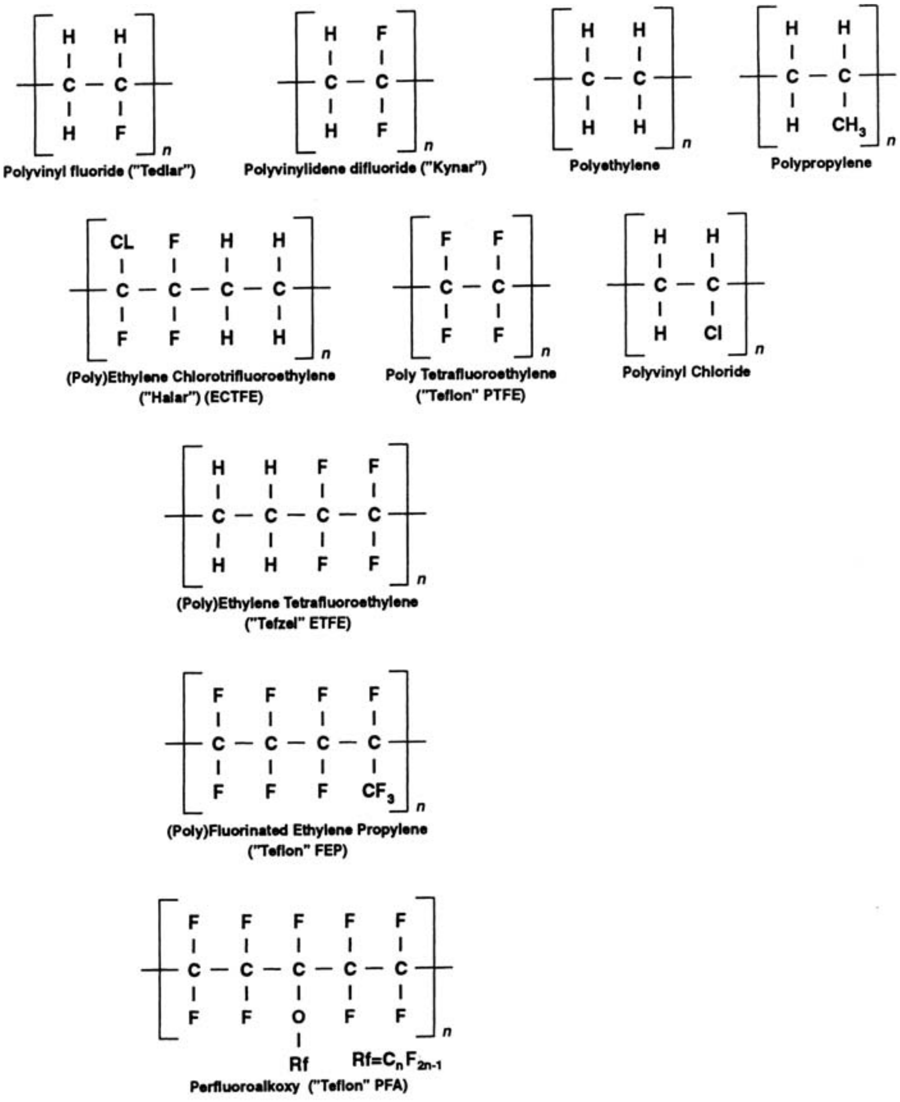


FIGURE 66.2. Structure of plastics-macromolecular arrangements. (Reprinted with permission from the International Plastics Handbook, Hanser Gardner Publishers.)



"Tefzel", "Tedlar" and "Teflon" are a trademarks of DuPont
Halar is a trademark of Solvay Solexis
Kynar is a trademark of Arkema

FIGURE 66.3. Chemical structures of some thermoplastic polymers used for chemical handling.

It becomes apparent that a complete description of a polymer material must include its generic nature, thermal processing method, and classification of its mechanical properties. For example, the rubber lining used for hydrochloric acid (HCl) is polyisoprene (chemical nature), thermosetting, (thermal processing), and elastomeric (mechanical properties).

Composite materials are a combination of two generically dissimilar materials brought together for synergy where one phase, the matrix, is continuous (thermoplastic or thermosetting) and the other phase, usually a reinforcement, is discontinuous. Reinforcements can be in the form of particulates, fibers, or cloth. A full description of a composite material must also include information on the reinforcement form. Examples of composites are fiber-reinforced plastic (FRP) tanks and piping, filled fluoropolymer gaskets, scrim-filled elastomers for gaskets, and impoundment basin liners. Wood is a naturally occurring composite with lignin as the matrix and cellulose fibers as the reinforcing material.

C. CHARACTERIZATION OF POLYMERS

Polymer-based materials are characterized by their mechanical properties (tensile strength, tensile modulus, flexural modulus, elongation at break, impact strength, and hardness), thermal properties (melting point, melt flow index, transition temperature, heat distortion temperature, and coefficient of expansion), electrical properties (dielectric strength), and chemical compatibility (weight gain/loss, swelling, chemical attack such as oxidative or hydrolysis). At a more fundamental level polymers are also characterized by molecular weight and molecular weight distribution, specific gravity, crosslink density, and void content. A list of standard ASTM tests is given in Table 66.1. Manufacturers usually report these properties measured at room temperature. To determine these properties at other temperatures, the user should perform his or her own testing.

Polymer characterization is important from the standpoint of materials selection, processability, long-term performance, and failure analysis.

D. COMPARISON OF POLYMERIC MATERIALS WITH METALS

Compared to metals, most polymeric materials are viscoelastic, that is, they creep. This property has implications in all applications of corrosion control. Polymeric materials also are limited in their ability to withstand higher temperatures. By and large, their use as linings is restricted to 500°F (260°C) and most applications are under 300°F (149°C). Polymer structures such as tanks and piping are rarely used above 200°F (93°C). Polymeric materials are nonhomogeneous as a result of the addition of additives and reinforcements. They absorb liquids more readily than metals and are more permeable than metals. Therefore, unit properties (mechanical, electrical, etc.) of polymers can change over a period of time whereas the unit properties of metals remain the same even after corrosion. Polymer structures and linings are very workmanship sensitive. The supply chain leading up to the final product can be long and complicated. Each step in the chain has an element of workmanship. Polymeric materials do not lend themselves to easy identification once they are in the field. Failure analysis, condition assessment by nondestructive testing (NDT), and accelerated testing for selection are evolving fields. However, there are applications where only-polymeric materials have the required chemical resistance and cost-effective performance. When the end user has stayed involved in all phases of application (e.g., selection, lab and field testing, specification, vendor selection, inspection, maintenance, repair, and replacement), the results have been extremely satisfactory.

E. APPLICATION OF POLYMERS FOR CORROSION CONTROL

Polymeric materials fall into three broad categories from the end-user perspective:

- Barrier applications
- Self-supporting structures (which can be made of composites or solid polymers in tanks, piping, valves, pumps, and other equipment)
- Others such as column internals, seals, gaskets, adhesives, and caulks

Figures 66.4 (a)–(c) show the organization of polymer-based materials used for corrosion control.

F. BARRIER APPLICATIONS (LININGS AND COATINGS)

F1. Introduction

Linings are barriers typically on steel or concrete substrates. In special cases, a lining is also applied to a FRP structure called dual laminates.

Just about all components can be lined for corrosion control. Examples include storage tanks, reaction vessels, columns, piping, valves, pumps, sumps, trenches, and transportation equipment such as railcars and tank trucks. The following polymeric materials are used as linings or coatings:

Thermoplastic: polyvinylchloride (PVC, CPVC), polypropylene (PP), polyethylene (PE), and ethylene copolymers, fluoropolymers (PTFE, FEP, PFA ETFE). Figure 66.3 shows the chemical structures.

Thermosetting: epoxies, phenolics, vinyl esters, elastomeric (natural and synthetic rubbers).

Linings can be classified as follows:

- By method of application: sheet, spray or trowel.
- By thickness: thin [<25 mils (635 μm)] or thick [>25 mils (635 μm)]
- By generic nature

The lining selection is most often determined by the desired thickness. Successful lining applications must take the following steps into account:

Selection of linings
Design of the vessel for lining
Specification writing
Vendor selection
Surface preparation
Application/installations
Inspection
Monitoring

These steps are common to all types and forms of linings. Linings differ in their installation, inspection, and monitoring methods. Linings can be applied both in the shop and field. Where possible, shop lining should be preferred because of better atmosphere control.

TABLE 66.1. Industry Codes and Standards

	Product
ASTM D2310	Standard classification of machine made reinforced thermosetting resin pipe
ASTM D2517	Standard specification for reinforced thermosetting (epoxy) resin pipe
ASTM D2996	Standard specification for filament-wound reinforced thermosetting pipe[a]
ASTM D2997	Standard specification for centrifugally cast-reinforced thermosetting pipe
ASTM D4024	Standard specification for reinforced thermosetting resin flanges
ASTM D3299	Standard specification for filament-wound glass fiber-reinforced thermoset resin chemical tanks
ASTM D4097	Standard specification for contact-molded FRP chemical-resistant tanks
ASTM F1545	Standard specification for PTEE, PFA, FEP and ETFE lined piping
ASTM F492	Standard specification for PE and polypropylene (PP) plastic-lined ferrous metal pipe and fittings
ASTM D1784	Rigid poly(vinyl chloride) (PVC) compounds and chlorinated poly(vinyl chloride) (CPVC) compounds
ASTM D1785	Standard specification for poly(vinyl chloride) (PVC) plastic pipe, schedules 40, 80, and 120
ASTM D3350	Standard specification for polyethylene pipe and fitting materials
ASTM D1248	Polyethylene molding and extrusion material
ASTM D4020	Ultrahigh-molecular-weight polyethylene material
ASTM D1123	Nonmetallic (rubber) expansion joints
ISO 3994	Chemical transfer hose
ASTM D2564	Solvent cements for PVC (CPVC) joints
ASTM D1998	Polyethylene upright storage tanks
ASTM F118	Definition of gasket terms
ASTM F104	Nonmetallic gasket materials
ASTM D1330	Standard specification for rubber sheet gaskets
	Compatibility Testing
ASTM D543	Test methods for determining chemical resistance of plastics
ASTM D471	Effects of liquids on rubbers, test method
ASTM C868	Test method for determining chemical resistance of protective linings
ASTM C581	Test method for chemical resistance of fiberglass-reinforced thermosetting resin
ASTM C3491	Chemical resistance test for rubber linings by Atlas blind flange test
ISO 175	Determination of effects of liquid chemicals on plastic
ISO 4599	Determination of environmental stress cracking (ESC) by the bent-strip method
ISO 4600	Determination of environmental stress cracking (ESC) by the ball or pin impression method
ISO 6252	Determination of environmental stress cracking (ESC) by the constant tensile test method
ISO 8308	Liquid transmission and permeation through hose and tube
ASTM F363	Corrosion testing for gaskets
ASTM F146	Fluid resistance of gasket materials
ASTM D3615	Chemical resistance of thermoset molded compounds used in the manufacture of molded fittings
ASTM D3681	Chemical resistance of reinforced thermosetting resin pipe in a deflected condition
(Not Standardized)	Roberts cell blind flange test for linings exposed to high temperatures and pressures
	Testing for Mechanical Properties
ASTM D638	Standard testing for tensile properties of plastic
ASTM D412	Standard testing for tensile properties of rubbers
ASTM D1415	Test method for indentation hardness of rubbers—international hardness
ASTM D2240	Test for Durometer hardness of rubbers
ASTM D2538	Indentation hardness by Barcol hardness tester for rigid plastics
ASTM F38	Creep relaxation of gasket material
ASTM D395	Compression set of rubbers at ambient and elevated temperatures
ASTM F152	Tension testing of gasket materials
ASTM F36	Short-term compressibility and sealability of gasket materials
ASTM F37	Sealability of gasket material
ASTM F586	Determination of Y and M values of gaskets
ASTM D2290	Apparent tensile strength of tubular (pipe) products by the split-disk method
ASTM D2412	External loading characteristics of plastic pipe by parallel-plate loading
ASTM D695	Compressive properties of plastics
ASTM D429	Adhesion of rubbers to metallic substrates (procedure E1)
ASTM D1781	Climbing drum peel test
ASTM D903	Peel strength of adhesives on metals
ASTM D790	Flexural properties of reinforced and unreinforced plastics

TABLE 66.1. (*Continued*)

	Product
ASTM D2584	Ignition loss of cured reinforced resin
ASTM D4541	Method of pull-off strength of coatings using portable tester
ASTM D4060	Test method for abrasion resistance of organic coatings
	Recommended Practices and Procedures
SSPC SP-5	Steel structure paint council white metal blast surface preparation
SPI FD118	Proposed test method for pinhole detection by high-voltage spark testing by DC
MTI Project 84	Spark testing practices for linings
NACE PRO 118	Tinker Rasor wet sponge testing for thin linings
ASTM D4787	Practice for continuity testing for linings on concrete
ASTM D4417	Method for measuring surface profile of steel surfaces for coating
ASTM D4258	Cleaning of concrete
ASTM D3486	Installation of vulcanizable rubber tank linings
	Codes
RTP-1	Reinforced Thermoset Plastic Corrosion Resistant Equipment, ASME, NY
Section X	ASME Boiler and Pressure Vessel Code (for fiber-reinforced plastic pressure vessels)
ASME B31.3	Chemical Process, Petroleum Refinery Piping Code

Note: Additional application-specific tests are shown in Table 66.2.

[a]There is no industry standard for contact molded FRP piping.

F2. Selection

Thickness forms the basis of the lining selection. Thickness is in turn dependent on the corrosion rate of the substrate, which is carbon steel (CS) in the majority of cases. Thin linings $\leq$25 mils 635 μm) are used if the corrosion rate of the CS is $<$0.25 mm/year (10 mils per year (mpy)). Thin linings are also used for localized corrosion resistance and in the case of thin fluoropolymers for nonstick and product purity. Thick linings $>$25 mils (635 μm) are used if the corrosion rate of the CS is $>$0.25 mm/year (10 mpy). Therefore, the corrosion rate of CS is an important determining factor. Linings used for concrete are almost always thick and are of reinforced thermosetting

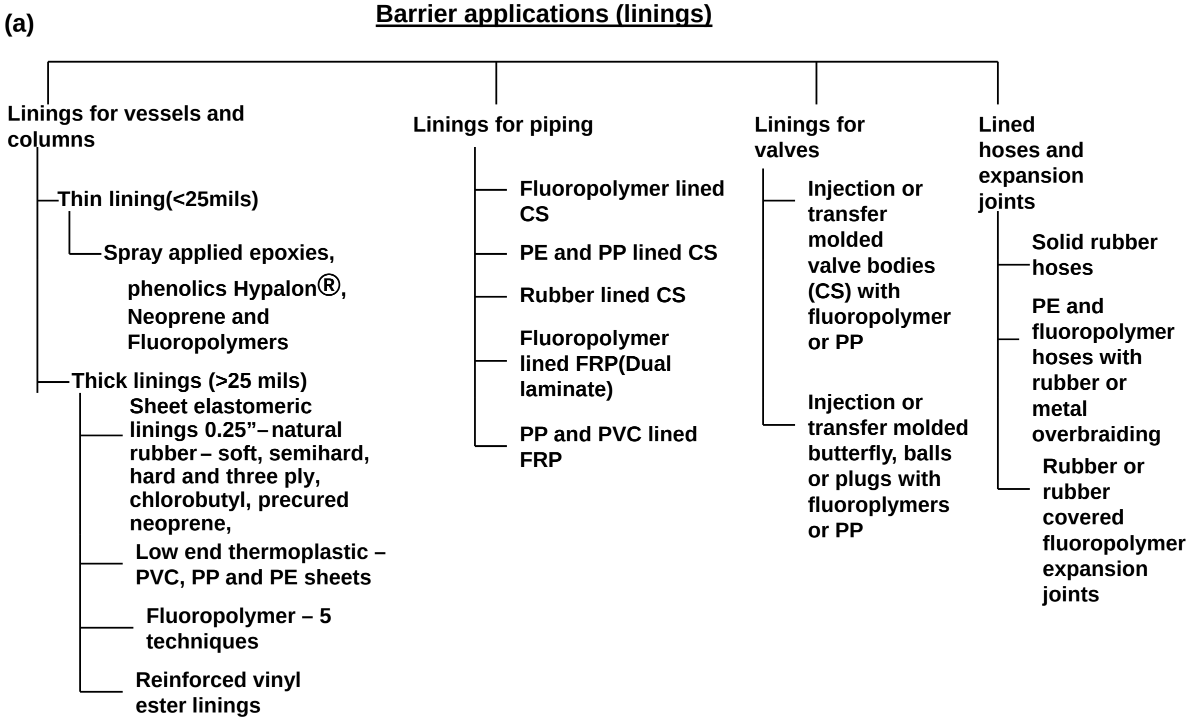


FIGURE 66.4. Overview of polymer-based materials for corrosion control showing classification of polymer-based materials by application: (a) barrier applications (linings); (b) self-supporting structures (vessels, piping, and valves; (c) other applications.

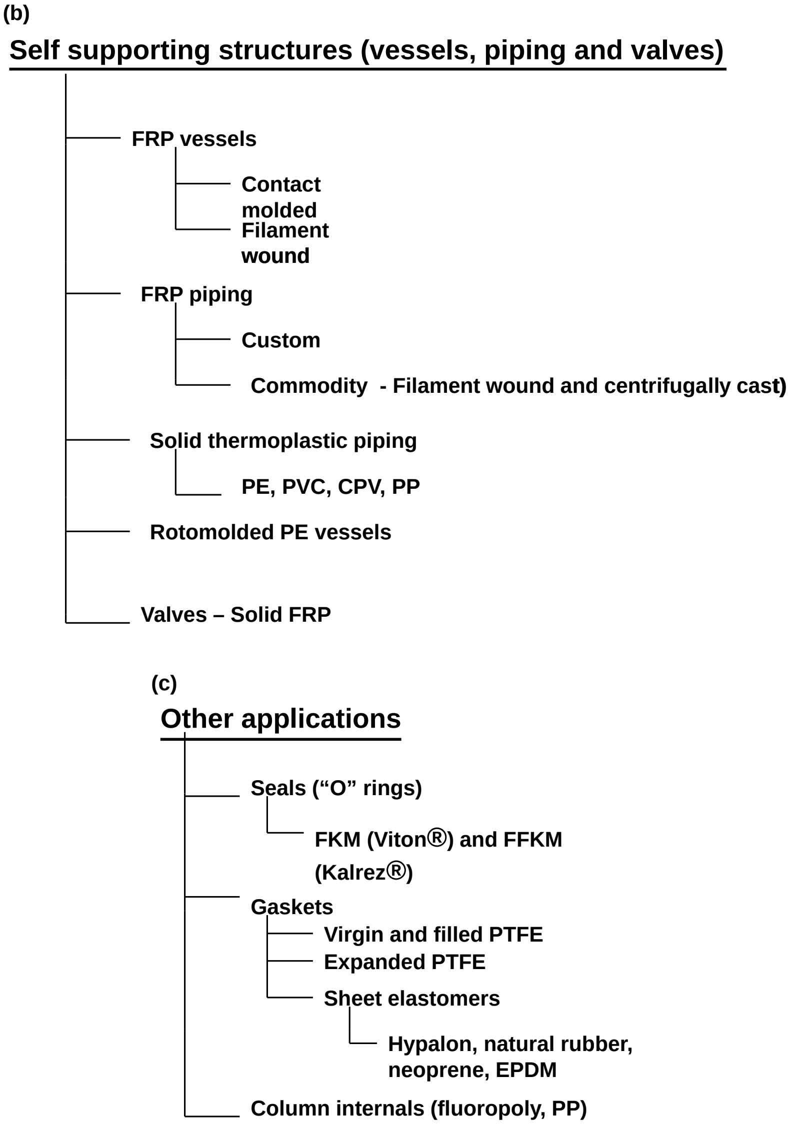


FIGURE 66.4. (*Continued*)

(epoxy or vinyl ester) polymers. Anchored polyethylene sheets are also becoming increasingly popular for concrete.

Corrosion allowance on CS, usually 0.0625 in. (1.6 mm) or 0.125 in. (3.2 mm), must also be considered in lieu of thin linings. Additionally, linings are selected on the basis of:

Successful case histories
Manufacturer's recommendation.
Testing (laboratory or field)

F3. Testing for Selection

Philosophy of testing and other details are covered in another chapter.

Laboratory testing can be simple coupon immersion (both in liquid and vapor) for a period of time at the application temperature. Chemical degradation and physical changes (color change, swelling, blistering) should be noted. This laboratory approach should be used for screening purposes only and lining selection should not be based entirely on the test results.

Chemical Resistance of Plastics and Elastomers (William Andrew Publishing/Plastics Design Library, 2001, 2008) provides a good system of rating coupons after exposure. A weighted value from 1 to 10 (10 being best) can be generated based on a combination of weight change, volume change, hardness change, retained mechanical properties (tensile and elongation), permeation rate, and breakthrough time.

In conjunction with the laboratory-screening test, Atlas blind flange tests (ASTM C868) should be performed [Fig. 66.5(a)]. These tests allow one-sided exposure of

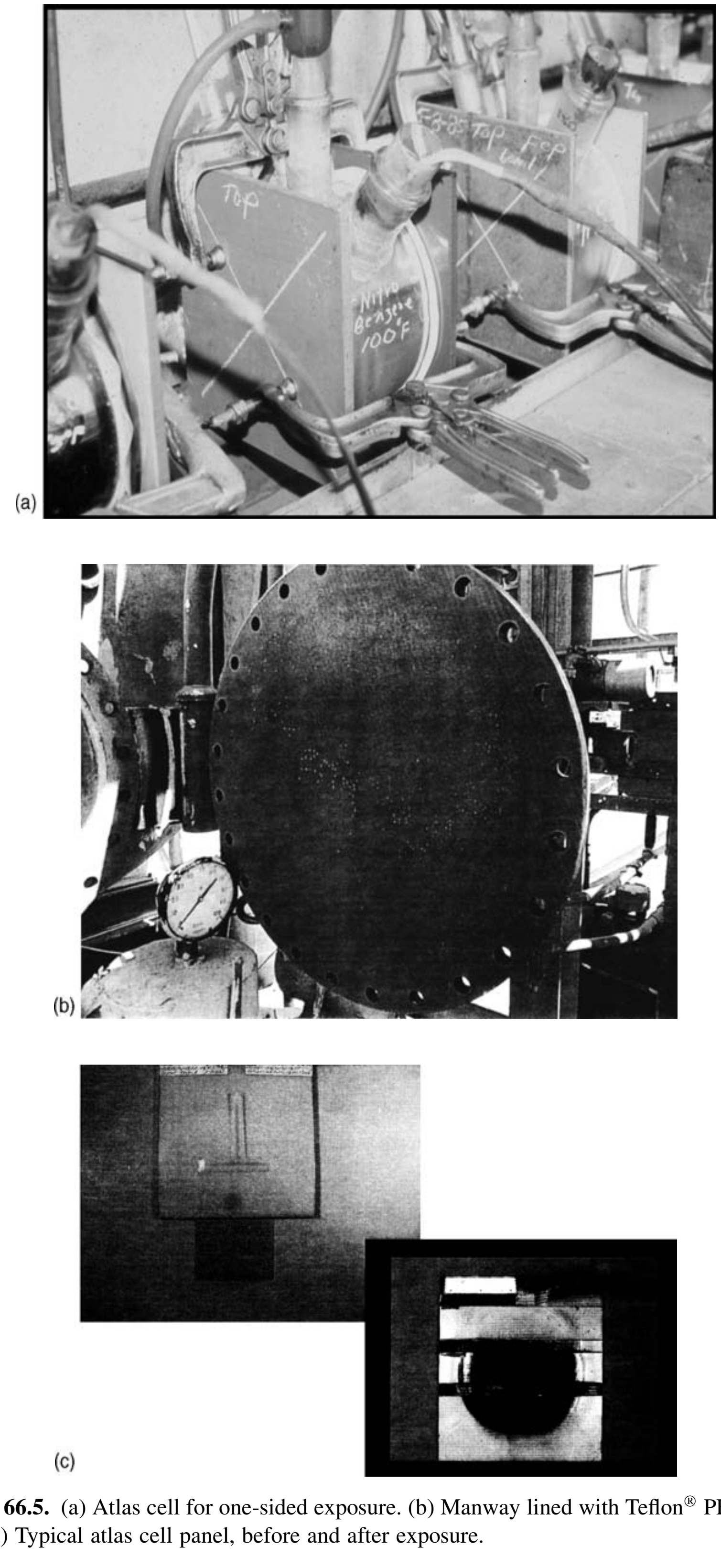


FIGURE 66.5. (a) Atlas cell for one-sided exposure. (b) Manway lined with Teflon® PFA for field testing. (c) Typical atlas cell panel, before and after exposure.

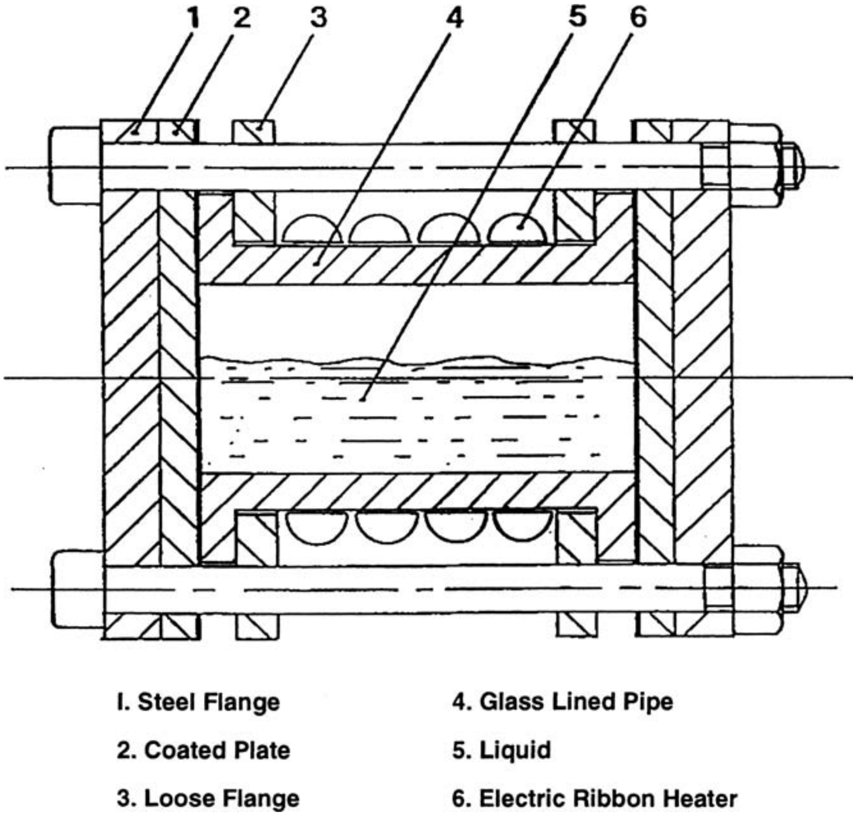


FIGURE 66.6. Schematic representation of modified Roberts cell.

the lining and simulate the actual field conditions of temperature gradient across the lining. This is an important factor for lining candidates that are susceptible to permeation. Temperature gradient is the main driving force behind permeation. Exposure to liquid above atmospheric boiling point is carried out in a specially designed test cell for higher pressures (Fig. 66.6). Even more realistic than the laboratory test is a blind flange test in the field [Fig. 66.5(b)]. This involves installing a blind flange on a storage tank or a column and monitoring its performance.

Certain thermoplastic linings contain welded seams (e.g., polypropylene and fluoropolymers).The lining on the blind flange must contain a representative seam for accurate evaluation.

Frequent change of test solution is important as is the analysis of the changed liquid to determine pickup of additives from the linings. This testing should be carried out for as long as possible since there is no accelerated testing.

At the end of the test, blind flanges should be observed for discoloration, blistering, swelling, and oxidative attack. Thick linings should be subjected to spark testing before and after testing to detect pinholes in the lining. Thick linings should also be subjected to a peel pull test to determine loss of adhesion, and the substrate should be inspected for obvious signs of corrosion [Fig. 66.5(c)].

Blind flanges with thin linings are a little harder to evaluate. Peel pull tests are not possible, so a qualitative scribe test is employed. This test consists of scribing the lining with an X and lifting the liner. The degree of difficulty is compared with a similar scribing on an unexposed lining area. Instead of a spark test, a low-voltage wet sponge continuity test is employed to detect pinholes.

It is important to note the limitations of the laboratory blind flange test. This test may not be able to simulate the surface area –volume ratio of the actual unit. It is also difficult to simulate thermal shock or thermocycling. It is impossible to simulate other operations such as steaming or other forms of cleaning operations. Field blind flange testing is more meaningful in such cases.

For elastomeric materials it is more important to carry out application-specific testing than coupon screening. Test for elastomer selection listed in Table 66.2.

F4. Design of Vessels To Be Lined

Designing a vessel to be lined is somewhat different from designing a vessel that does not need to be lined. All welds need to be smooth or ground flush, and any weld splatter must be ground off. For field-erected tanks, the shell-to-roof joint must be continuous. Internals should be round pipes

TABLE 66.2. Properties and Test Matrix For Elastomer Selection

	Static Seal “O”-Ring Gasket	Dynamic Seal “O”-Ring Gasket	Diaphragms	Hose	Linings for Vessels, Pipe, Valve, Pumps, etc.	Expansion Joints	Lined Valves
Chemical resistance	ISO 1817 ASTM D471		ASTM C868				
Permeation	ISO 1399 ISO 2782 ISO 2528 ISO 6179 MTI Guide						
Weather and sunlight stability				ISO 4665 ASTM D1171			
Heat aging[a] upper use temperature limit	ISO 188 ASTM D454 ASTM D572 ASTM D573						
Low-use temperature limit	ISO R812 ASTM D746 (brittle temp.) ASTM D1229 (compression set)						
Coefficient of thermal expansion	ASTM D864						
Adhesion to substrate					ISO 814 ISO 813 ASTM 429[b]		ISO 814 ISO 813 ASTM 429[b]
Tensile tests, % modules and elongation at break	ISO 37 ASTM D412					ISO 37 ASTM D412	
Abrasion resistance		ISO 4649 ASTM D22258 (Pico) ASTM D5963					
Tear strength	ISO 34 ISO 816					SO 34 ISO 816	
Stress relaxation	ASTM D6147						
Resistance to compression	ASTM D395 ASTM D1229 (low temp.)						
Hardness	ASTM D1415, ISO 48, (Durometer), ISO 7619						
Fatigue life		ISO 132 ASTM D430 ASTM D843 ISO 133				ISO 132 ISO 133, ASTM D430 ASTM D843	

Note: Properly conducted testing on authenticated samples can afford accurate and reproducible data that can be used to “estimate” seal performance life.

[a] Can be combined with chemical resistance.

[b] Are carried out in conjunction with ASTM C868.

TABLE 66.3. Fabrication Requirements for Vessels to be Lined

Specification Description	Rubber Linings	Thin Plastic Linings	Glass-Reinforced Plastic Linings	Sheet Linings[a] (Adhesively Bonded) Proprietary
Butt welds permitted	Yes	Yes	Yes	Yes
Lap welds permitted	No	Yes	Yes	No
Welds must be flush	Yes	No	No[b]	Yes
Welds must be smooth	Yes	Yes[c]	Yes[c]	Yes
Weld spatter permitted	No	No	No	No
Maximum nozzle length (in.)				
NPS 1	Not permitted (NP)	NP	NP	Unlimited[d]
NPS 2	6	NP	NP	Unlimited[d]
NPS 3	12	4	4	Unlimited[d]
NPS 4	24	8	8	Unlimited[d]
Minimum number of manholes in field-erected tanks	1	2 1	1 2	2
Grout tank bottom to minimize deflection or "oil canning"	No	Yes	Yes	Yes
Use insulating or structural lightweight aggregate concrete for tank foundation	No	Yes No	No	No

[a] Generally 60 mils thick or greater.

[b] Maximum height of weld bead shall be that permitted by ASME code or $\frac{1}{8}$ in., whichever is less. Welds shall blend into the adjacent surface so that the glass fabric saturated with plastic will be able to follow this contour and not leave a gap or air space.

[c] Weld ripples are acceptable if they are shallow enough so crevices and depressions can be cleaned by sandblasting to remove slag and oxides.

[d] Utilize insert linings. If loose linings are used for nozzles, venting is required.

instead of sharp corner angle irons or I-beams. Table 66.3 lists some lining requirements. Figure 66.7 shows the weld requirements.

F5. Surface Preparation

The extent of surface preparation depends on whether the equipment is new, used (without any lining previously), or to be relined. For new vessels, white metal blast per Steel Structure Painting Council (SSPC SP-5) followed immediately by a primer is needed. For used equipment, a thorough internal inspection is required and repairs or modifications must be performed as needed. Additionally, a chemical or steam cleaning may be needed to remove soluble salts and achieve a neutral pH of the surface. For equipment to be relined, a bake-out is usually required followed by a white metal blast to achieve 2.5–3.5 mils (64–89 μm) anchor profile on steel. In rare cases where stainless steel needs to be lined, a blast profile of 1.5 mils (38 μm) is adequate.

F6. Thin Linings

Classification of linings by thickness rather than lining material is useful because it focuses on both the application technology and lining functionality.

Thin linings <25 mils (635 μm) thick are predominantly based on epoxy and phenolic resins. To a lesser extent, spray-applied elastomeric thin linings (Hypalon® and Neoprene) are also used. Thin linings are used for situations where the corrosion rate of carbon steel is less than 10 mpy.

Epoxy and modified epoxy resins are cured (crosslinked) using either a chemical curing agent or heat (see Tables 66.4 and 66.5). The curing agent is typically one of several amines (aliphatic, aromatic, or polyamide). Baked phenolic linings based on phenol formaldehyde resin cure by heat alone, typically at 450°F (232°C). Baked phenolic coatings are very brittle and must be applied at the specified thickness only (no more than 8 mils). Epoxy- and phenolic-based linings are used in storage tanks for a variety of chemicals such as wastewater, sodium hydroxide, potable water, fuels, organic compounds, and strong sulfuric acids. Baked phenolic linings have exceptional resistance to a wide spectrum of organic compounds. In general, their, use is limited to 150°F (66°C). Testing is recommended for use at higher temperatures. Epoxy- and phenolic-based linings are very economical when compared to thick linings by installed cost. Although the (National Association of Corrosion Engineers (NACE) specifies three levels of acceptance by the number of allowable pinholes, pinhole-free linings are the most commonly specified.

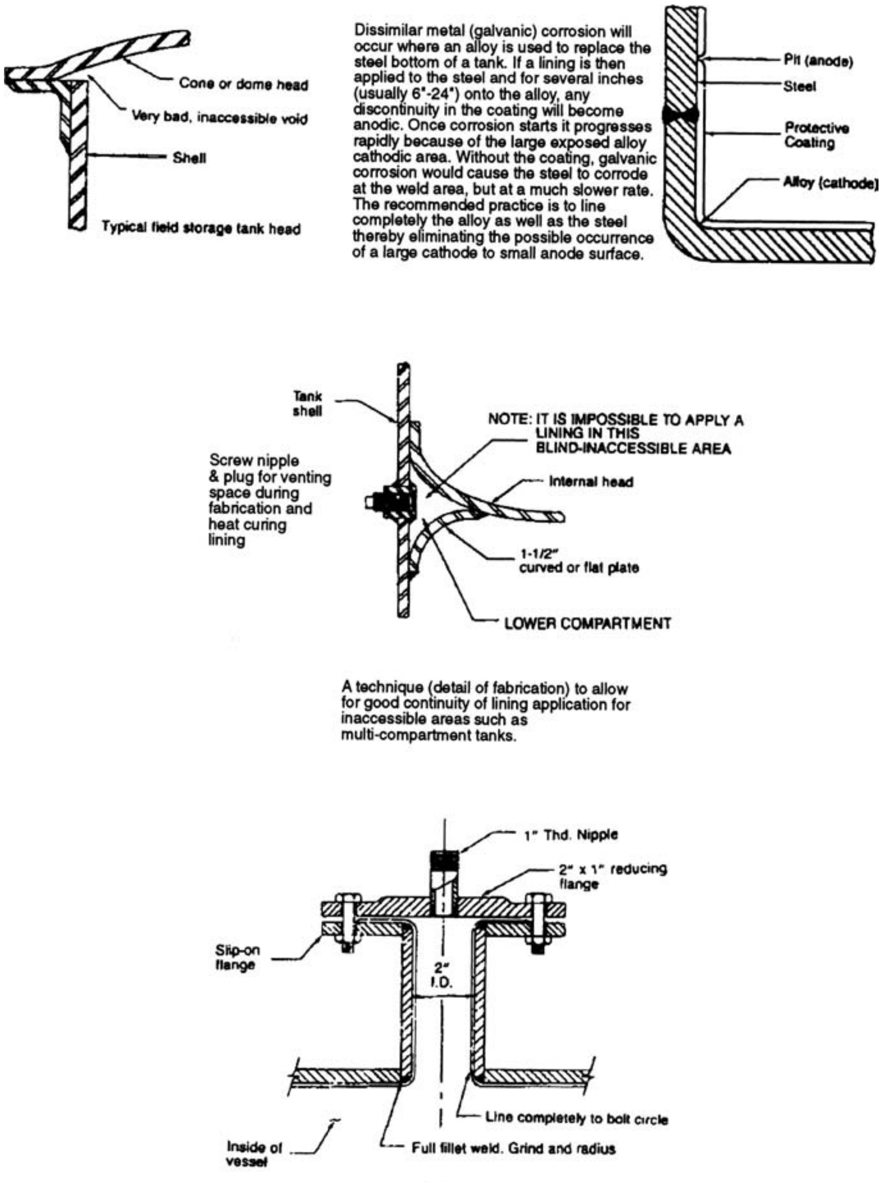
Epoxy and modified epoxy coatings are relatively easy to repair. Baked phenolic coatings are very difficult to repair. In-service linings are inspected visually and by means of a low-voltage wet sponge test (Tinker Rasor tester).

Spray-applied elastomeric coatings such as Hypalon® and neoprene have good chemical resistance and the ability to withstand thermal shock. However, they are expensive and labor intensive. (More information on elastomers can be found in Section F7.) They are spray applied in multiple coats and are used in hopper car and caustic storage. Spray-applied natural rubber is also used as membranes for acid bricks.

There is a special class of thin linings based on fluoropolymers (PTFE, polytetrafiuoroethylene; FEP, fluorinated ethylene propylene; PFA, perfluoroalkoxy; ETFF, ethylene tetrafluoroethylene; CTFE, chlorotrifluoroethylene; and PVDF, polyvinyledene fluoride). They are applied to primed surfaces as sprayed waterborne suspensions or electrostatically charged powders. Each coat is baked before the next is applied. Table 66.6 presents details about these coatings. These linings are expensive and are used mainly for nonstick and product purity applications, particularly at thickness <20 mil (508 µm). They can also be applied at higher thickness as thick linings (see Section F7).

F7. Thick Linings

Thick linings cover a large range of polymers such as polyvinyl chloride (PVC), polyethylene (PE), natural and synthetic elastomers, reinforced vinyl esters, and fluoropolymers. Table 66.7 lists the thick linings commonly used for corrosion control. All the guidelines of selection, vessel

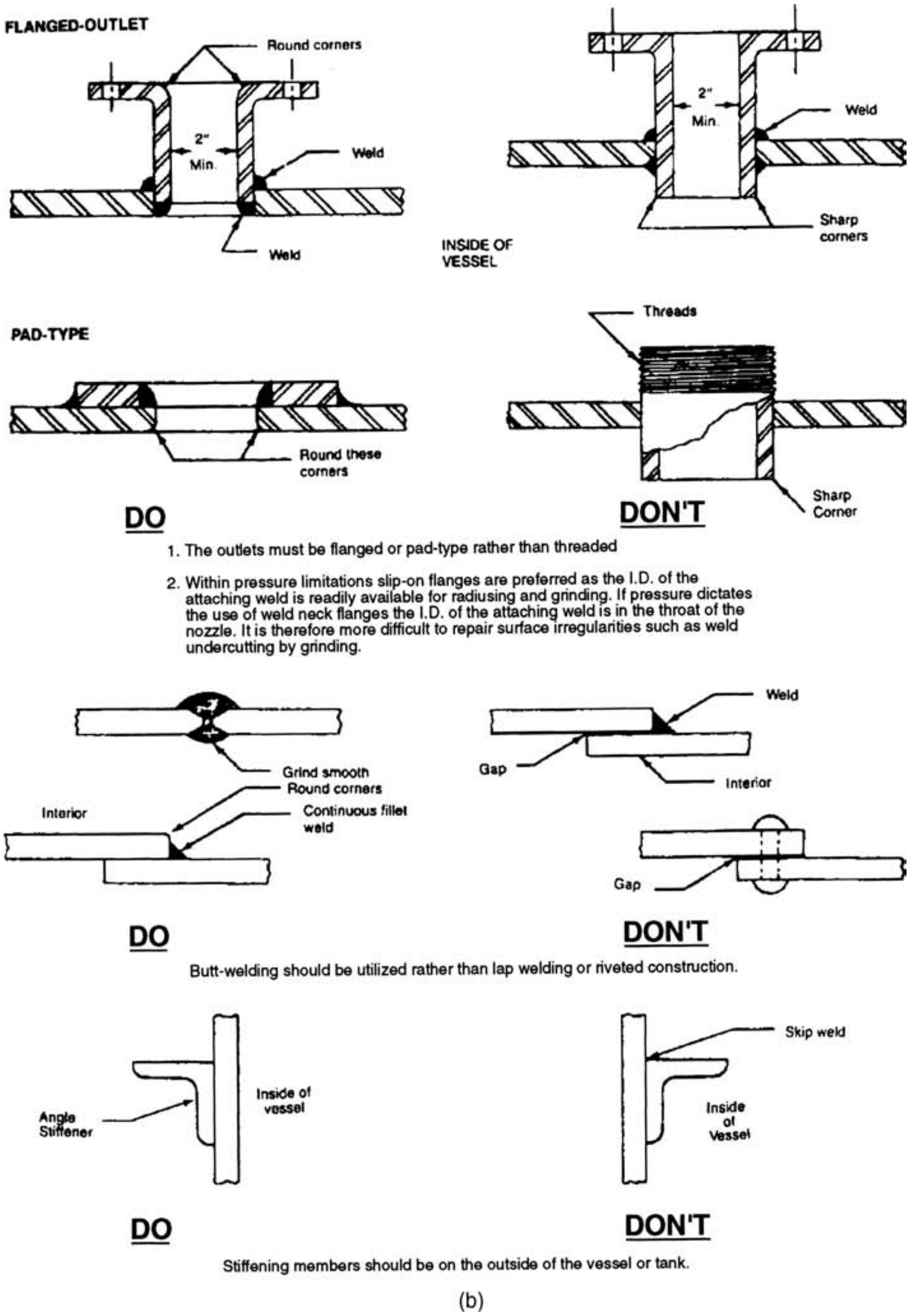


Dissimilar metal (galvanic) corrosion will occur where an alloy is used to replace the steel bottom of a tank. If a lining is then applied to the steel and for several inches (usually 6"-24") onto the alloy, any discontinuity in the coating will become anodic. Once corrosion starts it progresses rapidly because of the large exposed alloy cathodic area. Without the coating, galvanic corrosion would cause the steel to corrode at the weld area, but at a much slower rate. The recommended practice is to line completely the alloy as well as the steel thereby eliminating the possible occurrence of a large cathode to small anode surface.

A technique (detail of fabrication) to allow for good continuity of lining application for inaccessible areas such as multi-compartment tanks.

(a)

FIGURE 66.7. Requirements for the quality of welds for lining. (Courtesy of Wisconsin Protective Coatings Co.)



1. The outlets must be flanged or pad-type rather than threaded
2. Within pressure limitations slip-on flanges are preferred as the I.D. of the attaching weld is readily available for radiusing and grinding. If pressure dictates the use of weld neck flanges the I.D. of the attaching weld is in the throat of the nozzle. It is therefore more difficult to repair surface irregularities such as weld undercutting by grinding.

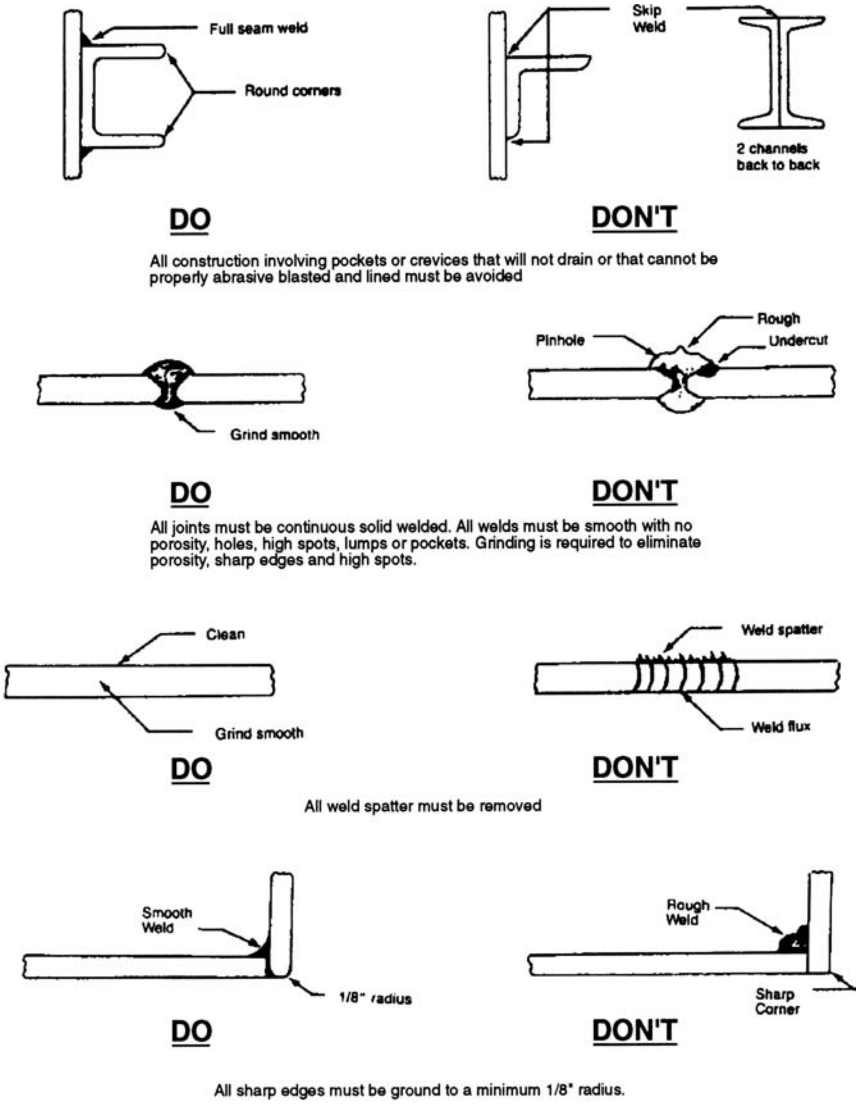
Butt-welding should be utilized rather than lap welding or riveted construction.

Stiffening members should be on the outside of the vessel or tank.

FIGURE 66.7. (*Continued*)

design, and surface preparation described in Sections F4 and F5 apply equally to thick linings.

F7.1. Reinforced Thermosetting Linings. Epoxy-, vinyl ester–, and polyester-based lining systems incorporate one of three types of reinforcements (i.e., glass flake, glass mat, or woven roving, see Section H3.2.2 for vinyl esters). Each serves a specific purpose. In general, glass or other forms of flake offer the maximum level of permeation resistance. Mat and woven cloth lower the coefficient of thermal expansion of the resin to close to that of steel. This is important for service where the operating temperature is higher than ambient. In addition, these reinforcements prevent cracking due to shrinkage as the resin cures. These linings are applied in two to three coats, which incorporate other additives such as other inert flakes (mica, silica, aluminum oxide) and pigments. These additives impart additional properties such as abrasion resistance, identification of coats, and so on. Figure 66.8 illustrates the components of a reinforced lining system. Figures 66.9 (a)–(d) illustrate the multilayer nature of these linings.



All construction involving pockets or crevices that will not drain or that cannot be properly abrasive blasted and lined must be avoided

All joints must be continuous solid welded. All welds must be smooth with no porosity, holes, high spots, lumps or pockets. Grinding is required to eliminate porosity, sharp edges and high spots.

All weld spatter must be removed

All sharp edges must be ground to a minimum 1/8" radius.

(c)

FIGURE 66.7. (*Continued*)

These linings are either trowelled or spray applied. They are applied on concrete as well as steel. Crosslinking is by a chemical curing agent and additional heat is rarely required. Typical thickness is 0.125 in. (3.2 mm) although higher thicknesses of up to 0.187 in. (4.8 mm) are also used. Maximum service temperature is limited to 170°F (77°C). They can be applied in the shop as well as in the field, which makes them attractive for a variety of applications such as waste treatment, ground water remediation, and hydrochloric acid. Table 66.8 is a general guide listing the chemical resistance rating of reinforced linings. For specific cases testing is recommended (see Section F3).

Vinyl ester–based linings are used for vessels, large-diameter columns, and concrete sumps and trenches.

Plasticized PVC is another useful thick lining material for service with many acids and bases. The maximum service temperature is ~150°F (66°C). It is sometimes used in combination with unplasticized PVC. Sheets are bonded with adhesive to primed surfaces.

F7.2. Rubber (Elastomer) Lining. Thermosetting rubber linings, either natural or synthetic, are well established in the chemical processing industry (CPI). Their highly elastic nature permits use as linings for vessels, column, piping, and valves. Typically, the minimum thickness is 0.25 in. (6.4 mm) for vessel linings and 0.125 in. (3.2 mm) or 0.1875 in. (4.8 mm) for piping, depending on size. These linings are installed as adhesive-bonded sheets in vessels and are heat cured (vulcanized) after installation. Loose linings for impoundments and spray-applied rubber coatings for some applications are also known.

TABLE 66.4. Recommended Heat-Cured Thin-Film Linings

Generic Type	No. Coats	Total DFT[a]	Typical Uses
Epoxy phenolic	2–3	12–15	Aliphatic and aromatic compounds, waste treat, weak acids and caustics
Epoxy phenolic glass flake	2–3	12–15	Same as above, at higher temperature and abrasion resistance
Epoxy Novalac	2–3	12–15	Stronger acids and caustics than above process affluent streams, solvents
Epoxy polysulfide	1–2	20–40	Aliphatic and aromatic compounds, waste treat, weak acids and caustics where flexibility is required
Epoxy amine	2–3	12–15	Nonpotable water, waste treatment
Epoxy amine	2–3	12–15	Water, demineralized water 82–121°C (180–250°F)
Epoxy polyamide	3	12–15	Portable water, fuels
Epoxy polyamide	3	12–15	Portable water, rules
Hypalon®	2–3	12–16	Hopper cars for terephthalic acid, adipic acid
Neoprene	2–3	12–16	Storage tanks of caustic

[a] Dry film thickness.

TABLE 66.5. Recommended Heat-Cured Thin-Film Linings

Generic Type	No. Coats	Total DFT	Typical Uses
High baked phenolic	3–4	6–8	Sulfuric acid rail cars, organic waste
High baked epoxy	3–4	12	Caustic storage

TABLE 66.6. Thin Fluoropolymer Coatings for Nonstick and Product Purity Applications

	ETFE	FEP	PFA	E-CTFE	PVDF
Dispersion		4–5 mils	8–10 mils		25 mils
Powder	90 + mils	8–10 mils	8–10 mils	50 + mils	25 mils

Note: For thicker versions of these please see Table 66.17

TABLE 66.7. Thick (>25-mil) Linings

Reinforced vinyl ester or epoxy linings
  Reinforced with glass cloth, mat or woven
  Spray or trowel applied
  Shop or field applied
  Chemically cured (no baking required)
  Relatively easy to repair

Sheet rubber linings
  Natural rubbers (soft, semihard, butyl)
  Standard thickness $\frac{1}{4}$ in.
  Shop or field applied
  Steam or autoclave curing needed
  Relatively easy to repair

Thermoplastic sheet lining
  General purpose (PVC, PP) for steel and PE (anchored) for concrete
  High performance (fluoropolymers—PVDF, FEP, PFA, ETFE, ECTFE) for steel

Elastomers are classified as either natural or synthetic and as general purpose, or high performance (Tables 66.10A and B). Rubber linings for chemical handling are usually of general -purpose type. High-performance rubbers are used principally for seal applications. In the past, rubber linings were also used for piping.

Natural rubber is manufactured from naturally occurring rubber gum mixed with carbon, antioxidant, accelerator, and crosslinking agent (Table 66.9 shows a typical recipe). The ingredients are mixed in a Banbury mixer and sheets are calendered with multiple layers. These sheets are applied as a lining to the interior of vessels, piping, and pumps. The lining is applied over a sandblasted and primed surface. Adhesive is applied to both the metal side and the rubber sheet. Joints are made by overlapping two adjoining sheets and "skiving," that is, either up skiving or down skiving. For semihard, hard, and chlorobutyl rubbers, a soft rubber backing material is used to attain better adhesion [Figs. 66.10(a) and (b)].

Elastomeric linings for chemical handling are natural rubbers. Occasionally synthetic rubbers such as ethylene

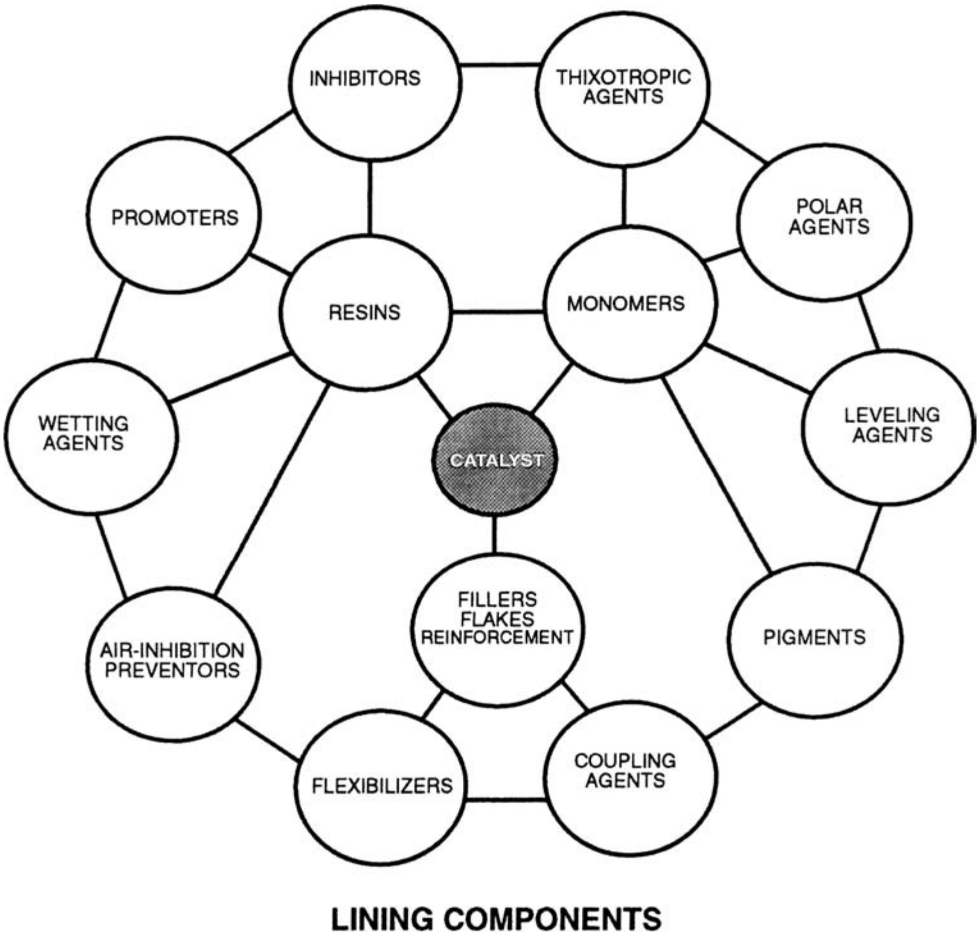


FIGURE 66.8. Elements of a reinforced lining system. (Courtesy of Ceilcote Company.)

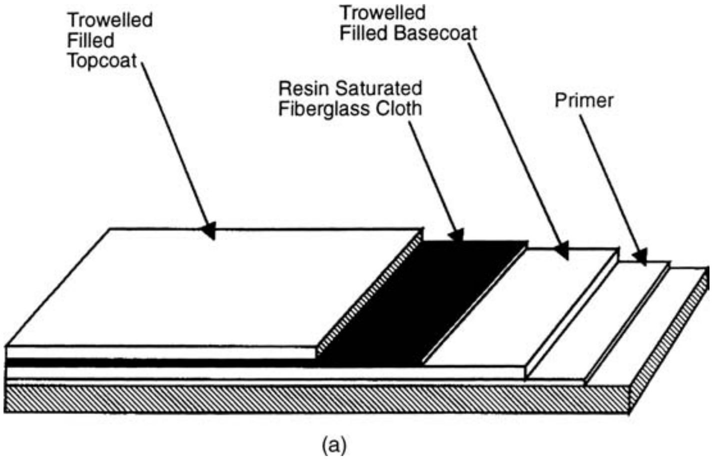


FIGURE 66.9. (a). Fiberglass cloth-reinforced lining with filled basecoat and topcoat. (Courtesy of Ceilcote Company.) (b). Fiberglass mat-reinforced lining with silica-filled basecoat. (Courtesy of Ceilcote Company.). (c). Trowelled glass flake lining. (Courtesy of Ceilcote Company.). (d). Spray-applied flake-reinforced lining. (Courtesy of Ceilcote Company.)

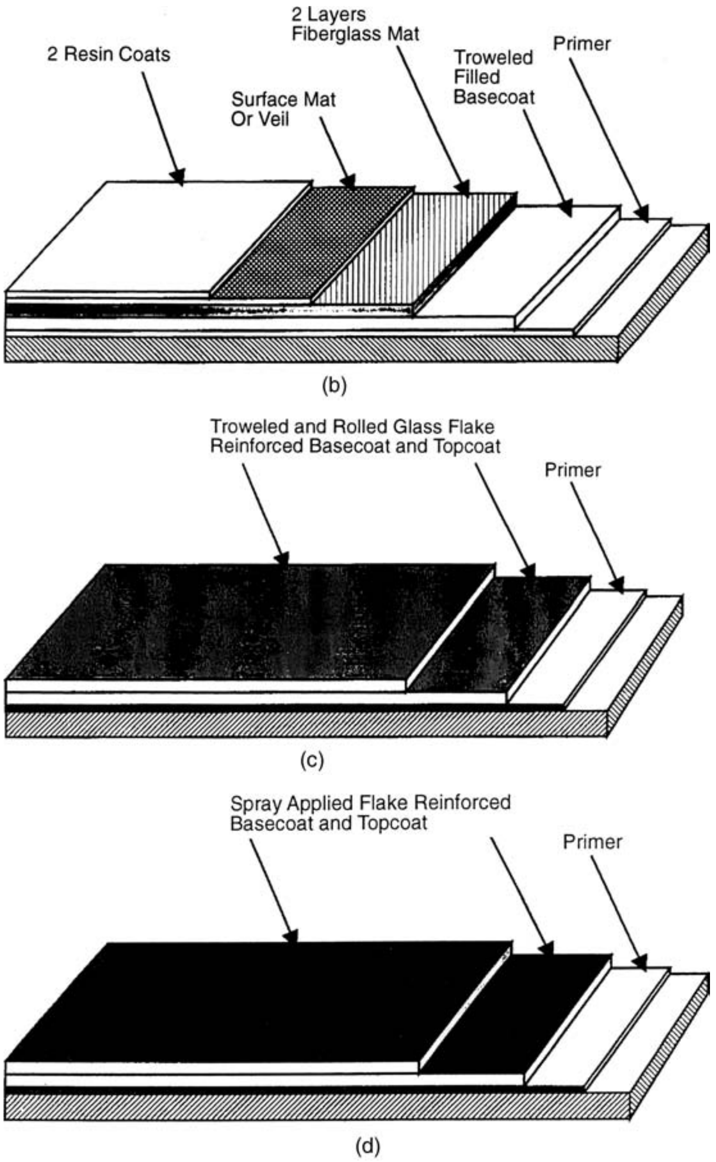


FIGURE 66.9. (*Continued*)

propylene diene monomer (EPDM) and chlorosulfonated polyethylene are used. The standardized lining thickness is 0.25 in. (6.35 mm). Once the sheets are applied, exhaust steam heat is used to cure the lining. Where possible, the vessel is placed in an autoclave and heated until the proper degree of crosslinking is achieved. The degree of crosslinking is determined by Durometer hardness. Two types of Durometers are used: A and D. Continuity testing is performed by high-voltage spark testing.

Cure is also achieved by applying sulfur-bearing organic compounds. This chemical curing technique is used when steam or autoclave curing is not possible, as in the case of repairs.

Because of the flexible nature of rubber, installation and use are straightforward. It is common to see rubber on bolted joints and on relatively sharp surfaces. It is also common not to grind the steel welds flush but to simply grind them smooth. For optimum performance, however, the design and surface preparation guidelines (see Sections F4 and F5) should be followed.

Elastomeric linings are relatively easy to repair. Condition assessment is by internal visual inspection, looking for loose laps, hardening surfaces, cracks, blisters, pinholes (by spark testing), and so on. Various rubber formulations are available for resistance to chemicals and food-grade handling at temperatures up to 180°F (82°C). Successful applications include storage vessels and railcars for HCl, HF, and abrasive slurries. Table 66.11 shows the ASTM classification of rubber and Table 66.12 is a chemical resistance chart.

TABLE 66.8. Chemical Resistance Rating for Polyester and Vinyl Ester Linings

	Generic Resin Type					Resin Abbreviations	
Chemical	ISO	BIS-A	CHLOR	VINYL-E	NOV-VE		
Acetic acid, 10%	D1	C1	C1	C1	A1	ISO	Isophthalic
Acetic acid, 100%	E2	D2	D2	D2	D1	BIS-A	Bisphenol-A fumarate
Acetone	N	N	N	N	C2	CHLOR	Chlorinated
Ammonium hydroxide — 20%	N	E1	N	E1	E1	VINYLE-E	Vinyl easter
Ammonium nitrate	A1	A1	A1	A1	A1	NOV-VE	Novolac vinyl easter
Benzene	D2	D1	D1	E2	D1		
Chromic acid, 10%	N	E1	C1	N	E1	Ratings	
Formaldehyde	A1	A1	A1	A1	A1		
Formic acid	E2	D1	D1	E1	D1		
Gasoline, unleaded	A1	A1	A1	A1	A1	1	Good for immersion or constant flow
Hydrochloric acid, 10%	A2	A1	A1	A1	A1		
Hydrochloric acid, 37%	E2	D2	D2	D1	D1		
Hydrofloric acid, 10%	E1	D1	D1	D1	D1	2	Limited to spillage or secondary containment
Kerosene	A1	A1	A1	A1	A1		
Methene Cloride	N	N	N	N	E2		
Methyl ethyl ketone	E2	E2	E2	E2	D2	A	Good to 200° F
Nitric acid, 10%	D2	B1	A1	CI	A1	B	Good to 180°F
Nitric acid, 60%	N	D1	D1	N	D1	C	Good to 140° F
Oils	A1	A1	A1	A1	A1	D	Good to 120°F
Phosphoric acid, 85%	A1	A1	A1	A1	A1	E	Good to 100°F
Sodium chlorate	B1	A1	A1	A1	A1	N	Not recommended
Sodium hydroxide, 10%[a]	N	D1	N	D1	D1		
Sodium hydroxide, 50%[a]	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	A1	A1	A1	A1	A1		

Note: The above 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. Courtsey of Ceilcote Co.

[a] Exposed lining surface requires carbon filler or synthetic veil.

F7.3. Thermoplastic Linings. Thermoplastic linings fall into two broad categories: general purpose and high performance. General-purpose linings consist of PVC, CPVC (chlorinated polyvinyl chloride), PE, and PP (polypropylene). High-performance thermoplastic lining materials include fluoropolymers such as PVDF, CTFE, ETFE, polytetrafluoroethylene (PTFE), FEP and perfluoroalkoxy (PFA).

TABLE 66.9. Formulation of a Soft Natural Rubber

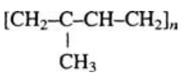
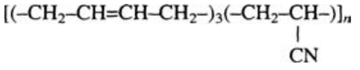
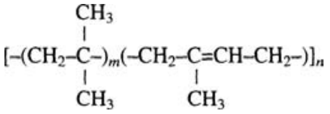
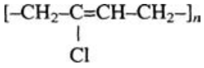
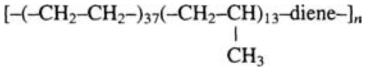
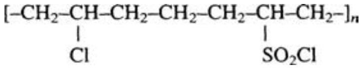
Ingredients	Parts by Weight
Natural rubber gum	100
Sulfur powder	1–2
Accelerator	1
Carbon black	25–50
Internal plasticizer (oils and resins)	1–3
Antioxidants	1

Thermoplastic linings are used for vessels, piping, valves, and pumps, Common lining methods include sheet linings for vessels, extruded loose linings for piping, and injection molded linings for valves and pumps. In some cases, spray-applied linings are also used. Examples are flame spray coatings of ethylene methacrylic acid and its ionomer. Spray and baked fluoropolymer linings will be discussed later.

F7.3.1. General-Purpose Linings. General-purpose linings are limited by their maximum temperature use and chemical resistence. Usually, their use is limited to 150°F (66°C). Many organic solvents easily attack general-purpose linings, but due to their relative low cost, they can be successfully used for many inorganic acids.

Among the commonly used thermoplastics materials in this category are PP (homopolymer and impact-grade copolymer), PVC (rigid and plasticized), CPVC, and PE. Table 66.13 summarizes these linings for vessels.

TABLE 66.10A. Chemical Structures of Commonly Used Elastomers

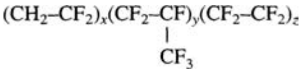
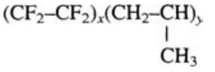
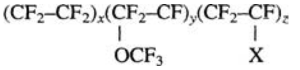
Name[a]	Chemical Name	Structure
Natural rubber	*Cis* –1,4-Polyisoprene	 $[CH_2{-}\underset{CH_3}{\underset{\vert}{C}}{-}CH{-}CH_2]_n$
Nitrile	Poly(butadiene-*co*-acrylonitrile)	 $[({-}CH_2{-}CH{=}CH{-}CH_2{-})_3({-}CH_2{-}\underset{CN}{\underset{\vert}{CH}}{-})]_n$
Butyl	Poly(isobutylene-*co*-isoprene)	 $[{-}(CH_2{-}\overset{CH_3}{\overset{\vert}{\underset{CH_3}{\underset{\vert}{C}}}}{-})_m({-}CH_2{-}\underset{CH_3}{\underset{\vert}{C}}{=}CH{-}CH_2{-})]_n$
Neoprene	Polychloroprene	 $[{-}CH_2{-}\underset{Cl}{\underset{\vert}{C}}{=}CH{-}CH_2{-}]_n$
EPDM (Nordel®)	Poly(ethylene-*co*-propylene-*co*-diene)	 $[{-}({-}CH_2{-}CH_2{-})_{37}({-}CH_2{-}\underset{CH_3}{\underset{\vert}{CH}})_{13}{-}diene{-}]_n$
Chlorosulfonated Polyethylene (Hypalon®)		 $[{-}CH_2{-}\underset{Cl}{\underset{\vert}{CH}}{-}CH_2{-}CH_2{-}CH_2{-}\underset{SO_2Cl}{\underset{\vert}{CH}}{-}CH_2{-}]_n$

[a] Nordel and Hypalon are registered trademarks of DuPont Dow Elastomers Company.

These materials are also used as linings for valves, pumps, and piping. Ultrahigh-density polyethylene is used as valve linings for its exceptional abrasion resistance. High-density PE is used as lining for complex shapes using the rotolining process. Polypropylene is used as lining for valves using the injection molding process. Extruded PP liners are used for lined pipe.

F7.3.2. Fluoropolymer Linings. Fluoropolymers, also known as high-performance thermoplastics, are well-proven materials used as thick linings to control corrosion of process equipment. They resist a broader range of chemicals than other polymers and generally have higher service temperatures as well. They typically compete with high-nickel alloys as well as titanium, tantalum, and zirconium.

TABLE 66.10B. Specialty Elastomers—Fluoroelastomers

Name	Tradenames[a]	Structure
Vinyledene fluoride/hexafluoropropylene	Viton®, Fluorel®, Technoflon®	 $[(CH_2{-}CF_2)_x(CF_2{-}\overset{CF_3}{\overset{\vert}{CF}})]_y$
Vinyledene fluoride/hexafluoropropylene/ tetrafluoroethylene/terpolymer	Viton®, Fluorel®, Technoflon®, Dai-El®	 $(CH_2{-}CF_2)_x(CF_2{-}\underset{CF_3}{\underset{\vert}{CF}})_y(CF_2{-}CF_2)_z$
Tetrafluoroethylene/propylene copolymer	Aflas®	 $(CF_2{-}CF_2)_x(CH_2{-}\underset{CH_3}{\underset{\vert}{CH}})_y$
Vinylidene fuoride/chlorotrifluoroethylene copolymer	Kel-F®	$(CF_2{-}CH_2)_x(CF_2{-}CFCl)_y$
Perfluorocarbon rubber (tetrafluoroethylene copolymer)	Kalrez®	 $(CF_2{-}CF_2)_x(CF_2{-}\underset{OCF_3}{\underset{\vert}{CF}})_y(CF_2{-}\underset{X}{\underset{\vert}{CF}})_z$

[a] Viton® and Kalrez® are registered trademarks of DuPont Dow. Fluorel® is a registered trademark of 3 M Company. Aflas® is a registered trademark of Green Tweed Company.

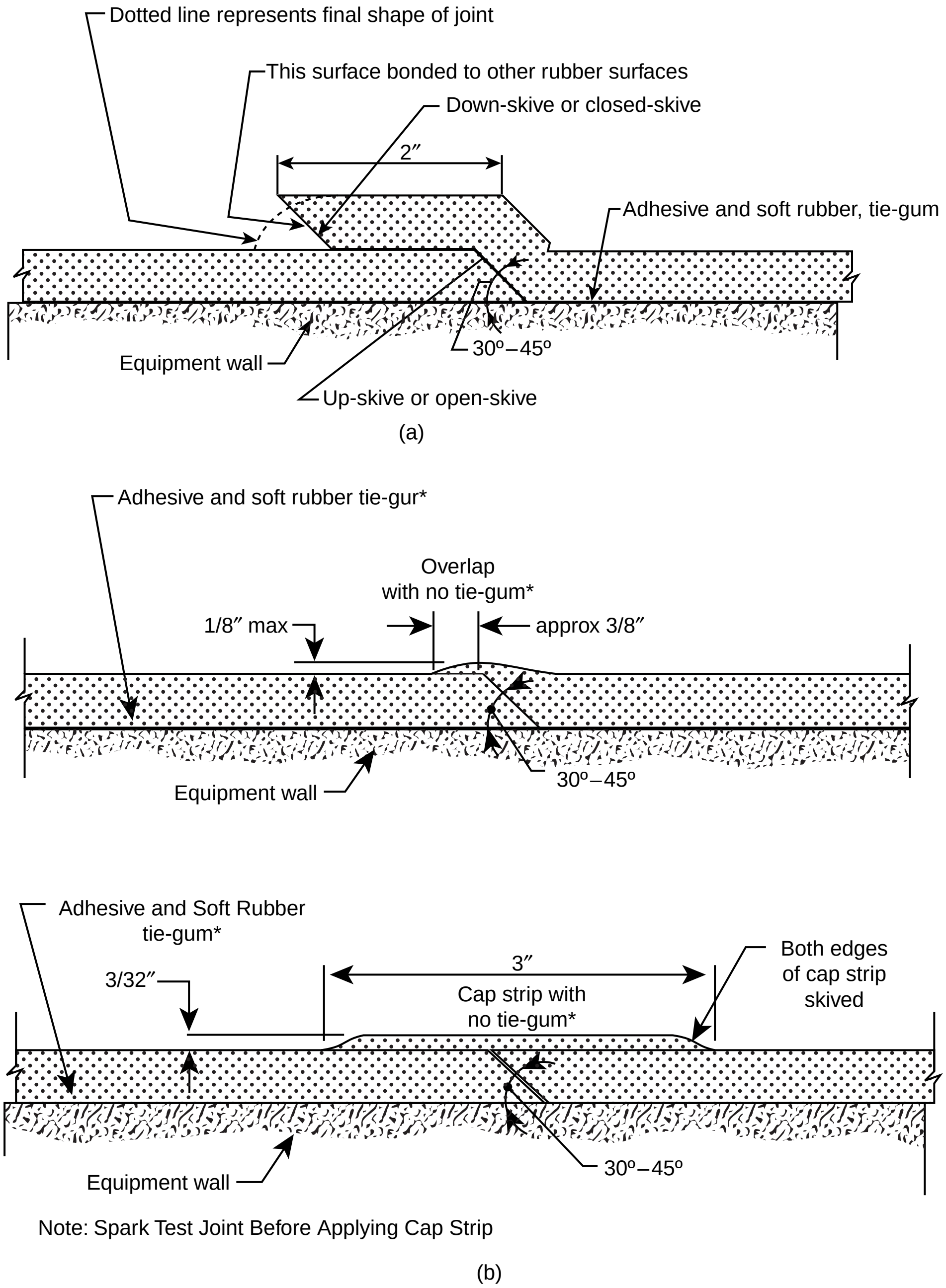


FIGURE 66.10. (a) Skived joint for semihard or hard rubber lining (e.g., code B) having a thin, soft-rubber, tie gum surface for bonding to steel. (b) Low-profile joints as typically called for under brick linings. (Courtesy of Dupont Co.)

Fluoropolymers are widely specified when contamination must be minimized.

There are two general categories of fluoropolymers: fully and partially fluorinated. The fully fluorinated materials PTFE, FEP, and PFA have higher service temperatures and broader chemical resistance than other fluoropolymers. The partially fluorinated fluoropolymers ETFE ethylene chlorotrifluoro, thylene (ECTFE), and PVDE have higher tensile strength and stiffness and less extensive chemical and thermal resistance.

Table 66.14 lists key properties of fluoropolymers. It should be noted that service temperatures vary with a number of factors, including the mechanical requirements of lining systems, and may be significantly lower than the maximum service temperatures shown.

Fully fluorinated fluoropolymers can be used with most aggressive corrosives. Partially fluorinated types can perform well, depending on the chemicals involved. Table 66.15 summarizes the chemical resistance of