

E

E-GLASS

This is a boroaluminosilicate glass used for reinforcing thermosetting resins. See “[Thermoset Reinforcing Materials](#).”

ELASTOMER CROSS REFERENCE

Generic name	Designation	Manufacturers ^a
		common or trade names
Natural rubber	NR	26–31
Isoprene	IR	
Polychloroprene	CR	26–31, neoprene (1), Bayprene (2)
Butadiene-styrene	SBR	26–30, Buna-S, GR-S
Butadiene-acrylonitrile	NBR	16, 26–31, nitrile rubber, Buna-N, Perbunan (2), Nytek (21)
Butyl rubber	IIR	Gr-I, 26–30, Kalar (19)
Chlorobutyl rubber	CiiR	26–30
Carboxylic-acrylonitrile-butadiene	NBR	16, 26–31
Chlorosulfonated polyethylene	CSM	26–28, 30, 31, Hypalon (1)
Polybutadiene	BR	26–28, 30, 31, Buna-85, Buna-DB (2)
Ethylene-acrylic	EA	13, 28 Vamac (1)
Acrylate-butadiene	ABR	13, 28
Acrylic ester-acrylic halide	ACM	13, 28
Ethylene-propylene	EPDM	26–31
	EPT	Nordel (1), Royalene EPDM (8), Dutral (9)
Styrene-butadiene styrene	SBS	Kraton G (3)
Styrene-ethylene-butylene-styrene	SEBS	Kraton G (3)
Polysulfide	ST	27, 28, 30, Thiokol (4)
	FA	Blak-Stretchy (14), Blak-Tufy (14), Gra-Tufy (14)
Urethane	AU	16, 27, 30, 38, 31, Adiprene (I), Baytec (2), Futrathane (11), Conathane (16), Texion (2), Urane (23), Pellethane (22), pure CMC (14)
Polyamides	Nylon	Nylon (1), Rilsan (12), Vydine (18), Plaskin (25)
Polyester	PE	Hytrel (1), Kodar (20)

Generic name	Designation	Manufacturers ^a common or trade names
Thermoplastic elastomers	TPE	Duracryn (1), Flexsorb (17), Geolast (18), Kodapak (20), Santoprene (18), Zurcon (24)
Silicone	SI	27–29, 32, Cohrplastic (15), Green Sil (14), Parshield (13), Baysilone (2), Blue-Sil (14)
Fluorosilicone	FSI	Parshield (13)
Vinylidene fluoride	HFP	Kynar (7), Forafion (5)
Fluoroelastomers	FKM	24, 26, 28–31, Viton (1), Fluorel (6), Technoflon (9)
Ethylene-tetrafluoroethylene	ETFE	Tefzel (1), Halon ET (9)
Ethylene-chlorotrifluoroethylene	ECTFE	Halar (9)
Perfluoroelastomers	FPM	Kalrez (1), Chemraz (10), Kel-F (6)

^aList of manufacturers:

1. E. I. du Pont; 2. Mobay Corp.; 3. Shell Chemical Co.; 4. Morton Thiokol Inc.; 5. Atochem Inc.; 6. 3-M Corp; 7. Penwalt Corporation; 8. Uniroyal; 9. Ausimont; 10. Greene, Tweed & Co., Inc.; 11. Futura Coatings Inc.; 12. Attochem Inc.; 13. Parker Seal Group; 14. The Perma-Flex Mold Co.; 15. CHR Industries; 16. Conap Inc.; 17. Polymer Corp.; 18. Monsanto Co.; 19. Hardman Inc.; 20. Eastman Chemical Products Inc.; 21. Edmont Div. of Becton, Dickinsen & Co.; 22. Dow Chemical USA; 23. Krebs Engineers; 24. W. S. Shamban & Co.; 25. Allied Signal; 26. General Rubber Co.; 27. Hecht Rubber Co.; 28. Minor Rubber Co.; 29. Newco Holz Rubber Co.; 30. Alvan Rubber Co.; 31. Burke Rubber Co.; 32. Unaflex.

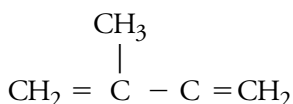
ELASTOMERS

Also see “Permeation,” “Adsorption,” and “Polymers.” An elastomer is generally considered to be any material, either natural or synthetic, that is elastic or resilient and in general resembles natural rubber in feeling and appearance. A more detailed technical definition is provided by ASTM, which states

An elastomer is a polymeric material which at room temperature can be stretched to at least twice its original length and upon immediate release of the stress will return quickly to its original length.

These materials are sometimes referred to as rubbers.

Natural rubber is a polymerized hydrocarbon whose commercial synthesis proved to be difficult. Synthetic rubbers now produced are similar but not identical to natural rubber. Natural rubber has the hydrocarbon butadiene as the simplest unit. Butadiene, $\text{CH}_2 = \text{CH} - \text{CH} = \text{CH}_2$, has two unsaturated linkages and is easily polymerized. It is produced commercially by cracking petroleum and also from ethyl alcohol. Natural rubber is a polymer of methyl butadiene (isoprene):



When butadiene or its derivatives become polymerized, the units link together to form long chains that each contain over 1000 units. In early attempts to develop a synthetic rubber it was found that simple butadiene does not yield a good grade of rubber, apparently because the chains are too smooth and do not interlock sufficiently strongly. Better results are obtained by introducing side groups into the chain

either by modifying butadiene or by making a copolymer of butadiene and some other compound.

As development work continued in the production of synthetic rubbers, other compounds were used as the parent material in place of butadiene. Two of them were isobutylene and ethylene.

Elastomers are primarily composed of large molecules that tend to form spiral threads, similar to coiled springs, that are attached to each other at frequent intervals. These coils tend to stretch or compress when a small stress is applied but exert an increasing resistance to the application of additional stress. This phenomenon is illustrated by the reaction of rubber to the application of additional stress.

In the raw state elastomers tend to be soft and sticky when hot, and hard and brittle when cold. Compounding increases the utility of rubber and synthetic elastomers. Vulcanization extends the temperature range within which they are flexible and elastic. In addition to vulcanizing agents, ingredients are added to make elastomers stronger, tougher, or harder, to make them age better, to color them, and in general to improve specific properties to meet specific application needs. The following examples illustrate some of the important properties that are required of elastomers and the typical services that require these properties:

Resistance to abrasive wear: automobile tire treads, conveyor belt covers, soles and heels, cables, hose covers

Resistance to tearing: tire treads, footwear, hot water bags, hose covers, belt covers, O-rings

Resistance to flexing: auto tires, transmission belts, V-belts, mountings, footwear

Resistance to high temperature: auto tires, belts conveying hot materials, steam hose, steam packing, O-rings

Resistance to cold: airplane parts, automotive parts, auto tires, refrigeration hose, O-rings.

Minimum heat buildup: auto tires, transmission belts, V-belts, mountings

High resilience: sponge rubber, mountings, elastic bands, thread, sandblast hose, jar rings, O-rings

High rigidity: packing, soles and heels, valve cups, suction hose, battery boxes

Long life: fire hose, transmission belts, tubing

Electrical resistivity: electrician's tape, switchboard mats, electrician's gloves, wire insulation

Electrical conductivity: hospital flooring, nonstatic hose, matting

Impermeability to gases: balloons, life rafts, gasoline hose, special diaphragms

Resistance to ozone: ignition distributor gaskets, ignition cables, windshield wipers

Resistance to sunlight: wearing apparel, hose covers, bathing caps, windshield wipers

Resistance to chemicals: tank linings, hose for chemicals

Resistance to oils: oil-suction hose, paint hose, creamery hose, packing house hose, special belts, tank linings, special footwear

Stickiness: cements, electrician's tape, adhesive tapes, pressure sensitive tapes

Low specific gravity: airplane parts, forestry hose, balloons

Lack of odor or taste: milk tubing, brewery and winery hose, nipples, jar rings

Acceptance of color pigments: ponchos, life rafts, welding hose

Table E.1 provides a comparison of the important properties of the most common elastomers. Specific values of each property will be found in the section dealing with each elastomer. Tensile strength and elongation as applied to elastomers are defined by the American Society for Testing and Materials as follows:

Table E.1 Comparative Properties of Elastomers^a

Property	Natural rubber (NR)	Isoprene (IR)	Neoprene (CR)	Butadiene-styrene (Bune S)	Nitrile-NBR (Buna N)	Burly (IIR)	Chloroburly (CIIR)	Hypalon (CSM)	Polybutadiene (BR)	Ethylene-acrylic (EA)	Acrylate-butadiene (ABR)	Acrylic ester-acrylic halide (ACM)
Abrasion resistance	E	E	G	G	G	G	G	G	E	E	G	FG
Acid resistance	P	P	GE	P	F	G	P	E	G	PG	G	P
Chemical resistance												
Aliphatic hydrocarbons	P	P	G	P	E	P	E	G	P	G	E	E
Aromatic hydrocarbons	P	P	F	P	G	P	P	F	P	F	P	P
Oxygenated (ketones, etc.)	G	G	P	G	P	G	P	P	G	P	P	P
Oil and gasoline	P	P	FG	P	E	P	E	G	P	G	E	E
Animal and vegetable oils	PG	PG	G	PG	E	E	G	G	PG	G	G	G
Resistance to												
Water absorption	E	E	G	GE	FG	G	G	GE	G	G	G	G
Ozone	P	P	GE	P	P	E	E	E	P	E	E	E
Sunlight aging	P	P	E	P	P	G	G	E	P	E	E	G
Heat aging	P	G	G	F	G	G	G	E	G	G	E	G
Flame	P	P	G	P	P	P	P	G	P	P	P	P
Electrical properties	G	G	F	E	F	E	PF	G	E	FG	G	PF
Impermeability	G	G	G	GE	G	E	G	E	G	G	G	G
Compression set resistance	E	E	F	G	GE	P	F	G	G	G	G	FG
Tear resistance	GE	GE	FG	P	FG	GE	G	G	G	G	G	G
Tensile strength	E	E	G	G	GE	G	G	GE	G	G	G	G
Water/steam resistance	E	E	F	E	FG	E	PF	G	E	G	G	PF
Weather resistance	P	P	E	P	F	E	F	E	G	G	E	F
Adhesion to metals	E	E	E	E	E	G	G	E	E	G	G	G
Adhesion to fabrics	E	E	E	E	G	G	G	E	E	G	G	G
Rebound												
Cold	E	E	E	G	G	P	F	G	E	P	G	F
Hot	E	E	E	G	G	G	F	G	E	F	G	F

^aE = excellent; G = good; F = fair; P = poor; PF = poor to fair; PG = poor to good; GE = good to excellent.



Tensile strength is the force per unit of the original cross-sectional area which is applied at the time of the rupture of the specimen.

Elongation or strain is the extension between benchmarks produced by a tensile force applied to a specimen and is expressed as a percentage of the original distance between the marks. Ultimate elongation is the elongation at the time of rupture.

Ethylene-propylene (EPDM)	Styrene-butadiene-styrene (SBS)	Styrene-ethylene-butylene-styrene (SEBS)	Polysulfide (ST)	Polysulfide (FA)	Urethane (AU)	Polyamides	Polyester (PE)	Thermoplastic (TPE)	Silicone (SI)	Fluorosilicone (FSI)	Vinylidene fluoride (HFP)	Fluoroelastomers (FKM)	Ethylene-tetrafluoroethylene (ETFE)	Ethylene-chlorotrifluoroethylene (ECTFE)	Perfluoroelastomers (FPM)
GE	G	GE	PF	PF	E	E	E	G	P	P	G	G	G	E	G
G	E	E	F	G	P	FG	F	G	FG	FG	E	E	E	E	E
P	P	P	E	E	E	G	E	P	G	E	G	E	E	E	E
P	P	P	E	E	P	G	G	P	P	FG	G	E	E	G	E
GE	P	P	G	G	P	G	F	P	P	PF	G	P	E	G	FG
P	F	FG	E	E	E	G	G	FG	P	G	E	E	E	E	E
G	P	G			E	FG	G	G	G	G	G	E	E	E	E
GE	E	E	G		G	G	G	E	G	G	G	GE	G	E	G
E	P	E	E	E	E	E	E	E	E	E	E	E	E	E	E
E	P	G	E	E	P	P	G	G	E	E	E	GE	E	E	E
E	G	E	P	G	F	G	E	G	E	E	E	E	E	E	E
P	P	PG	P	P	P	F	G	P	F	G	E	G	G		E
G	F	E	G	G	FG	G	FG	F	E	E	F	G	G	E	G
G	G	G	E	E	G	FG	G	P	P	G	G	E	G	G	E
GE	G	G	P	P	F	G	F	G	GE	GE	GE	GE			G
GE	G	G	P	P	GE	G	E	G	P	P	F	F	G		P
GE	G	G	F	G	E	G	E	G	P	F	GE	GE	G	G	G
E	FG	FG	E	G	P	G	FG	G	F	F	FG	G	G		G
E	F	G	E	E	G	E	G	E	E	E	E	E	E	E	E
GE	G	G	E	E	G	E	G	G	G	GE	G	GE	P		G
G	G	G	G	G	G	E	G	G	E	E		GE	F		
G	G	G	P	P	E	G	G	G	G	G		G			
G	G	G	P	P	E	G	E	G	G	G		E			

The procedure for conducting tensile tests is standardized and described in ASTM D412. Dumbbell-shaped specimens 4 or 5 inches long are die-cut from flat sheets and marked in the narrow section with benchmarks 1 or 2 in. apart. The ends of a specimen are placed in the grips of a vertical testing machine. The lower grip is power driven at 20 in./min and stretches the specimen until it breaks. As the distance between benchmarks widens, measurements are taken between their centers to determine elongation.

Tension tests are frequently conducted before and after an exposure test to determine the relative resistance of a group of compounds to deterioration by such things as oil, sunlight, weathering, ozone, heat, oxygen, and chemicals. Even a small amount of deterioration results in appreciable changes in tension properties.

Hardness, as applied to elastomeric products, is defined as relative resistance of the surface to indentation by a Shore A durometer. In this device the indenter point projects upward from the flat bottom of the case, held in the zero position by a spring. When pressed against a sample, the indenter point is pushed back into the case against the spring. This motion is translated through a rack-and-pinion mechanism into movement of the pointer on the durometer dial. Hardness numbers from a durometer scale for typical products are as follows:

Faucet washer, flooring, typewriter platen	90 ± 5
Shoe sole	80 ± 5
Solid tire, heel	70 ± 5
Tire tread, hose cover, conveyor belt cover	60 ± 5
Inner tube, bathing cap	50 ± 5
Rubber band	40 ± 5

Erasers and printing rolls usually have hardness values below 30.

Compression set is permanent deformation that remains in the elastomer after a compression force has been removed. The area of the elastomer that has compression set is not only permanently deformed but also less resilient than normal. The possibility of compression set occurring increases with increasing temperature, compression force, and length of time that the force is applied. Each type of elastomer has a different resistance to compression set. As with any material, each elastomer also has a limiting temperature range within which it may be used. [Table E.2](#) shows the allowable operating temperature range of each of the common elastomers.

Causes of Failure

Elastomeric materials can fail as the result of chemical action and/or mechanical damage. Chemical deterioration occurs as the result of a chemical reaction between the elastomer and the medium or by the absorption of the medium into the elastomer. This attack results in the swelling of the elastomer and a reduction in its tensile strength.

The degree of deterioration is a function of the temperature and concentration of the corrodent. In general, the higher the temperature and the higher the concentration of the corrodent, the greater will be the chemical attack. Elastomers, unlike metals, absorb varying quantities of the material they are in contact with, especially organic liquids. This can result in swelling, cracking, and penetration to the substrate in an elastomer-lined vessel. Swelling can cause softening of the elastomer and in a lined vessel introduce high stresses and failure of the bond. If an elastomeric lining has high absorption, permeation

Table E.2 Operating Temperature Range of Common Elastomers

Elastomer	Temperature range			
	°F		°C	
	Min	Max	Min	Max
NR, natural rubber	-59	175	-50	80
IR, isoprene rubber	-59	175	-50	80
CR, neoprene rubber	-13	203	-25	95
SBR, Buna-S	-66	175	-56	80
NBR, nitrile rubber, Buna-N	-40	250	-40	105
IIR, butyl rubber	-30	300	-34	149
CIIR, chlorobutyl rubber	-30	300	-34	149
CSM, Hypalon	-20	250	-30	105
BR, polybutadiene rubber	-150	200	-101	93
EA, ethylene-acrylic rubber	-40	340	-40	170
ABR, acrylate-butadiene rubber	-40	340	-40	170
EPDM, ethylene-propylene	-65	300	-54	149
SBS, styrene-butadiene-styrene		150		65
SEBS, styrene-ethylene butylene-styrene	-102	220	-75	105
ST, polysulfide	-50	212	-45	100
FA, polysulfide	-30	250	-35	121
AU, polyurethane	-65	250	-54	121
Polyamides	-40	300	-40	149
PE, polyesters	-40	302	-40	150
TPE, thermoplastic elastomers	-40	277	-40	136
SI, silicone	-60	450	-51	232
FSI, fluorosilicone	-100	375	-73	190
HEP, vinylidene fluoride	-40	450	-40	232
FKM, fluoroelastomers	-10	400	-18	204
ETFE, ethylene tetrafluoroethylene elastomer	-370	300	-223	149
ECTFE, ethylene chlorotrifluoroethylene elastomer	-105	340	-76	171
FPM, perfluoroelastomers	-58	600	-50	316

will probably result. Some elastomers, such as the fluorocarbons, are easily permeated but have little absorption. An approximation of the expected permeation and/or absorption of an elastomer can be based on the absorption of water.

Permeation is a factor closely related to absorption but is a function of other physical effects, such as diffusion and temperature. All materials are somewhat permeable to chemical molecules, but the permeability rate of elastomers tends to be an order of magnitude greater than that in metals. This permeation has been a factor in elastomer-lined vessels where corrodents have permeated the rubber and formed bubbles between the rubber lining and the steel substrate. Permeation and absorption can result in

1. Bond failure and blistering. These are caused by an accumulation of fluids at the bond when the substrate is less permeable than the lining or from the formation of corrosion or reaction products if the substrate is attacked by the corrodent.
2. Failure of the substrate due to corrosive attack.

3. Loss of contents through lining and substrate as the result of eventual failure of the substrate.

Thickness of lining is a factor affecting permeation. For general corrosion resistance, thicknesses of 0.010–0.020 in. are usually satisfactory, depending upon the combination of elastomeric material and specific corrodent. When mechanical factors such as thinning due to cold flow, mechanical abuse, and permeation rates are a consideration, thicker linings may be required.

Increasing the lining thickness will normally decrease permeation by the square of the thickness. Although this would appear to be the approach to follow to control permeation, there are disadvantages. First, as the thickness increases, the thermal stresses on the boundary increase, which can result in bond failure. Temperature changes and large differences in coefficients of thermal expansion are the most common causes of bond failure. Thickness and modulus of elasticity of the elastomer are two of the factors that would influence these stresses. Second, as the thickness of the lining increases, installation becomes more difficult, with a resulting increase in labor costs.

The rate of permeation is also affected by temperature and temperature gradient in the lining. Lowering these will reduce the rate of permeation. Lined vessels that are used under ambient conditions, such as storage tanks, provide the best service.

In unbonded linings it is important that the space between the liner and the support member be vented to the atmosphere not only to allow the escape of minute quantities of permeant vapors but also to prevent the expansion of entrapped air from collapsing the liner.

Although elastomers can be damaged by mechanical means alone, this is not usually the case. When in good physical condition, an elastomer will exhibit abrasion resistance superior to that of metal. The actual size, shape, and hardness of the particles and their velocity are the determining factors in how well a particular rubber resists mechanical damage from the medium. Hard, sharp objects, including those foreign to the normal medium, may cut or gouge the elastomer. Most mechanical damage occurs as a result of chemical deterioration of the elastomer. When the elastomer is in a deteriorated condition, the material is weakened, and consequently it is more susceptible to mechanical damage from flowing or agitated media.

Elastomers in outdoor use can be subject to degradation as a result of the action of ozone, oxygen, and sunlight. These three weathering agents can greatly affect the properties and appearance of a large number of elastomeric materials. Surface cracking, discoloration of colored stocks, serious loss of tensile strength and elongation, and other rubber-like properties are the result of this attack.

Selecting an Elastomer

Many factors must be taken into account when selecting an elastomer for a specific application. First and foremost is the compatibility of the elastomer with the medium at the temperature and concentration to which it will be exposed.

It should also be remembered that each of the materials can be formulated to improve certain of its properties. However, the improvement in one property may have an adverse effect on another property, such as corrosion resistance. Consequently, specifications of an elastomer should include the specific properties required for the application, such as resilience, hysteresis, static or dynamic shear and compression modulus, flex

fatigue and cracking, creep resistance to oils and chemicals, permeability, and brittle point, all in the temperature range to be encountered in service. This must also be accompanied by a complete listing of the concentrations of all media to be encountered. Providing this information will permit a competent manufacturer to supply an elastomer that will give years of satisfactory service. Because of the ability to change the formulation of many of these elastomers, the wisest policy is to permit a competent manufacturer to make the selection of the elastomer to satisfy the application. In addition to being able to change the formulation of each elastomer, it is also a common practice to blend two or more elastomers to produce a compound having specific properties. By so doing the advantageous properties of each elastomer can be made use of.

Fabrics are very often used as reinforcing members in conjunction with elastomers. Cotton, because of its ease of processing, availability in a wide range of weaves, and high adhesive strength, is the most widely used. It is also priced relatively low in comparison with synthetic fibers. The disadvantages of cotton are its poor heat resistance and the need for bulk in order to obtain the proper strength.

When operating temperatures of reinforced elastomeric products are in the range of 200–250°F (93–120°C), DuPont's Dacron polyester fiber is used to provide good service life. In addition to better heat-resisting qualities than cotton, Dacron has strength comparable to that of cotton with considerably less bulk. On the negative side, Dacron is more difficult to process than cotton, has lower adhesive strength, and is initially more expensive. [Table E.3](#) provides the corrosion resistance of selected elastomers and selected corrodents.

Applications

Elastomeric or rubber materials find a wide range of applications. One of the major areas of application is that of linings for vessels. Both natural and synthetic materials are used for this purpose. These linings have provided many years of service in the protection of steel vessels from corrosion. They are sheet applied and bonded to a steel substrate.

These materials are also used extensively as membranes in acid brick-lined vessels to protect the steel shell from corrosive attack. The acid brick lining in turn protects the elastomer from abrasion and excessive temperature. Another major use is as an impermeable lining for settling ponds and basins. These materials are employed to prevent pond contaminants from seeping into the soil and causing pollution of groundwater and contamination of the soil.

Natural rubber and most of the synthetic elastomers are unsaturated compounds that oxidize and deteriorate rapidly when exposed to air in thin films. These materials can be saturated by reacting with chlorine under the proper conditions, producing compounds that are clear, odorless, nontoxic, and noninflammable. They may be dissolved and blended with varnishes to impart high resistance to moisture and to the action of alkalis. This makes these products particularly useful in paints for concrete, where the combination of moisture and alkali causes the disintegration of ordinary paints and varnishes. These materials also resist mildew and are used to impart flame resistance and waterproofing properties to canvas. Application of these paints to steel will provide a high degree of protection against corrosion.

Table E.3 Corrosion Resistance of Selected Elastomers

Chemical	Butyl		Hypalon		EPDM		EPT		Viton A		Kalrez		Natural rubber		Neoprene		Buna N	
	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C
Acetaldehyde	80	27	60	16	200	93	210	99	x	x	x	x	x	x	200	93	x	x
Acetamide			x	x	200	93	200	93	210	99	x	x	x	x	200	93	180	82
Acetic acid 10%	150	66	200	93	140	60	x	x	190	88	200	93	150	66	160	71	200	93
Acetic acid 50%	110	43	200	93	140	60	x	x	180	82	200	93	x	x	160	71	200	93
Acetic acid 80%	110	43	200	93	140	60	x	x	180	82	90	32	x	x	160	71	210	99
Acetic acid, glacial	90	32	x	x	140	60	x	x	x	x	80	27	x	x	x	x	100	38
Acetic anhydride	150	66	200	93	x	x	x	x	x	x	210	99	x	x	90	32	200	93
Acetone	160	71	x	x	300	148	x	x	x	x	210	99	x	x	x	x	x	x
Acetyl chloride			x	x	x	x	x	x	190	88	210	99	x	x	x	x	x	x
Acrylic acid									x	x	210	99	x	x	x	x	x	x
Acrylonitrile	x	x	140	60	140	60	100	38	x	x	110	43	90	32	160	71	x	x
Adipic acid	x	x	140	60	200	93	140	60	180	82	210	99	80	27	160	71	180	82
Allyl alcohol	190	88	200	93	300	148	80	27	190	88			80	27	120	49	180	82
Allyl chloride	x	x			x	x	x	x	100	38			x	x	x	x	x	x
Alum	190	88	200	93	200	93	140	60	190	88	210	99	150	66	200	93	200	93
Aluminum acetate			x	x	200	93	180	82	180	82	210	99			x	x	200	93
Aluminum chloride, aqueous	150	66	250	121	210	99	180	82	190	88	210	99	140	60	200	93	200	93
Aluminum chloride, dry											190	88						
Aluminum fluoride	180	82	200	93	210	99	180	82	180	82	210	99	150	66	200	93	190	88
Aluminum hydroxide	100	38	250	121	210	99	140	60	190	88	210	99			180	82	180	82
Aluminum nitrate	190	88	250	121	210	99	180	82	190	88	210	99	150	66	200	93	200	93
Aluminum oxychloride									x	x								
Aluminum sulfate	190	88	200	93	210	99	210	99	190	88	210	99	160	71	200	93	210	99
Ammonia gas			140	60	140	60	140	60	x	x	210	99	x	x	140	60	190	88
Ammonium bifluoride	x	x			300	148	140	60	140	60	210	99	x	x	x	x	180	82
Ammonium carbonate	190	88	140	60	300	148	180	82	190	88	210	99	150	66	200	93	200	93
Ammonium chloride 10%	190	88	200	93	210	99	180	82	190	88	210	99	150	66	200	93	200	93
Ammonium chloride 50%	190	88	200	93	210	99	180	82	190	88	210	99	150	66	190	88	200	93
Ammonium chloride, sat.	190	88	200	93	300	148	180	82	190	88	210	99	150	66	200	93	200	93
Ammonium fluoride 10%	150	66	200	93	210	99	210	99	140	60	210	99	160	71	100	38	200	93
Ammonium fluoride 25%	150	66			300	148	140	60	140	60	210	99	80	27	200	93	120	49
Ammonium hydroxide 25%	190	88	250	121	100	38	140	60	190	88	210	99	x	x	200	93	200	93

Ammonium hydroxide, sat,	190	88	250	121	100	38	140	60	190	88	210	99	90	32	210	99	200	93
Ammonium nitrate	180	82	200	93	250	121	180	82	x	x	300	148	170	77	200	93	180	82
Ammonium persulfate	190	88	80	27	300	148	210	99	140	60	210	99	150	66	200	93	200	93
Ammonium phosphate	180	82	140	60	300	148	180	82	180	82	210	99	150	66	200	93	200	93
Ammonium sulfate 10–40%	190	88	200	93	300	148	180	82	180	82	210	99	150	66	200	93	200	93
Ammonium sulfide			200	93	300	148	210	99	x	x	210	99		160	71	180	82	
Ammonium sulfite											210	99				160	71	
Amyl acetate	x	x	60	16	210	99	x	x	x	x	210	99	x	x	x	x	x	x
Amyl alcohol	180	82	200	93	210	99	180	82	200	93	210	99	150	66	200	93	180	82
Amyl chloride			x	x	x	x	x	x	190	88	210	99	x	x	x	x	x	x
Aniline	150	66	140	60	140	60	x	x	230	110	250	121	x	x	x	x	x	x
Antimony trichloride	150	66	140	60	300	148	x	x	190	88	210	99		140	60			
Aqua regia 3:1				x	x	x	x	x	190	88	210	99	x	x	x	x	x	x
Barium carbonate			200	93	300	148	180	82	250	121	210	99	180	82	160	71	180	82
Barium chloride	190	88	250	121	250	121	180	82	190	88			150	66	200	93	200	93
Barium hydroxide	190	88	250	121	250	121	180	82	190	88	210	99	150	66	200	93	200	93
Barium sulfate			200	93	300	148	180	82	190	88	210	99	180	82	160	71	180	82
Barium sulfide	190	88	200	93	140	60	140	60	190	88	210	99	150	66	200	93	200	93
Benzaldehyde	90	32	x	x	150	66	x	x	x	x	210	99	x	x	x	x	x	x
Benzene	x	x	x	x	x	x	x	x	190	88	210	99	x	x	x	x	x	x
Benzene sulfonic acid 10%	90	32	x	x	x	x	x	x	170	77	210	99	x	x	100	38	x	x
Benzoic acid	150	66	200	93	x	x	140	60	190	88	310	154	150	66	200	93	x	x
Benzyl alcohol	190	88	140	60	x	x	x	x	350	177	210	99	x	x	x	x	140	60
Benzyl chloride	x	x	x	x	x	x	x	x	110	43	210	99	x	x	x	x	x	x
Borax	190	88	200	93	300	148	210	99	190	88	210	99	150	66	200	93	180	82
Boric acid	190	88	290	143	190	88	140	60	190	88	210	99	150	66	200	93	180	82
Bromine gas, dry			60	16	x	x	x	x			210	99			x	x	x	x
Bromine gas, moist			60	16	x	x									x	x	x	x
Bromine liquid			60	16	x	x	x	x	350	177	140	60			x	x	x	x
Butadiene			x	x	x	x	x	x	190	88	210	99		140	60	200	93	
Butyl acetate	x	x	60	16	140	60	x	x	x	x	210	99	x	x	60	16	x	x
Butyl alcohol	140	60	250	121	200	93	180	82	250	121	240	116	150	66	200	93	x	x
<i>n</i> -Butylamine							x	x	x	x	210	99					80	27
Butyl phthalate							x	x	80	27	210	99	x	x			x	x
Butyric acid	x	x	x	x	140	60	x	x	120	49	x	x	x	x	x	x	x	x
Calcium bisulfide							x	x	190	88	210	99					180	82

Table E.3 (Continued)

Chemical	Butyl		Hypalon		EPDM		EPT		Viton A		Kalrez		Natural rubber		Neoprene		Buna N	
	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C
Calcium bisulfite	120	49	250	121	x	x	x	x	190	88	210	99	120	49	180	82	200	93
Calcium carbonate	150	66	90	32	210	99	140	60	190	88	200	93	180	82	60	16	180	82
Calcium chlorate	190	88	90	32	140	60	140	60	190	88	210	99	150	66	200	93	200	93
Calcium chloride	190	88	200	93	210	99	180	82	190	88	210	99	150	66	200	93	180	82
Calcium hydroxide 10%	190	88	200	93	210	99	180	82	190	88	210	99	200	93	220	104	180	82
Calcium hydroxide, sat.	190	88	250	121	220	104	180	82	190	88	210	99	200	93	220	104	180	82
Calcium hypochlorite	190	88	250	121	210	99	180	82	190	88	210	99	200	93	220	104	80	27
Calcium nitrate	190	88	100	38	300	148	180	82	190	88	210	99	150	66	200	93	200	93
Calcium oxide			200	93	210	99									160	71	180	82
Calcium sulfate	100	38	250	121	300	148	180	82	200	93	210	99	180	82	160	71	180	82
Caprylic acid											210	99						
Carbon bisulfide			x	x	x	x	x	x	190	88	210	99	x	x	x	x	x	x
Carbon dioxide, dry	190	88	200	93	250	121	180	82	x	x	210	99	150	66	200	93	200	93
Carbon dioxide, wet	190	88	200	93	250	121	180	82	x	x	210	99	150	66	200	93	200	93
Carbon disulfide	190	88	230	110	250	121	180	82	x	x	210	99	150	66	x	x	200	93
Carbon monoxide	x	x	x	x	x	x	x	x	190	88	210	99	x	x	x	x	x	x
Carbon tetrachloride	90	32	200	93	250	121	180	82	190	88	210	99	x	x	200	93	180	82
Carbolic acid	x	x	x	x	x	x	x	x	350	177	210	99	x	x	x	x	x	x
Cellosolve	150	66			300	148	x	x	x	x	210	99	x	x	x	x	x	x
Chloroacetic acid, 50% water	150	66					x	x	x	x	210	99	x	x	x	x	x	x
Chloroacetic acid	160	71	x	x	160	71	x	x	x	x	210	99	x	x	x	x	x	x
Chlorine gas, dry	x	x	x	x	x	x	x	x	190	88	210	99	x	x	x	x	x	x
Chlorine gas, wet			90	32	x	x	x	x	190	88					x	x	x	x
Chlorine liquid	x	x			x	x	x	x	190	88	210	99	x	x	x	x	x	x
Chlorobenzene	x	x	x	x	x	x	x	x	190	88	210	99	x	x	x	x	x	x
Chloroform	x	x	x	x	x	x	x	x	190	88	210	99	x	x	x	x	x	x
Chlorosulfonic acid	x	x	x	x	x	x	x	x	x	x	210	99	x	x	x	x	x	x
Chromic acid 10%	100	38	150	66			x	x	350	177	210	99	x	x	140	60	190	88
Chromic acid 50%	x	x	160	71	x	x	x	x	350	177	210	99	x	x	100	38	190	88
Chromyl chloride											210	99						
Citric acid 15%	190	88	250	121	210	99	180	82			210	99	110	43	200	93	180	82

Citric acid, conc.	190	88	250	121	210	99	180	82	190	88	210	99	150	66	200	93	180	82
Copper acetate			x	x	100	38	100	38	x	x	210	99			160	71	180	82
Copper carbonate					210	99	210	99	190	88	210	99					x	x
Copper chloride	190	88	200	93	210	99	180	82	190	88	210	99	150	66	200	93	200	93
Copper cyanide			250	121	210	99	210	99	190	88	210	99	160	71	160	71	180	82
Copper sulfate	190	88	250	121	210	99	180	82	190	88	210	99	150	66	200	93	200	93
Cresol	x	x	x	x	x	x	100	38	x	x	210	99	x	x	x	x	x	x
Cupric chloride 5%			200	93	210	99	210	99	180	82					210	99	210	99
Cupric chloride 50%			200	93	210	99	210	99	180	82					160	71	180	82
Cyclohexane	x	x	x	x	x	x	x	x	190	88	210	99	x	x	x	x	180	82
Cyclohexanol			x	x	x	x	x	x	190	88	210	99			x	x	x	x
Dichloroacetic acid											210	99			x	x		
Dichloroethane	x	x	x	x	x	x	x	x	190	88	210	99	x	x	x	x	x	x
Ethylene glycol	190	88	200	93	210	99	180	82	350	177	210	99	150	66	160	71	200	93
Ferric chloride	190	88	250	121	220	104	180	82	190	88	210	99	150	66	160	71	200	93
Ferric chloride, 50% water	160	71	250	121	210	99	180	82	180	82	210	99	150	66	160	71	180	82
Ferric nitrate 10–50%	190	88	250	121	210	99	180	82	190	88	210	99	150	66	200	93	200	93
Ferrous chloride	190	88	250	121	200	93	180	82	180	82	210	99	150	66	90	32	200	93
Ferrous nitrate	190	88			210	99	180	82	210	99			150	66	200	93	200	93
Fluorine gas, dry	x	x	140	60			x	x	x	x	x	x	x	x	x	x	x	x
Fluorine gas, moist					60	16	100	38	x	x	x	x	x	x	x	x	x	x
Hydrobromic acid, dil.	150	66	90	32	90	32	140	60	190	88	210	99	100	38	x	x	x	x
Hydrobromic acid 20%	160	71	100	38	140	60	140	60	190	88	210	99	110	43	x	x	x	x
Hydrobromic acid 50%	110	43	100	38	140	60	140	60	190	88	210	99	150	66	x	x	x	x
Hydrochloric acid 20%	x	x	160	71	100	38	x	x	350	177	210	99	150	66	90	32	130	54
Hydrochloric acid 38%	x	x	140	60	90	32	x	x	350	177	210	99	160	71	90	32	x	x
Hydrocyanic acid 10%	140	60	90	32	200	93	x	x	190	88	210	99	90	32	x	x	200	93
Hydrofluoric acid 30%	350	177	90	32	60	16	140	60	210	99	210	99	100	38	200	93	x	x
Hydrofluoric acid 70%	150	66	90	32	x	x	x	x	350	177	210	99	x	x	200	93	x	x
Hydrofluoric acid 100%	x	x	90	32	x	x	x	x	60	16	210	99	x	x	x	x	x	x
Hypochlorous acid	x	x	x	x	300	148	140	60	190	88	190	88	150	66	x	x	x	x
Iodine solution 10%					140	60	140	60	190	88					80	27	80	27
Ketones, general			x	x	x	x			x	x	210	99	x	x	x	x	x	x
Lactic acid 25%	120	49	140	60	140	60	210	99	190	88	210	99	x	x	140	60	x	x
Lactic acid, concentrated	120	49	80	27			210	99	150	66	210	99	80	27	90	32	x	x
Magnesium chloride	200	93	250	121	250	121	180	82	180	82	150	66	150	66	210	99	180	82

Table E.3 (Continued)

Chemical	Butyl		Hypalon		EPDM		EPT		Viton A		Kalrez		Natural rubber		Neoprene		Buna N	
	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C	°F	°C
Malic acid	x	x			x	x	80	26	190	88	210	99	80	27			180	82
Manganese chloride			180	82			210	99	180	82	210	99			200	93	100	38
Methyl chloride	90	32	x	x	x	x	x	x	190	88			x	x	x	x	x	x
Methyl ethyl ketone	100	38	x	x	80	27	x	x	x	x	210	99	x	x	x	x	x	x
Methyl isobutyl ketone	80	27	x	x	60	16	x	x	x	x	210	99	x	x	x	x	x	x
Muriatic acid	x	x	140	60			x	x	350	177	210	99			x	x	x	x
Nitric acid 5%	160	71	100	38	60	16	x	x	190	88	210	99	x	x	x	x	x	x
Nitric acid 20%	160	71	100	38	60	16	x	x	190	88	210	99	x	x	x	x	x	x
Nitric acid 70%	90	32	x	x	x	x	x	x	190	88	160	71	x	x	x	x	x	x
Nitric acid, anhydrous	x	x	x	x	x	x	x	x	190	88	x	x	x	x	x	x	x	x
Nitrous acid, concentrated	120	49							100	38	210	99	x	x	x	x	x	x
Oleum	x	x	x	x	x	x	x	x	190	88	210	99	x	x	x	x	x	x
Perchloric acid 10%	150	66	100	38	140	60	190	88	190	88	210	99	150	66			x	x
Perchloric acid 70%			90	32			140	60	190	88					x	x	x	x
Phenol	150	66	x	x			80	27	210	99	210	99	x	x	x	x	x	x
Phosphoric acid 50–80%	150	66	200	93	140	60	180	82	190	88	210	99	110	43			x	x
Picric acid			80	27	300	148	140	60	190	88	210	99	x	x	200	93	130	54
Potassium bromide 30%			250	121	210	99	180	82	190	88	210	99	160	71	160	71	180	82
Salicylic acid	80	27			210	99	180	82	190	88	210	99						
Silver bromide 10%											210	99						

Sodium carbonate	180	82	250	121	300	148	180	82	190	88	210	99	180	82	200	93	200	93
Sodium chloride	180	82	240	116	140	60	180	82	190	88	210	99	130	54	200	93	180	82
Sodium hydroxide 10%	180	82	250	121	210	99	210	99	x	x	210	99	150	66	200	93	160	71
Sodium hydroxide 50%	190	88	250	121	180	82	200	93	x	x	210	99	150	66	200	93	150	66
Sodium hydroxide conc.	180	82	250	121	180	82	80	27	x	x	210	99	150	66	200	93	150	66
Sodium hypochlorite 20%	130	54	250	121	300	148	x	x	190	88			90	32	x	x	x	x
Sodium hypochlorite	90	32			300	148	x	x	190	88			90	32	x	x	x	x
Sodium sulfide to 50%	150	66	250	121	300	148	210	99	190	88	210	99	150	66	200	93	180	82
Stannic chloride	150	66	90	32	300	148	210	99	180	82	210	99	150	66	210	99	180	82
Stannous chloride	150	66	200	93	280	138	210	99	190	88	210	99	150	66	160	71	180	82
Sulfuric acid 10%	150	66	250	121	150	66	210	99	350	177	240	116	150	66	200	93	150	66
Sulfuric acid 50%	150	66	250	121	150	66	210	99	350	177	210	99	100	38	200	93	200	93
Sulfuric acid 70%	100	38	160	71	140	60	210	99	350	177	150	66	x	x	200	93	x	x
Sulfuric acid 90%	x	x	x	x	x	x	80	27	350	177	150	66	x	x	x	x	x	x
Sulfuric acid 98%	x	x	110	43	x	x	x	x	350	177			x	x	x	x	x	x
Sulfuric acid 100%	x	x	x	x	x	x	x	x	190	88			x	x	x	x	x	x
Sulfuric acid, fuming			x	x	x	x	x	x			210	99			x	x	x	x
Sulfurous acid	150	66	160	71	x	x	180	82	190	88	210	99	x	x	x	x	x	x
Thionyl chloride	x	x							x	x	210	99	x	x	x	x	x	x
Toluene	x	x	x	x	x	x	x	x	190	88	80	27	x	x	x	x	150	66
Trichloroacetic acid	x	x			80	27	x	x	190	88	210	99	x	x	x	x	x	x
While liquor					300	148	180	82	190	88	210	99	x	x	140	60	140	60
Zinc chloride	190	88	250	121	300	148	180	82	210	99	210	99	150	66	160	71	190	88

The chemicals listed are in the pure state or in a saturated solution unless otherwise indicated. Compatibility is shown to the maximum allowable temperature for which data are available. Incompatibility is indicated by an x. A blank space indicates that data are unavailable.

Source: Schweitzer, Philip A. *Corrosion Resistance Tables*. 4th ed. Vols. 1-3. New York: Marcel Dekker, 1995.

Large quantities of elastomeric materials are used to produce a myriad of products such as hoses, cable insulation, O-rings, seals and gaskets, belting, vibration mounts, flexible couplings, expansion joints, automotive and airplane parts, electrical parts and accessories, and many other items. With such a wide variety of applications requiring very diverse properties, it is essential that an understanding of the properties of each elastomer be acquired so that proper choices can be made.

See Refs. 1–3.

ELECTROCHEMICAL CORROSION

Corrosion of metals is caused by the flow of energy (electricity). This flow may be from one metal to another metal, or from one part of the surface of a metal to another part of the same metal, or from a metal to a recipient of some kind. This flow of electricity can take place in the atmosphere, underwater, or underground as long as a moist conductor or electrolyte such as water or especially salt water is present.

The difference in potential that causes the electric currents is mainly due to contact between dissimilar metallic conductors, or differences in concentration of the solution, generally related to dissolved oxygen in natural waters. Any lack of homogeneity on the metal surface may initiate attack by causing a difference in potentials that results in localized corrosion.

The flow of electricity (energy) may also be from a metal to a metal recipient of some kind, such as soil. Soils frequently contain dispersed metallic particles or bacterial pockets that provide a natural pathway with buried metal. The electrical path will be from metal to soil, with corrosion resulting.

The presence of water is the key factor for corrosion to take place. For example, in dry air such as a desert location, the corrosion of steel does not take place, and when the relative humidity of air is below 30% at normal or lower temperatures, corrosion is negligible.

Since aqueous corrosion is electrochemical in nature, it is possible to measure the corrosion rate by employing electrochemical techniques. Two methods based on electrochemical polarization are available: Tafel extrapolation and linear polarization. These methods permit rapid and precise corrosion rate measurement and may be used to measure corrosion rate in systems that cannot be visually inspected or subjected to weight loss tests.

Tafel Extrapolation Method

The Tafel extrapolation method is based on the mixed-potential theory, which is illustrated in Fig. E.1. The dashed lines represent the anodic and cathodic components of the mixed electrodes involved in the corrosion process, the intersecting point of which corresponds to i_{CORR} and E_{CORR} . When a corroding specimen is polarized by the applied current, usually cathodic, the experimental polarization curve originates at E_{CORR} and at high current densities becomes linear on a semilogarithmic plot. This linear portion coincides with the extended reduction curve as shown by the bold line in the figure. It is evident that an extrapolation of the linear portion of the experimental curve will intersect the E_{CORR} horizontal at the point that corresponds to i_{CORR} .

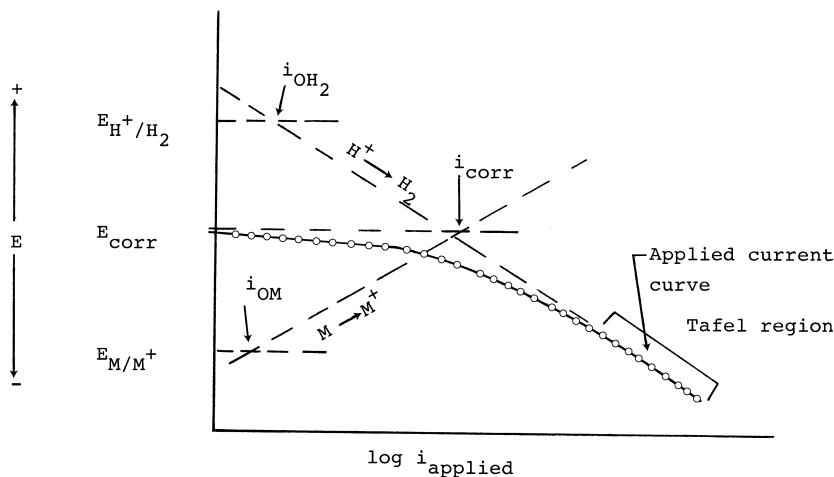


Figure E.1 Tafel extrapolation method of corrosion rate measurement through cathodic polarization.

This method is rapid. However, the linear portion should extend over a considerable length, not less than one order of magnitude, to ensure accuracy in extrapolation. Where more than one reduction process is prevailing, the linearity is also affected. These disadvantages are largely overcome in the linear polarization method.

Linear Polarization Method

Within 10 mV more noble or more active than the corrosion potential, the applied current density is a linear function of the electrode potential. This is shown in Fig. E.2. The slope of the linear polarization curve is given by

$$\frac{\Delta E}{\Delta i_{app}} = \frac{\beta_a \beta_c}{2.3(i_{corr})(\beta_a + \beta_c)}$$

where β_a and β_c are the Tafel slopes for anodic and cathodic reactors, respectively. The slope is in the unit of ohms and is referred to as the polarization resistance R_p . This method is also known as the polarization resistance method. Although the linearity of the curve deviates at higher overvoltages, the slope of the curve at the origin is independent of the degree of linearity. The slope of the linear curve is inversely proportional to the corrosion current i_{corr} .

Assuming $\beta_a = \beta_c = 0.12$ V,

$$\frac{\Delta E}{\Delta i_{app}} = \frac{0.026}{i_{corr}}$$

From this equation the corrosion rate can be calculated without knowledge of the kinetic parameters. This principle is utilized in commercial instruments designed for corrosion rate measurement. These instruments are based on galvanic circuitry and have two-electrode or three-electrode configurations.

See Refs. 4, 6.

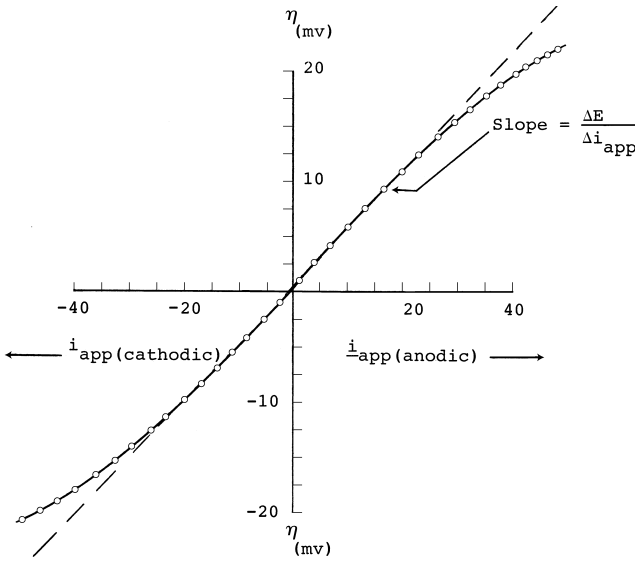


Figure E.2 Applied-current linear polarization curve for corrosion rate measurement.

ELECTROLYSIS

Electrolysis is the process of the passage of an electric current through a solution with simultaneous chemical changes either in the electrodes or in the solutions in contact with the electrodes, or both. Corrosion of a buried or immersed structure due to stray DC from an external source, such as an electric motor or welding machine, is known as electrolysis. The first observance of this phenomenon was around electric railways which were designed to furnish DC on an overhead wire and to have the current return to its source via the track or third rail. If the current found it easier to return to its source via an underground sewer system or water line, it would protect the pipe at the point of entry but cause severe corrosion damage at the point of discharge via the soil to the power source.

Similar problems have been experienced in the form of localized pitting when underground austenitic stainless steel pipe is welded in place.

ELECTROLYTE

An electrolyte is any substance that, when in solution or fused, forms a liquid that will conduct an electric current. Acids, bases, and salts are common electrolytes.

EMBEDDED IRON CORROSION

Embedded iron corrosion occurs when, during fabrication of stainless steel equipment, iron is embedded in the stainless steel surface. When exposed to moist air, or wetted, the iron corrodes, leaving rust streaks and possibly initiating crevice corrosion attack in the stainless steel.

EMBRITTLEMENT

This is the severe loss of ductility or toughness in a material, which may result in cracking. Some metals, when stressed, crack on exposure to corrosive environments, but corrosion is not necessarily a part of crack initiation or crack growth. This type of failure is not properly called stress corrosion cracking.

The most frequent occurrence of this form of attack is in steel equipment handling solutions containing hydrogen sulfide. Under these conditions corrosion of the steel generates atomic hydrogen, which penetrates the steel and at submicroscopic discontinuity of pressures high enough to cause cracking or blistering. Failures of this kind are called hydrogen cracking or hydrogen stress cracking.

See “[Hydrogen Damage](#).”

See [Refs. 7–10](#).

ENAMELING

See “[Glass Linings](#).”

ENGINEERING PLASTIC

This term is used interchangeably with the terms engineering polymers and high-performance polymers. The *ASM Handbook* defines engineering plastics as synthetic polymers of a resin-based material that have load-bearing characteristics and high-performance properties that permit them to be used in the same manner as metals and ceramics. In other words, these materials are plastics and polymeric compositions having well-defined mechanical properties such that engineering rather than empirical methods can be used for the design and manufacture of products that require definite and predictable performance in structural applications over a substantial temperature range. Many engineering polymers are reinforced and/or alloy polymers, blends of different polymers.

Among the engineering plastics are poly (*p*-phenyleneterephthalamide) (aromatic polyamide or aramid), polyaromatic ester, polyetherketone, polyphenylene sulfide, polyamide-imidepolyether sulfone, polyether-imide, polysulfone, and polyimide (thermoplastic).

Elastomers are cross-linked linear thermoplastic polymers and many fall into the engineering category. However, the major products of the polymer industry, such as polyethylene, polyvinyl chloride, polypropylene, and polystyrene, are not considered engineering products because of their low strength.

EPOXY RESINS

See also “[Polymers](#)” and “[Thermoset Polymers](#).” The epoxy resins are a family of resins as are the vinyl ester resins. They exhibit good resistance to alkalis, nonoxidizing acids, and many solvents. Specifically, they are compatible with acids such as 10% acetic, benzoic, butyric, 10% hydrochloric, 20% sulfuric, oxalic, and fatty acids. On the alkaline side they are compatible with 50% sodium hydroxide, 10% sodium sulfite, calcium hydroxide, trisodium phosphate, magnesium hydroxide, aluminum, barium, calcium, iron, magnesium, potassium, and sodium. Solvents such as methanol, ethanol, isopropanol, benzene, ethyl acetate, naphtha, toluene, and xylene can also be handled safely.

Bromine water, chromic acid, bleaches, fluorine, methylene chloride, hydrogen peroxide, sulfuric acid above 80%, wet chlorine gas, and wet sulfur dioxide will attack the epoxies. Refer to [Table E.4](#) for the compatibility of epoxies with selected corrodents.

Table E.4 Compatibility of Epoxy with Selected Corrodents^a

Chemical	Maximum temp.		Chemical	Maximum temp.	
	°F	°C		°F	°C
Acetaldehyde	150	66	Barium sulfide	300	149
Acetamide	90	32	Benzaldehyde	x	x
Acetic acid 10%	190	88	Benzene	160	71
Acetic acid 50%	110	43	Benzene sulfonic acid 10%	160	71
Acetic acid 80%	110	43	Benzoic acid	200	93
Acetic anhydride	x	x	Benzyl alcohol	x	x
Acetone	110	43	Benzyl chloride	60	16
Acetyl chloride	x	x	Borax	250	121
Acrylic acid	x	x	Boric acid 4%	200	93
Acrylonitrile	90	32	Bromine gas, dry	x	x
Adipic acid	250	121	Bromine gas, moist	x	x
Allyl alcohol	x	x	Bromine liquid	x	x
Allyl chloride	140	60	Butadiene	100	38
Alum	300	149	Butyl acetate	170	77
Aluminum chloride, aqueous 1%	300	149	Butyl alcohol	140	60
Aluminum chloride, dry	90	32	<i>n</i> -Butylamine	x	x
Aluminum fluoride	180	82	Butyric acid	210	99
Aluminum hydroxide	180	82	Calcium bisulfide		
Aluminum nitrate	250	121	Calcium bisulfite	200	93
Aluminum sulfate	300	149	Calcium carbonate	300	149
Ammonia gas, dry	210	99	Calcium chlorate	200	93
Ammonium bifluoride	90	32	Calcium chloride 37.5%	190	88
Ammonium carbonate	140	60	Calcium hydroxide, sat.	180	82
Ammonium chloride, sat.	180	82	Calcium hypochlorite 70%	150	66
Ammonium fluoride 25%	150	66	Calcium nitrate	250	121
Ammonium hydroxide 25%	140	60	Calcium sulfate	250	121
Ammonium hydroxide, sat.	150	66	Caprylic acid	x	x
Ammonium nitrate 25%	250	121	Carbon bisulfide	100	38
Ammonium persulfate	250	121	Carbon dioxide, dry	200	93
Ammonium phosphate	140	60	Carbon disulfide	100	38
Ammonium sulfate 10–40%	300	149	Carbon monoxide	80	27
Ammonium sulfite	100	38	Carbon tetrachloride	170	77
Amyl acetate	80	27	Carbonic acid	200	93
Amyl alcohol	140	60	Cellosolve	140	60
Amyl chloride	80	27	Chloracetic acid, 92% water	150	66
Aniline	150	66	Chloracetic acid	x	x
Antimony trichloride	180	82	Chlorine gas, dry	150	66
Aqua regia 3:1	x	x	Chlorine gas, wet	x	x
Barium carbonate	240	116	Chlorobenzene	150	66
Barium chloride	250	121	Chloroform	110	43
Barium hydroxide 10%	200	93	Chlorosulfonic acid	x	x
Barium sulfate	250	121	Chromic acid 10%	110	43
			Chromic acid 50%	x	x

Table E.4 Compatibility of Epoxy with Selected Corrodents^a (Continued)

Chemical	Maximum temp.		Chemical	Maximum temp.	
	°F	°C		°F	°C
Citric acid 15%	190	88	Methyl isobutyl ketone	140	60
Citric acid, 32%	190	88	Muriatic acid	140	60
Copper acetate	200	93	Nitric acid 5%	160	71
Copper carbonate	150	66	Nitric acid 20%	100	38
Copper chloride	250	121	Nitric acid 70%	x	x
Copper cyanide	150	66	Nitric acid, anhydrous	x	x
Copper sulfate 17%	210	99	Nitric acid, concentrated	x	x
Cresol	100	38	Oleum	x	x
Cupric chloride 5%	80	27	Perchloric acid 10%	90	32
Cupric chloride 50%	80	27	Perchloric acid 70%	80	27
Cyclohexane	90	32	Phenol	x	x
Cyclohexanol	80	27	Phosphoric acid 50–80%	110	43
Dichloroacetic acid	x	x	Picric acid	80	27
Dichloroethane (ethylene dichloride)	x	x	Potassium bromide 30%	200	93
Ethylene glycol	300	149	Salicylic acid	140	60
Ferric chloride	300	149	Sodium carbonate	300	149
Ferric chloride 50% in water	250	121	Sodium chloride	210	99
Ferric nitrate 10–50%	250	121	Sodium hydroxide 10%	190	88
Ferrous chloride	250	121	Sodium hydroxide 50%	200	93
Ferrous nitrate			Sodium hypochlorite 20%	x	x
Fluorine gas, dry	90	32	Sodium hypochlorite concentrated	x	x
Hydrobromic acid, dilute	180	82	Sodium sulfide to 10%	250	121
Hydrobromic acid 20%	180	82	Stannic chloride	200	93
Hydrobromic acid 50%	110	43	Stannous chloride	160	71
Hydrochloric acid 20%	200	93	Sulfuric acid 10%	140	60
Hydrochloric acid 38%	140	60	Sulfuric acid 50%	110	43
Hydrocyanic acid 10%	160	71	Sulfuric acid 70%	110	43
Hydrofluoric acid 30%	x	x	Sulfuric acid 90%	x	x
Hydrofluoric acid 70%	x	x	Sulfuric acid 98%	x	x
Hydrofluoric acid 100%	x	x	Sulfuric acid 100%	x	x
Hypochlorous acid	200	93	Sulfuric acid, fuming	x	x
Ketones, general	x	x	Sulfurous acid 20%	240	116
Lactic acid 25%	220	104	Thionyl chloride	x	x
Lactic acid, concentrated	200	93	Toluene	150	66
Magnesium chloride	190	88	Trichloroacetic acid	x	x
Methyl chloride	x	x	White liquor	90	32
Methyl ethyl ketone	90	32	Zinc chloride	250	121

^aThe chemicals listed are in the pure state or in a saturated solution unless otherwise indicated. Compatibility is shown to the maximum allowable temperature for which data are available. Incompatibility is shown by an x. A blank space indicates that the data are unavailable.

Source: PA Schweitzer. *Corrosion Resistance Tables*. 4th ed. Vols. 1–3. New York: Marcel Dekker, 1995.

Refer to [Ref. 4](#) for the compatibility of the epoxies over a wider range of selected corrodents.

See [Refs. 2, 3, 11, and 12](#).

EROSION CORROSION

The term erosion applies to deterioration due to mechanical forces. When the factors contributing to erosion accelerate the rate of corrosion of a metal, the attack is called erosion corrosion. Erosion corrosion is usually caused by a corrodent, aqueous or gaseous, flowing over the metal surface or impinging on it. The mechanical deterioration may be aggravated by the presence of a corrodent, as in the case of fretting corrosion or corrosive wear.

The attack takes the form of grooves, i.e., scooped-out rounded areas, horseshoe-shaped depressions, gullies, or waves, all of which often show directionality. At times the attack may be an assembly of pits. Ultimate perforation due to thinning or progression of pits, and rupture due to failure of the thinned wall to resist the internal fluid pressure are also common. All equipment exposed to flowing fluid are subject to erosion corrosion, but piping systems and heat exchangers are the most commonly affected.

Erosion corrosion is affected by velocity, turbulence, impingement, presence of suspended solids, temperature, and prevailing cavitation conditions. The acceleration of attack is due to the distribution or removal of the protective surface film by mechanical forces exposing fresh metal surfaces that are anodic to the uneroded neighboring film. A hard, dense, adherent and continuous film such as on stainless steel is more resistant than a soft, brittle film as on lead. The nature of the protective film depends largely on the corrosive itself.

In most metals and alloys corrosion rates increase with increased velocity, but a marked increase is experienced only when a critical velocity is reached.

Turbulence is caused when the liquid flows from a larger area to a small-diameter pipe, as in the inlet ends of tubing in heat exchangers. Internal deposits in the pipes or any obstruction to the flow inside a pipe by a foreign body, such as a carried-in pebble, can also cause turbulence.

Impingement, direct impact of the corrodent on the metal surface, occurs at bends, elbows, and tees in a piping system and causes intense attack. Impingement is also encountered on the surfaces of impellers and turbines in areas in front of inlet pipes in tanks and in many other situations. The attack appears as horseshoe-shaped pits with deep undercut and the end pointing in the direction of flow.

Attack is further aggravated at higher temperatures and when the solution contains solids in suspension. Steam carrying water condensate droplets provides an aggressive medium for erosion corrosion of steel and cast iron piping. The impingement of water droplets at the return bends destroys the protective oxide film and accelerates the attack on the substrate.

Soft and low-strength metals such as copper, aluminum, and lead are especially susceptible to erosion corrosion. So are the metals and alloys that are inherently less corrosion resistant, such as carbon steels.

Stainless steels of all grades, in general, are resistant to erosion corrosion. The addition of nickel, chromium, and molybdenum further improves their performance. Stainless steels and chromium steels are resistant as a result of their tenacious protective surface films.

As a rule, solid solution alloys provide better resistance than alloys hardened by heat treatment because the latter are heterogeneous in structure.

Cast irons usually perform better than steel. Alloy cast irons containing nickel and chromium show better performance. Duriron containing 14.5% silicon gives excellent performance under severe erosion corrosion conditions.

Impingement attack can be avoided by smoothing the bends in a piping system. Increasing the pipe diameter will ensure a laminar flow and less turbulence.

ESTERS

Esters are organic compounds formed by reaction between alcohols and acids. When the organic radical is not specified in the name, ethyl is often understood; e.g., acetic ester is ethylacetate.

ETHYLENE-ACRYLIC (EA) RUBBER

Ethylene-acrylic rubber is produced from ethylene and acrylic acid. As with other synthetic elastomers, the properties of the EA rubbers can be altered by compounding. Basically, EA is a cost-effective hot-oil-resistant rubber with good low-temperature properties.

Physical and Mechanical Properties

Ethylene-acrylic elastomers have good tear strength and tensile strength and high elongation at break. Exceptionally low compression set values are an added advantage, making the product suitable for many hose, sealing, and cut gasket applications. A unique feature is its practically constant damping characteristics over broad ranges of temperature, frequency, and amplitude. Very little change in damping value takes place between -4 and 320°F (-20 and 160°C). This property, which shows up as a poor rebound in resiliency tests, is actually a design advantage. Combined with EA's heat and chemical resistance, it allows the use of EA in vibration-damping applications. This elastomer provides heat resistance surpassed by only the more expensive polymers such as the fluorocarbon or fluorosilicone elastomers. In measurements of dry heat resistance, EA outlasts other moderately priced oil-resistant rubbers. Parts retain elasticity and remain functional after continuous air-oven exposures from 18 months at 250°F (121°C) to 7 days at 400°F (204°C). Parts fabricated of EA will perform at least as long as parts made of Hypalon or general-purpose nitrile rubber, but at exposure temperatures 50 – 100°F (27°C) higher.

The low-temperature performance of EA is inherently superior to that of most other heat- and oil-resistant rubbers, including standard fluoroelastomers, chlorosulfonated polyethylene, polyacrylates, and polyepichlorhydrin. Typical unplasticized compounds are flexible to -20°F (-29°C) and have brittle points as low as -75°F (-60°C).

Compounding EA with ester plasticizers will extend its low-temperature flexibility limits to -50°F (-46°C). When exposed to flame, EA has poor flame resistance but does have low smoke emission.

The physical and mechanical properties of ethylene-acrylic rubber are given in [Table E.5](#).

Resistance to Sun, Weather, and Ozone

The EA elastomers have extremely good resistance to sun, weather, and ozone. Long-term exposures have no effect on these rubbers.

Table E.5 Physical and Mechanical Properties of Ethylene-Acrylic (EA) Rubber^a

Specific gravity	1.08–1.12
Hardness, Shore A	40–95
Tensile strength, psi	2500
Elongation, % at break	650
Compression set, %	Good
Tear resistance	Good
Maximum temperature, continuous use	340°F (170°C)
Brittle point	–75°F (–60°C)
Water absorption, %/24 hr	Very low
Abrasion resistance	Excellent
Resistance to sunlight	Excellent
Effect of aging	Nil
Resistance to heat	Excellent
Dielectric strength	Good
Electrical insulation	Fair to good
Permeability to gases	Very low

^aThese are representative values since they may be altered by compounding.

Chemical Resistance

The ethylene-acrylic elastomers exhibit very good resistance to hot oils, to hydrocarbon- or glycol-based proprietary lubricants, and to transmission and power steering fluids. The swelling characteristics of EA will be retained better than those of the silicone rubbers after oil immersion.

Ethylene-acrylic rubber also has outstanding resistance to hot water. Its resistance to water absorption is very good. Good resistance is also displayed to dilute acids, aliphatic hydrocarbons, gasoline, and animal and vegetable oils. Ethylene-acrylic rubber is not recommended for immersion in esters, ketones, highly aromatic hydrocarbons, or concentrated acids. Neither should it be used in applications calling for long-term exposure to high-pressure steam.

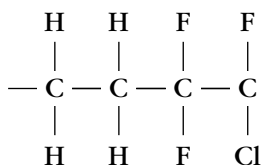
Applications

Ethylene-acrylic rubber is used in such products as gaskets, hoses, seals, boots, damping components, low-smoke floor tiling, and cable jackets for offshore oil platforms, ships, and building plenum installations. Ethylene-acrylic rubber in engine parts provides good resistance to heat, fluids, and wear as well as good low-temperature sealing ability.

See [Refs. 1 and 3](#).

ETHYLENE-CHLOROTRIFLUOROETHYLENE (ECTFE)

ECTFE is a 1:1 alternating copolymer of ethylene and chlorotrifluoroethylene. The chemical structure of this thermoplastic is



This chemical structure provides the polymer with a unique combination of properties. It possesses excellent chemical resistance, a broad use temperature range from cryogenic to 340°F (171°C) with continuous service to 300°F (149°C), and excellent abrasion resistance.

ECTFE exhibits excellent impact strength over its entire operating range, even in the cryogenic range. It also possesses good tensile, flexural, and wear-related properties. ECTFE is also one of the most corrosion-resistant polymers. Other important properties include a low coefficient of friction and the ability to be pigmented. Table E.6 lists the physical and mechanical properties of ECTFE.

ECTFE is resistant to strong mineral and oxidizing acids, alkalis, metal etchants, liquid oxygen, and practically all organic solvents except hot amines (aniline, dimethylamine, etc.). ECTFE is not subject to chemically induced stress cracking from strong acids, bases, or solvents. Some halogenated solvents can cause ECTFE to become slightly plasticized when it comes into contact with them. Under normal circumstances this does not affect the usefulness of the polymer since upon removal of the solvent from contact and upon drying, its mechanical properties return to their original values, indicating that no chemical attack has taken place. Like other fluoropolymers, ECTFE will be attacked by metallic sodium and potassium. Table E.7 lists the compatibility of ECTFE with selected corrodents. Reference 3 provides a wide range of compatibility of ECTFE with selected corrodents.

See Refs. 2 and 3.

Table E.6 Physical and Mechanical Properties of ECTFE

Specific gravity	1.68
Water absorption, 24 h at 73°F/23°C, %	< 0.01
Tensile strength at 73°F/23°C, psi	4500
Modulus of elasticity in tension at 73°F/23°C $\times 10^5$ psi	2.4
Flexural strength, psi	7000
Izod impact strength, notched at 73°F/23°C, ft-lb/in	No break
Linear coefficient of thermal expansion, in./in. °F at	
-22 to 122°F/-30 to 50°C	4.4×10^{-5}
122 to 185°F/50 to 80°C	5.6×10^{-5}
185 to 257°F/85 to 125°C	7.5×10^{-5}
257 to 365°F/125 to 180°C	9.2×10^{-5}
Thermal conductivity Btu/h/ft ² /°F/in	1.07
Heat distortion temperature, °F/°C	
at 66 psi	195/91
at 264 psi	151/66
Limiting oxygen index	60
Underwriters lab rating, Sub 94	V-0

Table E.7 Compatibility of ECTFE with Selected Corrodents^a

Chemical	Maximum temp.		Chemical	Maximum temp.	
	°F	°C		°F	°C
Acetic acid 10%	250	121	Barium sulfide	300	149
Acetic acid 50%	250	121	Benzaldehyde	150	66
Acetic acid 80%	150	66	Benzene	150	66
Acetic acid, glacial	200	93	Benzene sulfonic acid 10%	150	66
Acetic anhydride	100	38	Benzoic acid	250	121
Acetone	150	66	Benzyl alcohol	300	149
Acetyl chloride	150	66	Benzyl chloride	300	149
Acrylonitrile	150	66	Borax	300	149
Adipic acid	150	66	Boric acid	300	149
Allyl chloride	300	149	Bromine gas, dry	x	x
Alum	300	149	Bromine liquid	150	66
Aluminum chloride, aqueous	300	149	Butadiene	250	121
Aluminum chloride, dry			Butyl acetate	150	66
Aluminum fluoride	300	149	Butyl alcohol	300	149
Aluminum hydroxide	300	149	Butyric acid	250	121
Aluminum nitrate	300	149	Calcium bisulfide	300	149
Aluminum oxychloride	150	66	Calcium bisulfite	300	149
Aluminum sulfate	300	149	Calcium carbonate	300	149
Ammonia gas	300	149	Calcium chlorate	300	149
Ammonium bifluoride	300	149	Calcium chloride	300	149
Ammonium carbonate	300	149	Calcium hydroxide 10%	300	149
Ammonium chloride 10%	290	143	Calcium hydroxide, sat.	300	149
Ammonium chloride 50%	300	149	Calcium hypochlorite	300	149
Ammonium chloride, sat.	300	149	Calcium nitrate	300	149
Ammonium fluoride 10%	300	149	Calcium oxide	300	149
Ammonium fluoride 25%	300	149	Calcium sulfate	300	149
Ammonium hydroxide 25%	300	149	Caprylic acid	220	104
Ammonium hydroxide, sat.	300	149	Carbon bisulfide	80	27
Ammonium nitrate	300	149	Carbon dioxide, dry	300	149
Ammonium persulfate	150	66	Carbon dioxide, wet	300	149
Ammonium phosphate	300	149	Carbon disulfide	80	27
Ammonium sulfate 10–40%	300	149	Carbon monoxide	150	66
Ammonium sulfide	300	149	Carbon tetrachloride	300	149
Amyl acetate	160	71	Carbonic acid	300	149
Amyl alcohol	300	149	Cellosolve	300	149
Amyl chloride	300	149	Chloracetic acid, 50% water	250	121
Aniline	90	32	Chloracetic acid	250	121
Antimony trichloride	100	38	Chlorine gas, dry	150	66
Aqua regia 3:1	250	121	Chlorine gas, wet	250	121
Barium carbonate	300	149	Chlorine, liquid	250	121
Barium chloride	300	149	Chlorobenzene	150	66
Barium hydroxide	300	149	Chloroform	250	121
Barium sulfate	300	149	Chlorosulfonic acid	80	27

Table E.7 Compatibility of ECTFE with Selected Corrodents^a (Continued)

Chemical	Maximum temp.		Chemical	Maximum temp.	
	°F	°C		°F	°C
Chromic acid 10%	250	121	Muriatic acid	300	149
Chromic acid 50%	250	121	Nitric acid 5%	300	149
Citric acid 15%	300	149	Nitric acid 20%	250	121
Citric acid, conc.	300	149	Nitric acid 70%	150	66
Copper carbonate	150	66	Nitric acid, anhydrous	150	66
Copper chloride	300	149	Nitrous acid, concentrated	250	121
Copper cyanide	300	149	Oleum	x	x
Copper sulfate	300	149	Perchloric acid 10%	150	66
Cresol	300	149	Perchloric acid 70%	150	66
Cupric chloride 5%	300	149	Phenol	150	66
Cupric chloride 50%	300	149	Phosphoric acid 50–80%	250	121
Cyclohexane	300	149	Picric acid	80	27
Cyclohexanol	300	149	Potassium bromide 30%	300	149
Ethylene glycol	300	149	Salicylic acid	250	121
Ferric chloride	300	149	Sodium carbonate	300	149
Ferric chloride 50% in water	300	149	Sodium chloride	300	149
Ferric nitrate 1 0-50%	300	149	Sodium hydroxide 10%	300	149
Ferrous chloride	300	149	Sodium hydroxide 50%	250	121
Ferrous nitrate	300	149	Sodium hydroxide,		
Fluorine gas, dry	x	x	concentrated	150	66
Fluorine gas, moist	80	27	Sodium hypochlorite 20%	300	149
Hydrobromic acid, dilute	300	149	Sodium hypochlorite,		
Hydrobromic acid 20%	300	149	concentrated	300	149
Hydrobromic acid 50%	300	149	Sodium sulfide to 50%	300	149
Hydrochloric acid 20%	300	149	Stannic chloride	300	149
Hydrochloric acid 38%	300	149	Stannous chloride	300	149
Hydrocyanic acid 10%	300	149	Sulfuric acid 10%	250	121
Hydrofluoric acid 30%	250	121	Sulfuric acid 50%	250	121
Hydrofluoric acid 70%	240	116	Sulfuric acid 70%	250	121
Hydrofluoric acid 100%	240	116	Sulfuric acid 90%	150	66
Hypochlorous acid	300	149	Sulfuric acid 98%	150	66
Iodine solution 10%	250	121	Sulfuric acid 100%	80	27
Lactic acid 25%	150	66	Sulfuric acid, fuming	300	149
Lactic acid, concentrated	150	66	Sulfurous acid	250	121
Magnesium chloride	300	149	Thionyl chloride	150	66
Malic acid	250	121	Toluene	150	66
Methyl chloride	300	149	Trichloroacetic acid	150	66
Methyl ethyl ketone	150	66	White liquor	250	121
Methyl isobutyl ketone	150	66	Zinc chloride	300	149

^aThe chemicals listed are in the pure state or in a saturated solution unless otherwise indicated. Compatibility is shown to the maximum allowable temperature for which data are available. Incompatibility is shown by an x. A blank space indicates that data are unavailable.

Source: PA Schweitzer. *Corrosion Resistance Tables*. 4th ed. Vols 1–3. New York: Marcel Dekker, 1995.

ETHYLENE-CHLOROTRIFLUOROETHYLENE (ECTFE) ELASTOMER

Ethylene-chlorotrifluoroethylene (ECTFE) elastomer is a 1:1 alternating copolymer of ethylene and chlorotrifluoroethylene. This chemical structure gives the polymer a unique combination of properties. It possesses excellent chemical resistance, good electrical properties, and a broad use temperature range (from cryogenic to 340°F [171°C]) and meets the requirements of the UL-94V-0 vertical flame test in thicknesses as low as 7 mils. ECTFE is a tough material with excellent impact strength over its entire operating range. Of all the fluoropolymers, ECTFE ranks among the best for abrasion resistance.

Most techniques used for processing polyethylene can be used to process ECTFE. It can be extruded, injection molded, rotomolded, and applied by ordinary fluidized bed or electrostatic coating techniques.

Physical and Mechanical Properties

ECTFE possesses advantageous electrical properties. It has high resistivity and low loss. The dissipation factor varies somewhat with frequency, particularly above 1 kHz. The AC loss properties of ECTFE are superior to those of vinylidene fluoride and come close to those of PTFE. The dielectric constant is stable across a broad temperature and frequency range. Refer to [Table E.8](#).

According to ASTM D-149, the dielectric strength of ECTFE has a value of 2000 V/mil in 1 mil thickness and 500 V/mil in $\frac{1}{8}$ in. thickness, which are similar to those obtained for PTFE or polyethylene.

The resistance to permeation by oxygen, carbon dioxide, chlorine gas, or hydrochloric acid is superior to that of PTFE and PE, being 10–100 times better. Water absorption is less than 0.1%.

Other important physical properties include low coefficient of friction, excellent machinability, and the ability to be pigmented. In thicknesses as low as 7 mils, ECTFE has a UL-94-V-0 rating. The oxygen index (ASTM D2863) is 60 on a $\frac{1}{16}$ in. thick sample and 48 on a 0.0005 in. filament yarn. ECTFE is a strong, highly impact-resistant material that retains useful properties over a wide range of temperatures. Outstanding in this respect are properties related to impact at low temperatures. ECTFE can be applied at elevated temperatures in the range of 300–340°F (149–171°C). (Refer to [Table E.8](#).)

In addition to its excellent impact properties, ECTFE also possesses good tensile, flexural, and wear-related properties.

The resistance of ECTFE to degradation by heat is excellent. It can resist temperatures of 300–340°F (149–171°C) for extended periods of time without degradation. It is one of the most radiation-resistant polymers. Laboratory testing has determined that the following useful life can be expected at the temperatures indicated:

Temperature		Useful-life years
°F	°C	
329	165	10
338	170	4.5
347	175	2
356	180	1.25

Table E.8 Physical and Mechanical Properties of ECTFE^a Elastomer

Specific gravity	1.68
Refractive index, nD	1.44
Specific heat, Btu/lb-°F	0.28
Brittle point	-105°F (-76°C)
Insulation resistance, ohms	>10 ¹⁵
Thermal conductivity at 203°F (93°C)	
Btu-in./h-ft ² -°F	1.09
Coefficient of linear expansion, °F ⁻¹ or °C ⁻¹	
-22 to 122°F	4.4 × 10 ⁻⁵
122 to 185°F	5.6 × 10 ⁻⁵
185 to 257°F	7.5 × 10 ⁻⁵
257 to 356°F	9.2 × 10 ⁻⁵
-30 to 50°C	8 × 10 ⁻⁵
50 to 85°C	10 × 10 ⁻⁵
85 to 125°C	13.3 × 10 ⁻⁵
125 to 180°C	16.5 × 10 ⁻⁵
Dielectric strength, V/mil	
0.0001 in. thick	2000
1/8 in. thick	490
Dielectric constant	
at 60 Hz	2.6
at 10 ³ Hz (1 kHz)	2.5
at 10 ⁶ Hz (1 MHz)	2.5
Dissipation factor at 60 Hz	<0.0009
at 10 ³ Hz (1 kHz)	0.005
at 10 ⁶ Hz (1 MHz)	0.003
Arc resistance, s	135
Moisture absorption, %	<0.1
Tensile strength, psi	6000-7000
Elongation at break, % at room temperature	200-300
Hardness, Shore D	75
impact resistance, ft-lb/in. notch	
at 73°F (23°C)	No break
at -40°F (-40°C)	2-3
Abrasion resistance. Armstrong (ASTM D1242)	
30 lb load, volume loss, cm ³	0.3
Coefficient of friction	
static	0.15
dynamic, 50 cm/s	0.65
Maximum temperature, continuous use	340°F (171°C)
Machining qualities	Excellent
Resistance to sunlight	Excellent
Effect of aging	Good
Resistance to heat	Good

^aThese are representative values since they may be altered by compounding.

Resistance to Sun, Weather, and Ozone

ECTFE is extremely resistant to sun, weather, and ozone attack. Its physical properties undergo very little change after long exposures.

Chemical Resistance

The chemical resistance of ECTFE is outstanding. It is resistant to most of the common corrosive chemicals encountered in industry. Included in this list of chemicals are strong mineral and oxidizing acids, alkalies, metal etchants, liquid oxygen, and practically all organic solvents except hot amines (aniline, dimethylamine, etc.). No known solvent dissolves or stress cracks ECTFE at temperatures up to 250°F (120°C).

Some halogenated solvents can cause ECTFE to become slightly plasticized when it comes into contact with them. Under normal circumstances this does not impair the usefulness of the polymer. When the part is removed from contact with the solvent and allowed to dry, its mechanical properties return to their original values, indicating that no chemical attack has taken place.

As with other fluoropolymers, ECTFE will be attacked by metallic sodium and potassium.

The useful properties of ECTFE are maintained on exposure to cobalt-60 radiation of 200 Mrad. Refer to [Table E.7](#) for the compatibility of ECTFE with selected corrodents.

Applications

This elastomer finds many applications in the electrical industry such as wire and cable insulation; jacketing plenum cable insulation; oil well wire and cable insulation; logging wire jacketing; jacketing for cathodic protection; aircraft, mass transit, and automotive wire; connectors; coil forms; resistor sleeves; wire tie wraps; tapes; tubing; flexible printed circuitry; and flat cable.

Applications are also found in other industries as diaphragms, flexible tubing, closures, seals, gaskets, and convoluted tubing and hose, particularly in the chemical, cryogenic, and aerospace industries.

Materials of ECTFE are also used for lining vessels, pumps, and other equipment. See [Refs. 1 and 3](#).

ETHYLENE-PROPYLENE RUBBERS (EPDM AND EPT)

Ethylene-propylene rubber is a synthetic hydrocarbon-based rubber made either from ethylene-propylene diene monomer or from ethylene-propylene terpolymer. These monomers are combined so as to produce an elastomer with a completely saturated backbone and pendant unsaturation for sulfur vulcanization. As a result of this configuration, vulcanates of EPDM elastomers are extremely resistant to attack by ozone, oxygen, and weather.

Ethylene-propylene rubber possesses many properties superior to those of natural rubber and conventional general-purpose elastomers. In some applications it will perform better than other materials, while in other applications it will last longer or require less maintenance and may even cost less.

EPDM has exceptional heat resistance, being able to operate at temperatures of 300–350°F (148–176°C), while also finding application at temperatures as low as –70°F (–56°C). Experience has shown that EPDM has exceptional resistance to steam. Hoses manufactured from EPDM have had lives several times longer than those of hoses manufactured from other elastomers.

Dynamic properties of EPDM remain constant over a wide temperature range, making this elastomer suitable for a variety of applications. It also has a very high resistance to sunlight, aging, and weather, excellent electrical properties, and good chemical resistance. However, being hydrocarbon based, it is not resistant to petroleum-based oils or flame.

This material may be processed and vulcanized by the same techniques and with the same equipment as those used for processing other general-purpose elastomers. As with other elastomers, compounding plays an important part in tailoring the properties of EPDM to meet the needs of a specific application. Each of the properties of the elastomer can be enhanced or reduced by the addition or deletion of chemicals and fillers. Because of this, the properties discussed must be considered in general terms.

Ethylene-propylene terpolymer is a synthetic hydrocarbon-based rubber produced from an ethylene-propylene terpolymer. It is very similar in physical and mechanical properties to EPDM.

Physical and Mechanical Properties

It is possible to compound EPDM to provide either higher resilience or higher damping. When compounded to provide high resilience, the products are similar to natural rubber in liveliness and minimum hysteresis values. The energy-absorbing compounds have low resilience values approaching those of specialty elastomers used for shock and vibration damping. Whether the compound has been compounded for resilience or high damping, its properties remain relatively constant over a wide temperature range. As can be seen from [Table E.9](#), a temperature variation of 200°F (110°C) has little effect on the resilience of the compound. The isolation efficiency (based on the percentage of disturbing force transmitted) over a temperature range of 0–180°F (–18–82°C) varies by only 10%. This property is particularly important in vibration isolation applications such as in automotive body mounts.

EPDM exhibits little sensitivity to changes in load. When properly compounded, it has excellent resistance to creep under both static and dynamic conditions.

Flexibility at low temperature is another advantage of this elastomer. Standard compounds have brittle points of –90°F (–68°C) or below. Special compounding can supply material with stiffness values of –90°F (–68°C) and brittle points below –100°F (–73°C).

The electrical properties of EPDM are excellent, particularly for high-voltage insulation. The properties are also stable after long periods of immersion in water. Excellent resistance is also provided against cutting caused by high-voltage corona discharge.

Ethylene-propylene rubber can be produced in any color, including white and pastel shades. The color stability is excellent, with aging characteristics that are available in other elastomers only in black. Since techniques have been developed whereby the material can be painted with permanent waterproof colors, the elastomer can be produced in a black stock providing the maximum physical properties.

Table E.9 Physical and Mechanical Properties of Ethylene-Propylene Rubber (EPDM)^a

Specific gravity	0.85
Specific heat, cal/g	0.56
Brittle point	-90°F (-68°C)
Resilience, %	
at 212°F (100°C)	78
at 75°F (24°C)	77
at 14°F (-10°C)	63
Dielectric strength, V/mil	800
Insulation resistance, megohms/1000 ft	25,500
Insulation resistance, constant <i>K</i> , megohms/1000 ft	76,400
Permeability to air at 86°F (30°C), cm ³ /cm ² -cm-s-atm	8.5 × 10 ⁻⁸
Tensile strength, psi	To 3500
Elongation, % at break	560
Hardness, Shore A	30-90
Abrasion resistance	Good
Maximum temperature, continuous use	300°F (148°C)
Impact resistance	Good
Compression set, %	
at 158°F (70°C)	8-10
at 212°F (100°C)	12-26
Resistance to sunlight	Excellent
Effect of aging	Nil
Resistance to heat	Excellent
Tear resistance	Good

^aThese are representative values since they may be altered by compounding.

Ethylene-propylene rubber has a relatively high resistance to heat. Standard formulations can be used continuously at temperatures of 250–300°F (121–148°C) in air. In the absence of air, such as in a steam hose lining or cable insulation covered with an outer jacket, higher temperatures can be tolerated. It is also possible by special compounding to produce material that can be used in services up to 350°F (176°C). Standard compounds can be used in intermittent service at 350°F (176°C).

Other advantageous properties of EPDM include good resistance to impact, tearing, abrasion, and cut growth over a wide temperature range. These properties make the elastomer suitable for applications that involve continuous flexing or twisting during operation.

Ethylene-propylene rubber exhibits a low degree of permanent deformation. Table E.9 gives examples of these values. The ranges shown are for both standard and special compounds. In addition, compounds can be supplied that will have a permanent deformation of only 26% after compression at 350°F (176°C).

Resistance to Sun, Weather, and Ozone

Ethylene-propylene rubber is particularly resistant to sun, weather, and ozone attack. Excellent weather resistance is obtained whether the material is formulated in color,

white, or black. The elastomer remains free of surface crazing and retains a high percentage of its properties after years of exposure. Ozone resistance is inherent in the polymer, and for all practical purposes it can be considered immune to ozone attack. It is not necessary to add any special compounding ingredients to produce this resistance.

Chemical Resistance

Ethylene-propylene rubber resists attack from oxygenated solvents such as acetone, methyl ethyl ketone, ethyl acetate, weak acids and alkalies, detergents, phosphate esters, alcohols, and glycols. It exhibits exceptional resistance to hot water and high-pressure steam. The elastomer, being hydrocarbon based, is not resistant to hydrocarbon solvents or oils, chlorinated hydrocarbons, or turpentine. However, by proper compounding, its resistance to oil can be improved to provide adequate service life in many applications where such resistance is required. Ethylene-propylene terpolymer rubbers are in general resistant to most of the same corrodents as EPDM but do not have as broad a resistance to mineral acids and some organics. [Table E.10](#) lists the compatibility of EPDM rubber with selected corrodents.

Applications

Extensive use is made of ethylene-propylene rubber in the automotive industry. Because of its paintability, this elastomer is used as the gap-filling panel between the grills and the bumper, which provides a durable and elastic element. Under-hood components such as radiator hose, ignition wire insulation, overflow tubing, window washing tubing, exhaust emission control tubing, and various other items make use of EPDM because of its resistance to heat, chemicals, and ozone. Other automotive applications include body mounts, spring mounting pads, miscellaneous body seals, floor mats, and pedal pads. Each application takes advantage of one or more specific properties of the elastomer.

Appliance manufacturers, especially washer manufacturers, have also found wide use for EPDM. Its heat and chemical resistance combined with its physical properties make it ideal for such applications as door seals and cushions, drain and water circulating hoses, bleach tubing, inlet nozzles, boots, seals, gaskets, diaphragms, vibration isolators, and a variety of grommets. The elastomer is also used in dishwashers, refrigerators, ovens, and a variety of small appliances.

Ethylene-propylene rubber finds application in the electrical industry and in the manufacture of electrical equipment. One of the primary applications is as an insulating material. It is used for medium voltage (up to 35 kV) and secondary network power cable, coverings for line and multiplex distribution wire, jacketing and insulation for types S and SJ flexible cords, and insulation for automotive ignition cable.

Accessory items such as molded terminal covers, plugs, transformer connectors, line tap and switching devices, splices, and insulating and semiconductor tape are also produced from EPDM.

Medium- and high-voltage underground power distribution cable insulated with EPDM offers many advantages. It provides excellent resistance to tearing and failure caused by high-voltage contaminants and stress. Its excellent electrical properties make it suitable for high-voltage cable insulation. It withstands heavy corona discharge without sustaining damage.

Table E.10 Compatibility of EPDM Rubber with Selected Corrodents^a

Chemical	Maximum temp.		Chemical	Maximum temp.	
	°F	°C		°F	°C
Acetaldehyde	200	93	Barium sulfide	140	60
Acetamide	200	93	Benzaldehyde	150	66
Acetic acid 10%	140	60	Benzene	x	x
Acetic acid 50%	140	60	Benzene sulfonic acid 10%	x	x
Acetic acid 80%	140	60	Benzoic acid	x	x
Acetic acid, glacial	140	60	Benzyl alcohol	x	x
Acetic anhydride	x	x	Benzyl chloride	x	x
Acetone	200	93	Borax	200	93
Acetyl chloride	x	x	Boric acid	190	88
Acrylonitrile	140	60	Bromine gas, dry	x	x
Adipic acid	200	93	Bromine gas, moist	x	x
Allyl alcohol	200	93	Bromine liquid	x	x
Allyl chloride	x	x	Butadiene	x	x
Alum	200	93	Butyl acetate	140	60
Aluminum fluoride	190	88	Butyl alcohol	200	93
Aluminum hydroxide	200	93	Butyric acid	140	60
Aluminum nitrate	200	93	Calcium bisulfite	x	x
Aluminum sulfate	190	88	Calcium carbonate	200	93
Ammonia gas	200	93	Calcium chlorate	140	60
Ammonium bifluoride	200	93	Calcium chloride	200	93
Ammonium carbonate	200	93	Calcium hydroxide 10%	200	93
Ammonium chloride 10%	200	93	Calcium hydroxide, sat.	200	93
Ammonium chloride 50%	200	93	Calcium hypochlorite	200	93
Ammonium chloride, sat.	200	93	Calcium nitrate	200	93
Ammonium fluoride 10%	200	93	Calcium oxide	200	93
Ammonium fluoride 25%	200	93	Calcium sulfate	200	93
Ammonium hydroxide 25%	100	38	Carbon bisulfide	x	x
Ammonium hydroxide, sat.	100	38	Carbon dioxide, dry	200	93
Ammonium nitrate	200	93	Carbon dioxide, wet	200	93
Ammonium persulfate	200	93	Carbon disulfide	200	93
Ammonium phosphate	200	93	Carbon monoxide	x	x
Ammonium sulfate 10–40%	200	93	Carbon tetrachloride	200	93
Ammonium sulfide	200	93	Carbonic acid	x	x
Amyl acetate	200	93	Cellosolve	200	93
Amyl alcohol	200	93	Chloroacetic acid	160	71
Amyl chloride	x	x	Chlorine gas, dry	x	x
Aniline	140	60	Chlorine gas, wet	x	x
Antimony trichloride	200	93	Chlorine, liquid	x	x
Aqua regia 3:1	x	x	Chlorobenzene	x	x
Barium carbonate	200	93	Chloroform	x	x
Barium chloride	200	93	Chlorosulfonic acid	x	x
Barium hydroxide	200	93	Chromic acid 50%	x	x
Barium sulfate	200	93	Citric acid 15%	200	93

Table E.10 Compatibility of EPDM Rubber with Selected Corrodents^a (Continued)

Chemical	Maximum temp.		Chemical	Maximum temp.	
	°F	°C		°F	°C
Citric acid, concentrated	200	93	Methyl chloride	x	x
Copper acetate	100	38	Methyl ethyl ketone	80	27
Copper carbonate	200	93	Methyl isobutyl ketone	60	16
Copper chloride	200	93	Nitric acid 5%	60	16
Copper cyanide	200	93	Nitric acid 20%	60	16
Copper sulfate	200	93	Nitric acid 70%	x	x
Cresol	x	x	Nitric acid, anhydrous	x	x
Cupric chloride 5%	200	93	Oleum	x	x
Cupric chloride 50%	200	93	Perchloric acid 10%	140	60
Cyclohexane	x	x	Phosphoric acid 50–80%	140	60
Cyclohexanol	x	x	Picric acid	200	93
Dichloroethane			Potassium bromide 30%	200	93
(ethylene dichloride)	x	x	Salicylic acid	200	93
Ethylene glycol	200	93	Sodium carbonate	200	93
Ferric chloride	200	93	Sodium chloride	140	60
Ferric chloride 50% in water	200	93	Sodium hydroxide 10%	200	93
Ferric nitrate 10–50%	200	93	Sodium hydroxide 50%	180	82
Ferrous chloride	200	93	Sodium hydroxide,		
Ferrous nitrate	200	93	concentrated	180	82
Fluorine gas, moist	60	16	Sodium hypochlorite 20%	200	93
Hydrobromic acid, dilute	90	32	Sodium hypochlorite,		
Hydrobromic acid 20%	140	60	concentrated	200	93
Hydrobromic acid 50%	140	60	Sodium sulfide to 30%	200	93
Hydrochloric acid 20%	100	38	Stannic chloride	200	93
Hydrochloric acid 38%	90	32	Stannous chloride	200	93
Hydrocyanic acid 10%	200	93	Sulfuric acid 10%	150	66
Hydrofluoric acid 30%	60	16	Sulfuric acid 50%	150	66
Hydrofluoric acid 70%	x	x	Sulfuric acid 70%	140	60
Hydrofluoric acid 100%	x	x	Sulfuric acid 90%	x	x
Hypochlorous acid	200	93	Sulfuric acid 98%	x	x
Iodine solution 10%	140	60	Sulfuric acid 100%	x	x
Ketones, general	x	x	Sulfuric acid, fuming	x	x
Lactic acid 25%	140	60	Toluene	x	x
Lactic acid, concentrated			Trichloroacetic acid	80	27
Magnesium chloride	200	93	White liquor	200	93
Malic acid	x	x	Zinc chloride	200	93

^aThe chemicals listed are in the pure state or in a saturated solution unless otherwise indicated. Compatibility is shown to the maximum allowable temperature for which data are available. Incompatibility is shown by an x. A blank space indicates that the data are unavailable.

Source: PA Schweitzer. *Corrosion Resistance Tables*. 4th ed. Vols 1–3. New York: Marcel Dekker, 1995.

Manufacturers of other industrial products take advantage of the heat and chemical resistance, physical durability, ozone resistance, and dynamic properties of EPDM.

Typical applications include high-pressure steam hose, high-temperature conveyor belting, water and chemical hose, hydraulic hose for phosphate-type liquids, vibration mounts, industrial tires, tugboat and dock bumpers, tank and pump linings, O-rings, gaskets, and a variety of molded products. Standard formulations of EPDM are also used for such consumer items as garden hose, bicycle tires, sporting goods, and tires for garden equipment.

See Refs. 1 and 3.

ETHYLENE-TETRAFLUOROETHYLENE (ETFE)

This thermoplast is sold under the trade name of Tefzel by DuPont. ETFE is a partially fluorinated copolymer of ethylene and tetrafluoroethylene. It has a maximum service temperature of 300°F (149°C). The physical and mechanical properties are given in Table E.11.

ETFE is inert to strong mineral acids, halogens, inorganic bases, and metal salt solutions. Carboxylic acids, aldehydes, aromatic and aliphatic hydrocarbons, alcohols, aldehydes, ketones, ethers, esters, chlorocarbons, and classic polymer solvents have little effect on Tefzel.

Very strong oxidizing acids such as nitric, and organic bases such as amines and sulfonic acids at high concentrations and near their boiling points will affect ETFE to various degrees. Refer to Table E.12 for the compatibility of ETFE with selected corrosives.

Table E.11 Physical and Mechanical Properties of ETFE

Specific gravity	1.70
Tensile strength, psi	6500
Modulus of elasticity, $\text{psi} \times 10^5$	2.17
Elongation, %	300
Flexural modulus, $\text{psi} \times 10^5$	1.7
Impact strength, ft-lb/in.	No break
Hardness, Shore D	67
Water absorption, 24 h at 73°F/2°C, %	<0.03
Thermal conductivity, Btu/h/ft ² /°F/in.	1.6
Heat distortion temperature °F/°C	
at 66 psi	220/104
at 264 psi	160/71
Limiting oxygen index, %	30
Underwriters lab rating, Sub 94	V-0

Table E.12 Compatibility of ETFE with Selected Corrodents^a

Chemical	Maximum temp.		Chemical	Maximum temp.	
	°F	°C		°F	°C
Acetaldehyde	200	93	Barium hydroxide	300	149
Acetamide	250	121	Barium sulfate	300	149
Acetic acid 10%	250	121	Barium sulfide	300	149
Acetic acid 50%	250	121	Benzaldehyde	210	99
Acetic acid 80%	230	110	Benzene	210	99
Acetic acid, glacial	230	110	Benzene sulfonic acid 10%	210	99
Acetic anhydride	300	149	Benzoic acid	270	132
Acetone	150	66	Benzyl alcohol	300	149
Acetyl chloride	150	66	Benzyl chloride	300	149
Acrylonitrile	150	66	Borax	300	149
Adipic acid	280	138	Boric acid	300	49
Allyl alcohol	210	99	Bromine gas, dry	150	66
Allyl chloride	190	88	Bromine water 10%	230	110
Alum	300	149	Butadiene	250	121
Aluminum chloride, aqueous	300	149	Butyl acetate	230	110
Aluminum chloride, dry	300	149	Butyl alcohol	300	149
Aluminum fluoride	300	149	<i>n</i> -Butylamine	120	49
Aluminum hydroxide	300	149	Butyl phthalate	150	66
Aluminum nitrate	300	149	Butyric acid	250	121
Aluminum oxychloride	300	149	Calcium bisulfide	300	149
Aluminum sulfate	300	149	Calcium carbonate	300	149
Ammonium bifluoride	300	149	Calcium chlorate	300	149
Ammonium carbonate	300	149	Calcium chloride	300	149
Ammonium chloride 10%	300	149	Calcium hydroxide 10%	300	149
Ammonium chloride 50%	290	143	Calcium hydroxide, sat.	300	149
Ammonium chloride, sat.	300	149	Calcium hypochlorite	300	149
Ammonium fluoride 10%	300	149	Calcium nitrate	300	149
Ammonium fluoride 25%	300	149	Calcium oxide	260	127
Ammonium hydroxide 25%	300	149	Calcium sulfate	300	149
Ammonium hydroxide, sat.	300	149	Caprylic acid	210	99
Ammonium nitrate	230	110	Carbon bisulfide	150	66
Ammonium persulfate	300	149	Carbon dioxide, dry	300	149
Ammonium phosphate	300	149	Carbon dioxide, wet	300	149
Ammonium sulfate 10–40%	300	149	Carbon disulfide	150	66
Ammonium sulfide	300	149	Carbon monoxide	300	149
Amyl acetate	250	121	Carbon tetrachloride	270	132
Amyl alcohol	300	149	Carbonic acid	300	149
Amyl chloride	300	149	Cellosolve	300	149
Aniline	230	110	Chloracetic acid, 50% water	230	110
Antimony trichloride	210	99	Chloracetic acid 50%	230	110
Aqua regia 3:1	210	99	Chlorine gas, dry	210	99
Barium carbonate	300	149	Chlorine gas, wet	250	121
Barium chloride	300	149	Chlorine, water	100	38

Table E.12 Compatibility of ETFE with Selected Corrodents^a (Continued)

Chemical	Maximum temp.		Chemical	Maximum temp.	
	°F	°C		°F	°C
Chlorobenzene	210	99	Methyl ethyl ketone	230	110
Chloroform	230	110	Methyl isobutyl ketone	300	149
Chlorosulfonic acid	80	27	Muriatic acid	300	149
Chromic acid 10%	150	66	Nitric acid 5%	150	66
Chromic acid 50%	150	66	Nitric acid 20%	150	66
Chromyl chloride	210	99	Nitric acid 70%	80	27
Citric acid 15%	120	49	Nitric acid, anhydrous	x	x
Copper chloride	300	149	Nitrous acid, concentrated	210	99
Copper cyanide	300	149	Oleum	150	66
Copper sulfate	300	149	Perchloric acid 10%	230	110
Cresol	270	132	Perchloric acid 70%	150	66
Cupric chloride 5%	300	149	Phenol	210	99
Cyclohexane	300	149	Phosphoric acid 50–80%	270	132
Cyclohexanol	250	121	Picric acid	130	54
Dichloroacetic acid	150	66	Potassium bromide 30%	300	149
Ethylene glycol	300	149	Salicylic acid	250	121
Ferric chloride 50% in water	300	149	Sodium carbonate	300	149
Ferric nitrate 10–50%	300	149	Sodium chloride	300	149
Ferrous chloride	300	149	Sodium hydroxide 10%	230	110
Ferrous nitrate	300	149	Sodium hydroxide 50%	230	110
Fluorine gas, dry	100	38	Sodium hypochlorite 20%	300	149
Fluorine gas, moist	100	38	Sodium hypochlorite, concentrated	300	149
Hydrobromic acid, dilute	300	149	Sodium sulfide to 50%	300	149
Hydrobromic acid 20%	300	149	Stannic chloride	300	149
Hydrobromic acid 50%	300	149	Stannous chloride	300	149
Hydrochloric acid 20%	300	149	Sulfuric acid 10%	300	149
Hydrochloric acid 38%	300	149	Sulfuric acid 50%	300	149
Hydrocyanic acid 10%	300	149	Sulfuric acid 70%	300	149
Hydrofluoric acid 30%	270	132	Sulfuric acid 90%	300	149
Hydrofluoric acid 70%	250	121	Sulfuric acid 98%	300	149
Hydrofluoric acid 100%	230	110	Sulfuric acid 100%	300	149
Hypochlorous acid	300	149	Sulfuric acid, fuming	120	49
Lactic acid 25%	250	121	Sulfurous acid	210	99
Lactic acid, concentrated	250	121	Thionyl chloride	210	99
Magnesium chloride	300	149	Toluene	250	121
Malic acid	270	132	Trichloroacetic acid	210	99
Manganese chloride	120	49	Zinc chloride	300	149
Methyl chloride	300	149			

^aThe chemicals listed are in the pure state or in a saturated solution unless otherwise indicated. Compatibility is shown to the maximum allowable temperature for which data are available. Incompatibility is shown by an x.
Source: PA Schweitzer. *Corrosion Resistance Tables*. 4th ed. Vols 1–3. New York: Marcel Dekker, 1995.

ETHYLENE-TETRAFLUOROETHYLENE (ETFE) ELASTOMER

Ethylene-tetrafluoroethylene (ETFE) is a modified partially fluorinated copolymer of ethylene and polytetrafluoroethylene (PTFE). Since it contains more than 75% TFE by weight, it has better resistance to abrasion and cut-through than TFE while retaining most of the corrosion resistance properties.

Physical and Mechanical Properties

Ethylene-tetrafluoroethylene has excellent mechanical strength, stiffness, and abrasion resistance, with a service temperature range of -370 to 300°F (-223 to 149°C). It also exhibits good tear resistance and good electrical properties. However, its outstanding property is its resistance to a wide range of corrodents.

The physical and mechanical properties of ETFE are given in Table E.13.

Resistance to Sun, Weather, and Ozone

Ethylene-tetrafluoroethylene has outstanding resistance to sunlight, ozone, and weather. This feature, coupled with its wide range of corrosion resistance, makes the material particularly suitable for outdoor applications subject to atmospheric corrosion.

Chemical Resistance

Ethylene tetrafluoroethylene is inert to strong mineral acids, inorganic bases, halogens, and metal salt solutions. Even carboxylic acids, anhydrides, aromatic and aliphatic hydrocarbons, alcohols, aldehydes, ketones, ethers, esters, chlorocarbons, and classic polymer solvents have little effect on ETFE.

Table E.13 Physical and Mechanical Properties of ETFE Elastomer^a

Specific gravity	1.7
Hardness range, Rockwell	R-50 to D-75
Tensile strength, psi	6500
Elongation, % at break	100–400
Tear resistance	Good
Maximum temperature, continuous use	300°F (149°C)
Brittle point	-150°F (-101°C)
Water absorption, %/24 h	0.029
Abrasion resistance	Good
Volume resistivity, ohm-cm	$>10^{16}$
Dielectric strength, kV/mm	16 (3 mm)
Dielectric constant (10^{-3} to 10^6 Hz range)	2.6
Dissipation (power) factor	8×10^{-4}
Resistance to sunlight	Excellent
Resistance to heat	Good
Machining qualities	Good

^aThese are representative values since they may be altered by compounding.

Very strong oxidizing acids near their boiling points, such as nitric acid at high concentration, will affect ETFE in varying degrees, as will organic bases such as amines and sulfonic acids. Refer to [Table E.12](#) for the compatibility of ETFE with selected corrodents.

Applications

The principal applications for ETFE are found in such products as gaskets, packings, and seals (O-rings, lip, and X-rings) in areas where corrosion is a problem. The material is also used for sleeve, split curled, and thrust bearings, and for bearing pads for pipe and equipment support where expansion and contraction or movement may occur.

EXFOLIATION CORROSION

When intergranular corrosion takes place in a metal with a highly directional grain structure, it propagates internally, parallel to the surface of the metal. The corrosion product formed is about five times as voluminous as the metal consumed, and it is trapped beneath the surface. As a result, an internal stress is produced that splits off the overlying layers of metal—hence the name exfoliation.

This is a dangerous form of corrosion, since the splitting off of uncorroded metal rapidly reduces load-carrying ability. The splitting action continually exposes film-free metal, so the rate of corrosion is not self-limiting.

Exfoliation corrosion is mostly found in certain alloys and tempers of aluminum, particularly in areas of high chloride content such as de-icing salts and seacoast atmospheres. In these applications an aluminum with a resistant temper should be used.

REFERENCES

1. PA Schweitzer. *Corrosion Resistance of Elastomers*. New York: Marcel Dekker, 1990.
2. GT Murray. *Introduction to Engineering Materials*. New York: Marcel Dekker, 1993.
3. PA Schweitzer. *Corrosion Resistance Tables*. 4th ed. Vols. 1–3. New York: Marcel Dekker, 1995.
4. D Landolt. Introduction to surface reactions: Electrochemical basis of corrosion. In: P Marcus and J. Oudar, eds. *Corrosion Mechanisms in Theory and Practice*. New York: Marcel Dekker, 1995, pp 1–8.
5. DM Berger. Fundamentals and prevention of metallic corrosion. In: PA Schweitzer, ed. *Corrosion and Corrosion Protection Handbook*. 2nd. ed. New York: Marcel Dekker, 1989, pp 3–11.
6. HH Uhlig. *Corrosion and Corrosion Control*. New York: John Wiley, 1963.
7. CP Dillon. *Corrosion Control in the Chemical Process Industries*. 2nd. ed. St. Louis: Materials Technology Institute of the Chemical Process Industries, 1994.
8. CP Dillon. *Corrosion Resistance of Stainless Steels*, New York: Marcel Dekker, 1995.
9. MR Louthan Jr. The effect of hydrogen on metals. In: F Mansfield, ed. *Corrosion Mechanisms*. New York: Marcel Dekker, 1987.
10. FP Ford and PL Andersen. Corrosion in nuclear systems: Environmentally assisted cracking in light water reactors. In: P Marcus and J Oudar, eds. *Corrosion Mechanisms in Theory and Practice*. New York: Marcel Dekker, 1995.
11. JH Mallinson. *Corrosion-Resistant Plastic Composites in Chemical Plant Design*. New York: Marcel Dekker, 1988.
12. PA Schweitzer, *Corrosion Resistant Piping Systems*. New York: Marcel Dekker, 1994.
13. PA Schweitzer. Mechanisms of chemical attack, corrosion resistance, and failure of plastic materials. In: PA Schweitzer, ed. *Corrosion Engineering Handbook*. New York: Marcel Dekker, 1996.