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**Guide to Selecting Protective
Treatments for Concrete**

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Guide to Selecting Protective Treatments for Concrete

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Guide to Selecting Protective Treatments for Concrete

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Concrete structures can be subjected to physical or chemical attacks by various substances, including water, acids, alkalis, salt solutions, and organic chemicals. Damage may vary in intensity from surface discoloration or roughening to catastrophic loss of structural integrity due to acid attack. This guide addresses the effects of various substances on untreated concrete and provides recommendations for protective treatments.

Keywords: acids; alkali; chemical attack; coal tar distillates; coatings; deicer; distress; durability; exposure condition; fatty acids; hardener; membrane; petroleum oils; protective treatment; resin; salt solution; sealer; solvents; topping; vegetable oils.

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

The rate of attack on concrete is directly related to the activity of aggressive chemicals. Solutions of high concentration are generally more corrosive than those of low concentration and produce more rapid disintegration of concrete, although, in some cases, the reverse is true. The rate of attack might be altered by the solubility of the reaction products based on concrete type. A lower hydroxide ion concentration generally causes more rapid attack on concrete surfaces. Also, because high temperatures usually accelerate chemical attack as compared to normal temperatures, better protection is required for concrete as temperature increases. Rapid disintegration in the context used refers to immediate and very aggressive attack. Slow disintegration refers to attack over a time period of months to years, depending on the factors previously described as well as interactions with other substances.

Generally there are three methods for mitigating chemical attack: 1) choosing the optimized concrete mixture to make it less permeable (ACI 201.2R); 2) isolating it from the agents causing chemical attack by using a suitable coating, overlay, lining, or barrier; or 3) modifying the composition, temperature, or other factors affecting the rate of chemical attack to make it less aggressive to the concrete (Addis 1994). Isolation materials include coatings, sheet membranes, chemical-resistant grouted masonry (brick and tile), as well as combinations of these materials; it is not uncommon to use a membrane between the substrate concrete and chemical-resistant masonry for a redundant protective system. The focus of this document is selection of materials to isolate the concrete from aggressive chemical substances. When protective material is bonded to concrete, bond strength should be evaluated and should be in compliance with the producer's and specifier's requirements.

Kuening (1966) studied the nature of aggressive chemicals, modes of attack, and reaction products for mortars exposed to acids, alcohols, aluminates, amino acids, ammonium salts, benzene, borates, carbonates, chlorates, chlorides, chromates, esters, ferrocyanides, fluosilicates, linseed oils, magnesium salts, manganates, molybdates, nitrates, nitrites, phosphates, seawater, stannates, sulfates, and sugars. Type I and Type V cements were studied at varying water-cement ratios (w/c). The study found resistance of mortar to chemical attack was increased by a longer period of curing and a decrease in w/c . Type V cement mortar was more resis-

tant to sulfate attack than the other mortars, but not to acidic sulfates or those that contained ammonium or magnesium. The zero- C_3A cement mortar generally had lower resistance to chemical attack than Type V.

Basson (1989) created an aggressiveness index taken from a chemical analysis of a water sample adjusted by factors such as prevailing temperature, flow conditions, or wet and dry cycles of the exposed concrete (National Association of Corrosion Engineers 1991). Guidelines with protective treatments are given in Chapter 4.

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This information, based both on literature sources and experience, must be considered a guide to assist in designing a test program using the concrete mixtures and chemicals for a specific application. Many of the recommended treatments were taken from Kerkhoff (2001).

Unless otherwise specified, percentage concentration of dissolved substance is the mass concentration of solute in solvent (assumed to be water unless otherwise described).

1.2—Scope

This guide refers to common protective treatments for the chemicals classified in Tables 3.1a through 3.1h. More exotic treatments, such as lead sheet, glass, or metalizing are included, but not usually called for except in extreme or unusual circumstances. Because various treatments provide different degrees of protection, product producers should be consulted for each application.

In all cases, specific recommendations from material producers should be followed instead of the general guidance given in this guide, as individual treatment types vary widely within a specific product type. Specific product recommendations are beyond the scope or intent of this guide.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

Special notation characters are referenced in Tables 3.1a through 3.1h to provide further clarification of specific chemicals and are shown as letters in the column headed "Notes."

- a = sometimes used in food processing or as food or beverage ingredient; ask for advisory opinion of Food and Drug Administration (FDA) regarding coatings for use with food ingredients.
- b = water with a pH higher than 6.5 may be aggressive if it also contains bicarbonates; natural water is usually of pH higher than 7.0 and seldom lower than 6.0, though pH values as low as 0.4 have been

- reported (Nordstrom et al. 2000); for pH values below 3, protect as for dilute acid.
- c = frequently used as a deicer for concrete pavements. If the concrete contains too little entrained air, a poor-quality air-void system, or has not been aged more than 1 month, repeated application may cause surface scaling; for protection under these conditions, refer to deicing salts.
- d = carbon dioxide dissolves in natural waters to form carbonic acid solutions; when it dissolves to an extent of 0.9 to 3 ppm, it is destructive to concrete.
- e = frequently used as deicer for airplanes; heavy spillage on runway pavements containing too little entrained air may cause surface scaling.
- f = in addition to the intentional fermentation of many raw materials, much unwanted fermentation occurs in the spoiling of foods and food wastes, also producing lactic acid.
- g = contains carbonic acid, fish oils, hydrogen sulfide, methyl amine, brine, and other potentially reactive substances.
- h = water used for cleaning coal gas; compositionally, coal-washing gas can contain gases based on hydrogen sulfide, ammonia, carbon dioxide, and carbon monoxide (Kohl and Neilsen 1997); the reported pH can range from as low as 5.7 to as high as 8.5.
- j = in those limited areas of the United States where concrete is made with reactive aggregates, reactive aggregate reaction products can cause disruptive expansion.
- k = composed mostly of nitrogen, oxygen, carbon dioxide, carbon monoxide, and water vapor; also contains unburned hydrocarbons, partially burned hydrocarbons, oxides of nitrogen, and oxides of sulfur. Nitrogen dioxide and oxygen in sunlight may produce ozone, which reacts with some of the organics to produce formaldehyde, peracynitrates, and other products.
- l = contain chromium trioxide and a small amount of sulfate or nearly saturated ammonium chromic sulfate, and sodium sulfate.
- m = many types of solutions are used, including
- (a) sulfate—contains copper sulfate and sulfuric acid
 - (b) cyanide—contains copper and sodium cyanides and sodium carbonate
 - (c) rochelle—contains these cyanides, sodium carbonate, and potassium sodium tartrate
 - (d) others such as fluoborate, pyrophosphate, amine, or potassium cyanide
- n = contains lead fluosilicates and fluosilicic acid.
- p = reference to combustion of coal, which produces carbon dioxide, water vapor, nitrogen, hydrogen, carbon monoxide, carbohydrates, ammonia, nitric acid, sulfur dioxide, hydrogen sulfide, soot, and ashes.

- q = molten paraffin absorbed by porous concrete that is subsequently immersed in water can cause concrete disintegration from sorptive forces.
- r = contains nickelous chloride, nickelous sulfate, boric acid, and ammonium ion.
- s = may contain various mixtures of blood, fats and oils, bile and other digestive juices, partially digested vegetable matter, urine, and manure, with varying amounts of water.
- v = usually contains zinc sulfate in sulfuric acid; sulfuric acid concentration may be low—approximately 6 mass percent in low current density process—or higher, approximately 22 to 28 mass percent in high current density process.

2.2—Definitions

ACI provides a comprehensive list of definitions through an online resource, “ACI Concrete Terminology,” <http://terminology.concrete.org>.

CHAPTER 3—TABLES OF CHEMICALS, THEIR EFFECTS ON CONCRETE, AND PROTECTIVE TREATMENTS

3.1—Aggressive substances

These aggressive substances include:

Table 3.1a—Acids

Table 3.1b—Salts and alkalis

Table 3.1c—Petroleum oils

Table 3.1d—Coal-tar distillates

Table 3.1e—Solvents and alcohols

Table 3.1f—Vegetable oils

Table 3.1g—Fats and fatty acids (animal)

Table 3.1h—Miscellaneous substances

3.2—Treatment methods

Recommended treatment methods for protection of concrete from the various aggressive substances listed in the following are referenced in **Tables 3.1a** through **3.1h**.

The following protective treatments are referenced as numbers 1 through 25 in **Tables 3.1a** through **3.1h**. They are generally accepted treatments for providing at least some resistance to the chemicals listed in the tables. Specific combinations of materials commonly combined as a composite system (for example, acid-resistant brick and mortar) are listed under treatment 16 (16a through 16l). All 25 protective treatments are described in depth in Chapter 4. The order of the list is not alphabetical and corresponds to that used by **Kerkhoff (2001)**. Additives, reinforcements, and fillers can be added to most resin systems to modify their properties and are discussed in **Section 4.26**. These are adjuncts to the binder and are excluded in the tables as an alternative method.

1. Magnesium fluosilicate or zinc fluosilicate
2. Alkali silicates, sodium silicate (water glass), potassium silicate, lithium silicate
3. Drying oils
4. Coumarone-indene resin

5. Styrene-butadiene (SBR) copolymer resin
6. Chlorinated rubber
7. Chlorosulfonated polyethylene (hypalon)
8. Vinyls and latex-based materials
9. Bituminous paints, mastics, and enamels
10. Polyester and vinyl ester materials
11. Polyurethane/urethane
12. Epoxy
13. Neoprene
14. Polysulfide
15. Coal tar and coal-tar epoxy
16. Chemical-resistant masonry units, mortars, grouts, and concretes
 - (I) Asphaltic and bituminous membranes
 - (II) Epoxy-resin mortars or grouts
 - (III) Furan-resin mortars or grouts
 - (IV) Hydraulic-cement mortars or grouts
 - (V) Phenolic-resin mortars
 - (VI) Polyester-resin mortars
 - (VII) Silicate mortars
 - (VIII) Sulfur mortars
 - (IX) Vinyl ester-resin mortars

- (X) Sulfur concretes
- (XI) Polymer concretes
- (XII) Silicate-based concretes
17. Sheet rubber
18. Resin sheets
19. Lead sheet
20. Glass
21. Acrylics, methyl methacrylate (MMA), and high-molecular-weight methacrylate (HMWM)
22. Silane, siloxane, and silicates (organosilicon compounds)
23. Metalizing
24. Crystalline coatings and admixtures
25. Polyurea
26. Adjunct additives
 - i. Fillers
 - ii. Reinforced coatings
 - iii. Flake-filled coatings

The following tables are primarily based on information from [Kerkhoff \(2001\)](#). Refer to [2.1](#) for notation and [3.2](#) to cross-reference protective treatments.

Table 3.1a—Acids

Substance	Notes	Effect on concrete	Protective treatments
Acetic acid, less than 10 mass percent	a	Slow disintegration	1, 2, 9, 10, 12, 14, 16 (II, III, V, VI, VII, VIII)
Acetic acid, 30 mass percent	a	Slow disintegration	9, 10, 14, 16 (III, V, VI, VII)
Acetic acid, 100 percent (glacial)		Slow disintegration	9, 16 (V, VII)
Acid waters	b	Slow disintegration. In porous or cracked concrete, attacks steel. Steel corrosion could cause concrete to spall.	1, 2, 3, 6, 8, 9, 10, 11, 12, 13, 16 (II, III, V, VI, VII, VIII), 17, 24, 25
Acid waters (pH 6.5 or less)	b	Natural, slightly acid waters could erode surface mortar, but then action usually stops. Disintegration increases as pH decreases.	1, 2, 3, 6, 8, 9, 10, 11, 12, 13, 16 (II, III, V, VI, VII, VIII), 17
Arsenious acid		None	
Boric acid		Negligible effect	2, 6, 7, 8, 9, 10, 12, 13, 15, 16 (II, III, V, VI, VII, VIII), 17, 19, 24, 25
Butyric acid	a	Slow disintegration	3, 4, 8, 9, 10, 12, 16 (II, III, V, VI)
Carbolic acid		Slow disintegration	1, 2, 16 (III, V, VII), 17, 25
Carbonic acid (soda water, club soda)	a, d	0.9 to 3 ppm of carbon dioxide dissolved in natural waters, disintegrates concrete slowly, and higher concentrations are slightly more aggressive.	2, 3, 4, 8, 9, 10, 12, 13, 15, 16 (II, III, V, VI, VIII), 17
Chromic acid 5 mass percent	l	None. In porous or cracked concrete, attacks steel. Steel corrosion could cause concrete to spall.	2, 6, 7, 8, 9, 10, 16 (VI, VII, VIII), 19
Chromic acid, 50 mass percent	l	None. In porous or cracked concrete, attacks steel. Steel corrosion could cause concrete to spall.	16 (VII), 19
Formic acid, 10 mass percent	a	Slow disintegration	2, 5, 6, 7, 10, 12, 13, 16 (II, III, V, VII), 17, 24, 25
Formic acid, 90 mass percent		Slow disintegration	2, 7, 10, 13, 16 (III, V, VII), 17
Humic acid		Slow disintegration possible (aggressiveness depends on humus type)	1, 2, 3, 9, 10, 12, 15, 16 (II, III, V), 25
Hydrochloric acid, 10 mass percent	a	Rapid disintegration, including steel	5, 6, 7, 8, 9, 10, 12, 14, 16 (II, III, V, VI, VII, VIII), 17, 19, 20, 25
Hydrochloric acid, 37 mass percent (muriatic acid)		Rapid disintegration, including steel	5, 6, 8, 9, 10, 16 (III, V, VI, VII, VIII)
Hydrofluoric acid, 10 mass percent		Rapid disintegration, including steel	5, 6, 7, 8, 9, 12, 16 (carbon and graphite brick; II, III, V, VII), 17
Hydrofluoric acid 75 mass percent		Rapid disintegration, including steel	16 (carbon and graphite brick; V, VIII), 17
Hypochlorous acid 10 mass percent		Slow disintegration	5, 8, 9, 10, 16 (VI, VII), 24
Lactic acid, 5 to 25 mass percent	a	Slow disintegration	3, 4, 5, 7, 8, 9, 10, 11, 12, 13, 15, 16 (II, III, V, VI, VII, VIII), 17, 21, 25
Nitric acid, 2 mass percent		Rapid disintegration	6, 8, 9, 10, 13, 16 (VI, VII, VIII), 20
Nitric acid, 40 mass percent (red fuming)		Rapid disintegration	8, 16 (VII)
Oleic acid, 100 percent	a	None	
Oxalic acid		No disintegration. When applied to concrete, oxalic acid forms calcium oxalate, which protects concrete against acetic acid, carbon dioxide, and salt water. Oxalic acid and its salts are poisonous and must not be used on concrete in contact with food or drinking water.	
Perchloric acid, 10 mass percent		Disintegration	8, 10, 16 (V, VI, VII, VIII)
Phosphoric acid, 10 mass percent	a	Slow disintegration	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16 (II, III, V, VI, VII, VIII), 17, 19, 25
Phosphoric acid, 85 mass percent	a	Slow disintegration	1, 2, 3, 5, 7, 8, 9, 10, 13, 14, 15, 16 (III, V, VI, VII, VIII), 17, 19
Stearic acid	a	Slow disintegration	5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16 (II, III, V, VI, VII, VIII), 17, 24, 25
Sulfuric acid, 10 mass percent	a	Rapid disintegration	5, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16 (II, III, V, VI, VII, VIII), 17, 19, 20, 25
Sulfuric acid, 100 mass percent (oleum)		Disintegration	16 (VII), 19
Sulfurous acid		Rapid disintegration	6, 7, 9, 10, 11, 12, 13, 16 (II, III, V, VIII), 19, 20, 25
Tannic acid		Slow disintegration	1, 2, 3, 6, 7, 8, 9, 10, 11, 12, 13, 16 (II, III, V, VII), 17, 24, 25
Tartaric acid (solution)	a	None: refer to wine under Table 3.1h—Miscellaneous substances	

Table 3.1b—Salts and alkalis; solutions where dry materials generally have no effect

Substance	Notes	Effect on concrete	Protective treatments
Acetate, calcium	c	Slow disintegration*	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16 (II, III, V, VI, VII, VIII), 17, 24, 25
Acetate, magnesium		Slow disintegration*	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16 (II, III, V, VI, VII, VIII), 17
Acetate, potassium		None*	
Acetate, sodium	c	None*	
Bicarbonate, ammonium	a	None	
Bicarbonate, sodium	a	None	
Bisulfate, ammonium		Disintegration. In porous or cracked concrete, attacks steel. Steel corrosion could cause concrete to spall.	5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16 (II, III, V, VI, VIII), 17, 25
Bisulfate, sodium		Disintegration. In porous or cracked concrete, attacks steel. Steel corrosion could cause concrete to spall.	5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16 (II, III, V, VI, VIII), 17
Sulfite, calcium (sulfite solution)		Rapid disintegration	7, 8, 9, 10, 12, 13, 16 (II, III, V, VI, VIII), 17, 25
Bromide, sodium		Slow disintegration. In porous or cracked concrete, attacks steel. Steel corrosion could cause concrete to spall.	1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16 (II, III, V, VI, VIII), 17, 24, 25
Carbonate, ammonium		None	
Carbonate, potassium		None	
Carbonate, sodium		None	
Chlorate, sodium		Slow disintegration	1, 4, 6, 7, 8, 9, 10, 16 (VI, VII, VIII), 17, 19, 24
Chloride, calcium [†] Chloride, potassium Chloride, sodium* Chloride, strontium	a, c a, c a, c a, c	None, unless concrete is alternately wet and dry with the solution. Concentrated CaCl ₂ solutions, however, disintegrate concrete, whereas weak solutions do not. In porous or cracked concrete, attacks steel. Steel corrosion could cause concrete to spall (Concrete Construction Problem Clinic 1976; Portland Cement Association 2012).	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16 (II, III, V, VI, VII, VIII), 17, 21, 24, 25
Chloride, ammonium Chloride, copper Chloride, ferric (iron) Chloride, ferrous Chloride, magnesium [†] Chloride, mercuric Chloride, mercurous Chloride, zinc	a a	Slow disintegration. In porous or cracked concrete, attacks steel. Steel corrosion could cause concrete to spall.	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16 (II, III, V, VI, VII, VIII), 17, 24, 25
Chloride, aluminum		Rapid disintegration	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16 (II, III, V, VI, VIII), 17, 25
Chromate, sodium		None	
Cyanide, ammonium Cyanide, potassium Cyanide, sodium		Slow disintegration	7, 8, 9, 10, 12, 13, 16 (II, III), 17, 24, 25
Dichromate, potassium		Disintegration	1, 2, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16 (II, III, V, VI, VIII), 17, 24, 25
Dichromate, sodium		Slow disintegration with dilute solutions	1, 2, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16 (II, III, V, VI, VIII), 17, 24, 25
Ferrocyanide, sodium		None	
Fluoride, ammonium Fluoride, sodium		Slow disintegration	3, 4, 8, 9, 10, 13, 16 (I, III, V, VIII), 17, 24
Fluosilicate, magnesium	n	None. Reacts to harden older concrete when wet.	
Formate, potassium Formate, sodium	a a	None	
Hexametaphosphate, sodium		Slow disintegration	5, 6, 7, 8, 9, 10, 12, 13, 15, 16 (II, III, V), 17, 24, 25
Hydroxide, ammonium Hydroxide, barium Hydroxide, calcium Hydroxide, potassium, 15 mass percent Hydroxide, sodium, 10 mass percent	 a j a, j	None	

Table 3.1b—Salts and alkalis; solutions where dry materials generally have no effect (cont.)

Substance	Notes	Effect on concrete	Protective treatments
Hydroxide, potassium, 25 mass percent	j	Disintegration. Use of calcareous aggregate lessens attack.	5, 7, 8, 10, 12, 13, 14, 15, 16, (carbon and graphite brick; II, III), 17, 25
Hydroxide, sodium, 20 mass percent	a, j		
Nitrate, calcium		None	
Nitrate, ferric			
Nitrate, zinc			
Nitrate, lead		Slow disintegration	2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 16 (II, III, V, VI, VII, VIII), 17, 20, 24, 25
Nitrate, magnesium	a		
Nitrate, potassium	a		
Nitrate, sodium			
Nitrate, ammonium		Disintegration	2, 5, 6, 8, 9, 10, 11, 12, 13, 16 (II, III, V, VI, VII, VIII), 17, 20, 25
Nitrite, sodium	a	Slow disintegration	1, 2, 5, 6, 7, 8, 9, 10, 12, 13, 16 (II, III), 17, 24, 25
Orthophosphate, sodium (dibasic and tribasic)		None	
Oxalate, ammonium		None	
Perborate, sodium		Slow disintegration	1, 4, 7, 8, 9, 10, 13, 16 (IV, VI, VII, VIII), 17, 24
Permanganate, potassium		None, unless potassium sulfate is present.	
Persulfate, potassium		Disintegration of concrete with inadequate sulfate resistance	1, 2, 5, 7, 8, 9, 10, 12, 13, 16 (II, III, V, VI, VIII), 17, 24, 25
Phosphate, sodium (monobasic)		Slow disintegration	5, 6, 7, 8, 9, 10, 12, 15, 16 (II, III), 17, 25
Pyrophosphate, sodium		None	
Stannate, sodium		None	
Sulfate, ammonium	a	Disintegration	5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16 (II, III, V, VI, VII, VIII), 17, 25
Sulfate, aluminum	a	Disintegration of concrete with inadequate sulfate resistance. Concrete products cured in high-pressure steam are highly resistant to sulfates.	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16, (II, III, V, VI, VII, VIII), 17, 24, 25
Sulfate, calcium			
Sulfate, cobalt			
Sulfate, copper			
Sulfate, ferric	a		
Sulfate, ferrous (iron vitriol)	a		
Sulfate, magnesium (epsom salt)	a		
Sulfate, manganese			
Sulfate, nickel			
Sulfate, potassium			
Sulfate, potassium aluminum (alum)	a		
Sulfate, sodium	a		
Sulfate, zinc			
Sulfide, copper		None, unless sulfates are present	7, 8, 9, 10, 12, 13, 15, 16 (II, III, V, VI, VIII), 17, 24, 25
Sulfide, ferric			
Sulfide, potassium			
Sulfide, sodium		Slow disintegration	6, 7, 8, 9, 10, 11, 12, 13, 15, 16 (II, III), 17, 25
Sulfide, ammonium		Disintegration	7, 8, 9, 10, 12, 13, 15, 16 (I, II, III, V), 17, 25
Sulfite, sodium	a	None unless sulfates are present	1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16 (II, III, V), 17, 24, 25
Sulfite, ammonium	a	Disintegration	8, 9, 10, 12, 15, 16 (II, III, V, VIII), 17, 25
Superphosphate, ammonium		Disintegration	8, 9, 10, 12, 13, 15, 16 (II, III, V), 17, 19
Tetraborate, sodium (borax)		Slow disintegration	5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16 (II, III, V, VI, VII, VIII), 17, 24, 25
Tetrachloride, carbon		Impervious concrete is required to prevent loss from penetration. Sometimes used in food, processing, or both and requires compatible coating. Refer to "Tetrachloride, carbon" under Table 3.1e—Solvents and alcohols .	
Thiosulfate, sodium		Slow disintegration of concrete with inadequate sulfate resistance.	1, 2, 5, 6, 7, 8, 9, 10, 12, 13, 15, 16, (II, III, V), 17, 24, 25
Thiosulfate, ammonium		Disintegration	8, 9, 12, 13, 15, 16 (III, V), 17, 25

[†]Refer to "Deicers and anti-icers" under [Table 3.1h—Miscellaneous substances](#).

[‡]Frequently used as deicer for concrete pavements. Any substance used as a deicer on concrete could increase scaling if the concrete contains insufficient entrained air. For more information, refer to "Deicers and anti-icers" under [Table 3.1h—Miscellaneous substances](#), and [Cody et al. \(1996\)](#), [National Cooperative Highway Research Program \(2007\)](#), and [Kozikowski et al. \(2007\)](#), [Shil et al. \(2009\)](#) and [Sutter et al. \(2005\)](#) have demonstrated destructive expansive damage due to the use of deicers not related to freezing-and-thawing cycling.

Note: If concrete is made with reactive aggregates, disruptive expansion could occur from sodium and potassium salts.

Table 3.1c—Petroleum oils

Substance	Notes	Effect on concrete	Protective treatments
Heavy oil below 35 Baumé* Paraffin should not be used on masonry	q	None	
Gasoline Kerosene Light oil above 35 Baumé Ligroin Lubricating oil* Machine oil* Mineral spirits		None. Impervious concrete is required to prevent loss from penetration, and surface treatments are generally used.	1, 2, 8, 10, 11, 12, 14, 16 (II, III, V, VI), 17, 19, 24, 25
Mineral oil	a	Slow disintegration if fatty oils are present	
Gasoline, high octane		None. Surface treatments are generally used to prevent contamination with alkalis in concrete.	10, 11, 14, 17, 24, 25

*Could contain some vegetable or fatty oils; concrete should be protected from such oils.

Table 3.1d—Coal tar distillates

Substance	Notes	Effect on concrete	Protective treatments
Alizarin Anthracene Carbazole Chrysen Pitch		None	
Benzol (benzene) Cumol (cumene) Phenanthrene Toluol (toluene) Xylol (xylene)		None. Impervious concrete is required to prevent loss from penetration, and surface treatments are generally used.	1, 2, 11, 12, 16 (II, III, V, VI, VII), 19, 24
Creosote Cresol Dinitrophenol Phenol, 5 mass percent		Slow disintegration	1, 2, 16 (III, V, VII), 17, 19, 24

Table 3.1e—Solvents and alcohols

Substance	Notes	Effect on concrete	Protective treatments
Carbon tetrachloride		None. Impervious concrete is required to prevent loss of alcohol from penetration, and surface treatments are generally used.	1, 2, 10, 12, 16 (II, III, V, VII), 24, 25
Ethyl alcohol	a	None. Impervious concrete is required to prevent loss of alcohol from penetration, and surface treatments are generally used. Frequently used as deicer for airplanes. Heavy spillage on concrete containing insufficient entrained air could cause surface scaling.	1, 2, 5, 7, 10, 12, 13, 14, 16 (II, III, V, VI, VII, VIII), 17, 19, 24
Ethyl ether		None. Impervious concrete is required to prevent loss of ether from penetration, and surface treatments are generally used.	11, 12, 16 (III, V), 19, 24, 25
Methyl alcohol		None. Impervious concrete is required to prevent loss of alcohol from penetration, and surface treatments are generally used.	1, 2, 5, 7, 10, 12, 13, 14, 16 (II, III, V, VI, VII, VIII), 17, 19, 24
Methyl ethyl ketone		None. Impervious concrete is required to prevent loss of ketone from penetration, and surface treatments are generally used.	16 (III, V), 17, 19, 24
Methyl isoamyl ketone		None. Impervious concrete is required to prevent loss of ketone from penetration, and surface treatments are generally used.	16 (III, V), 17, 24
Methyl isobutyl ketone		None. Impervious concrete is required to prevent loss of ketone from penetration, and surface treatments are generally used.	16 (III, V), 17, 24
Perchloroethylene		None. Impervious concrete is required to prevent loss of perchloroethylene from penetration, and surface treatments are generally used.	12, 16 (II, III, V), 24, 25
t-Butyl alcohol		None. Impervious concrete is required to prevent loss of alcohol from penetration, and surface treatments are generally used.	1, 2, 5, 7, 10, 12, 13, 14, 16 (II, III, V, VI, VII, VIII), 17, 19, 24, 25
Trichloroethylene		None. Impervious concrete is required to prevent loss of trichloroethylene from penetration, and surface treatments are generally used.	1, 2, 12, 16 (II, III, V, g), 24, 25
Acetone		None. Impervious concrete is required to prevent loss of acetone from penetration, and surface treatments are generally used. Acetone could, however, contain acetic acid as impurity. Refer to Table 3.1a—Acids .	1, 2, 16 (III, V, VII), 17, 19, 24
Carbon disulfide	a	Slow disintegration possible	1, 2, 11, 16 (III, V, VII), 24, 25
Glycerin (glycerol)	a	Slow disintegration possible	1, 2, 3, 4, 7, 10, 11, 12, 13, 16 (II, III, V, VI, g), 17, 24, 25
Ethylene glycol	e	Slow disintegration. Frequently used as deicer for airplanes. Heavy spillage on concrete containing insufficient entrained air could cause surface scaling.	1, 2, 7, 10, 12, 13, 14, 16 (II, III, V, VI, VII, VIII), 17, 24, 25

Table 3.1f—Vegetable oils

Substance	Notes	Effect on concrete	Protective treatments
Rosin and rosin oil		None	
Turpentine		Mild attack and considerable penetration. Impervious concrete is required to prevent loss from penetration, and surface treatments are generally used.	1, 2, 10, 11, 12, 14, 16 (II, III, V), 24, 25
Almond Linseed* Olive Peanut Poppyseed Soybean* Tung* Walnut	a a a a a a a	Slow disintegration. For expensive cooking oils, use 20.	1, 2, 8, 10, 11, 12, 14, 16 (II, III, V, VI), 17, 24, 25
Margarine	a	Slow disintegration, faster with melted margarine.	1, 2, 8, 10, 11, 12, 13, 16 (II, III, V, VI), 24, 25
Castor Cocoa bean Cocoa butter Coconut Cottonseed Mustard Rapeseed	a a a a a a	Disintegration, especially if exposed to air.	1, 2, 8, 10, 11, 12, 14, 16 (II, III, V, VI), 17, 25

*Applied in thin coats, the material quickly oxidizes and has no effect. The effect indicated is for constant exposure to the substance in liquid form.

Table 3.1g—Fats and fatty acids (animal)

Substance	Notes	Effect on concrete	Protective treatments
Fish liquor	g	Disintegration	3, 8, 10, 12, 13, 16 (II, III, V, VI), 17, 25
Fish oil	a	Slow disintegration with most fish oils	1, 2, 3, 8, 10, 12, 13, 16 (II, III, V, VI), 17, 24, 25
Whale oil	a	Slow disintegration	1, 2, 3, 8, 10, 12, 13, 16, (II, III, V, VI), 17, 24, 25
Neatsfoot oil Tallow and tallow oil		Slow disintegration	1, 2, 3, 8, 10, 12, 13, 16 (II, III, V, VI), 17, 24, 25
Beef fat Horse fat Lamb fat	a a	Slow disintegration with solid fat, faster with melted	1, 2, 3, 8, 10, 12, 13, 16 (II, III, V, VI), 17, 24, 25
Lard and lard oil	a	Slow disintegration, faster with oil	1, 2, 3, 8, 10, 12, 13, 16 (II, III, V, VI), 17, 24, 25
Slaughterhouse wastes	g, s	Disintegration due to organic acids	8, 10, 12, 13, 16 (II, III, V), 24, 25

Table 3.1h—Miscellaneous substances

Substance	Notes	Effect on concrete	Protective treatments
Alum	a	Refer to “Sulfate, potassium aluminum,” under Table 3.1b—Salts and alkalis .	
Ammonia, liquid		None, unless it contains harmful ammonium salts. Refer to Table 3.1b—Salts and alkalis .	
Ammonia, vapors		Possible slow disintegration of moist concrete and steel attacked in porous or cracked moist concrete.	8, 9, 10, 12, 13, 16 (I, II, III, VI), 17, 24, 25
Ashes, cold	c	Harmful if wet, when sulfides and sulfates leach out. Refer to “Sulfate, sodium,” under Table 3.1b—Salts and alkalis .	1, 2, 3, 8, 9, 10, 13, 16 (II, III, V), 24, 25
Ashes, hot	c	Thermal expansion	16 (calcium aluminate cement, fire-clay, and refractory-silicate-clay mortars)
Automobile and diesel exhaust gases by action of carbonic, nitric, or sulfurous acid. Refer to Table 3.1a—Acids .	k	Possible disintegration of moist concrete	1, 5, 8, 10, 12, 16 (II, III, V), 24, 25
Baking soda (sodium bicarbonate)	a	None.	
Beer	a, f	No progressive disintegration, but in beer storage and fermenting tanks a special coating is used to guard against beer contamination. Beer could contain, as fermentation products, acetic, carbonic, lactic, or tannic acids. Refer to Table 3.1a—Acids .	8, 10, 12, 16 (II, III, VI), 17, 24, 25
Bleaching solution	a	Refer to specific chemical, such as hypochlorous acid, sodium hypochlorite, and sulfurous acid.	
Borax (salt)		Refer to “Tetraborate, sodium,” under Table 3.1b—Salts and alkalis .	
Brine	a	Refer to “Chloride, sodium,” or other salts under Table 3.1b—Salts and alkalis .	
Bromine		Disintegration if bromine is gaseous, or if a liquid containing hydrobromic acid and moisture.	10, 13, 16 (VI, VII)
Buttermilk	a, f	Slow disintegration due to lactic acid	2, 3, 4, 7, 8, 9, 10, 11, 12, 13, 16 (II, III, V, VI), 17, 24, 25
Butyl stearate		Slow disintegration	8, 9, 10, 16 (II, III, V)
Carbon dioxide	a, d	Gas could cause permanent shrinkage or carbonation. Carbonation will not harm plain (nonreinforced) concrete; however, steel embedded in carbonated concrete is prone to corrosion. Refer to “Carbonic acid” under Table 3.1a—Acids , if moisture is present in carbon dioxide gas.	1, 2, 3, 6, 8, 9, 10, 11, 12, 13, 15, 16 (II, III, V, VI, VIII), 17, 24, 25
Caustic soda	a	Refer to hydroxide, sodium under Table 3.1b—Salts and alkalis .	
Chile saltpeter		Refer to “Nitrate, sodium,” under Table 3.1b—Salts and alkalis .	
Chlorine gas		Slow disintegration of moist concrete	2, 8, 9, 10, 16 (VI, VII), 17
Chrome plating solutions	l	Slow disintegration	7, 8, 9, 10, 16 (VI, VII), 20
Cider	a, f	Slow disintegration. Refer to “Acetic acid” under Table 3.1a—Acids .	1, 2, 9, 10, 12, 14, 16 (II, III, V, VI, g), 17, 24, 25
Cinders cold and hot	c, p	Refer to Table 3.1a—Acids .	

Table 3.1h—Miscellaneous substances (cont.)

Substance	Notes	Effect on concrete	Protective treatments
Coal	p	None, unless coal is high in pyrites (sulfide or iron) and moisture. Sulfides leaching from damp coal could oxidize to sulfurous or sulfuric acid, or ferrous sulfate. Refer to Table 3.1a—Acids and Table 3.1b—Salts and alkalis. Rate is greatly retarded by deposit of an insoluble film.	1, 2, 3, 6, 7, 8, 9, 10, 12, 13, 16 (II, III, V, VIII), 17, 24, 25
Coke	p	Sulfides leaching from damp coke could oxidize to sulfurous or sulfuric acid. Refer to Table 3.1a—Acids.	1, 2, 3, 6, 7, 8, 9, 10, 12, 13, 16 (II, III, V, VIII), 24, 25
Copper plating solutions	m	None	
Corn syrup (glucose)	a, f	Slow disintegration	1, 2, 3, 7, 8, 9, 10, 12, 13, 16 (II, III, V), 17, 22, 25
Deicers and anti-icers	c	Chlorides (calcium, magnesium, and sodium) and non-chlorides (calcium magnesium acetate, potassium and sodium acetates and formates, urea, and ethyl alcohol) cause scaling of concrete. Air-entrained concrete does not need added protection from deicers. Potassium acetate deicers or anti-icers and, to a lesser extent, potassium formate and sodium acetate or formate could accelerate alkali-silica reaction when reactive aggregates are present (Rangaraju et al. 2005).	50 mass percent solution of boiled linseed oil in kerosene, soybean oil, modified castor oil, cottonseed oil, sand-filled epoxy, coal-tar epoxy, 21, ⁴ 22
Distiller's slop		Slow disintegration due to lactic acid	1, 8, 9, 10, 12, 13, 15, 16 (II, III, V, VI, VIII), 17, 24, 25
Fermenting fruits, grains, vegetables, or extracts	a, f	Slow disintegration. Industrial fermentation processes produce lactic acid. Refer to Table 3.1a—Acids.	1, 2, 3, 8, 9, 10, 12, 16 (II, III, V), 17, 24, 25
Flue gases	d, k	Hot gases (400 to 1100°F [200 to 600°C]) cause thermal stresses. Cooled, condensed sulfurous, hydrochloric acids disintegrate concrete slowly.	9 (high melting), 16 (VII, fireclay mortar)
Formaldehyde, 37 mass percent (formalin)		Slow disintegration due to formic acid formed in solution	2, 5, 6, 8, 10, 11, 12, 13, 14, 16 (II, III, V, VI, VII, VIII), 17, 20, 24, 25
Fruit juices	a, f	Little, if any, effect for most fruit juices as tartaric and citric acids do not appreciably affect concrete. Sugar fermentation and other acids cause disintegration.	1, 2, 3, 6, 7, 8, 9, 10, 11, 12, 16 (II, III, V), 17, 25
Gas water	h	Ammonium salts seldom present in sufficient quantity to disintegrate concrete.	9, 10, 12, 16 (II, III)
Glyceryl tristearate		None	
Honey	a	None	
Hydrogen sulfide		Slow disintegration in moist oxidizing environments where hydrogen sulfide converts to sulfurous acid.	1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 16 (II, III, V, VI, VII, VIII), 17, 19, 24, 25
Iodine		Slow disintegration. In porous or cracked concrete, attacks steel. Steel corrosion could cause concrete to spall.	1, 2, 6, 10, 12, 13, 16 (II, III, V, VII), 17, 24, 25
Lead refining solution	n, v	Slow disintegration	1, 2, 6, 8, 9, 10, 12, 16 (carbon and graphite brick; II, III, V, VIII), 17, 20
Leuna saltpeter		Disintegration. Refer to ammonium nitrate and ammonium sulfate.	5, 6, 8, 9, 10, 11, 12, 13, 16 (II, III, V, VI, VII, VIII), 17
Lignite oils		Slow disintegration if fatty oils present	1, 2, 6, 8, 10, 12, 16 (II, III, V, VI), 24, 25
Lye: Refer to "Hydroxide, sodium" and "Hydroxide, potassium," under Table 3.1b—Salts and alkalis			
Manure	f	Slow disintegration	1, 2, 8, 9, 10, 12, 13, 16 (II, III, V), 24, 25
Marsh, fermenting	f	Slow disintegration due to acetic and lactic acids and sugar. Refer to Table 3.1a—Acids.	1, 8, 9, 10, 12, 13, 16 (II, III)
Milk	a, f	None, unless milk is sour. Then lactic acid disintegrates concrete slowly.	3, 4, 8, 9, 10, 11, 12, 13, 16 (II, III, VI), 17, 24, 25
Mine water, waste		Sulfides, sulfates, or acids present disintegrate concrete and attack steel in porous or cracked concrete.	1, 2, 5, 8, 9, 10, 12, 13, 15, 16 (II, III, V, VI, VIII), 17, 24, 25
Molasses	a	Slow disintegration at temperatures of 120°F (50°C) or more.	1, 2, 7, 8, 9, 10, 12, 13, 16 (II, III, V), 17

Table 3.1h—Miscellaneous substances (cont.)

Substance	Notes	Effect on concrete	Protective treatments
Nickel plating solutions	m, r	Slow disintegration due to nickel ammonium sulfate	2, 5, 6, 7, 8, 9, 10, 13, 16 (III, V, VI), 17, 24, 25
Niter: refer to “Nitrate, potassium” under Table 3.1b—Salts and alkalis			
Ores		Sulfides leaching from damp ores could oxidize to sulfuric acid or ferrous sulfate. Refer to these materials under Table 3.1a—Acids and Table 3.1b—Salts and alkalis.	2, 9, 10, 12, 13, 15, 16 (II, III, V, VI, VII), 17, 24, 25
Pickling brine	a	Steel attacked in porous or cracked concrete. Refer to Table 3.1b—Salts and alkalis, “Boric acid,” or “Sugar (sucrose).”	1, 7, 8, 9, 10, 12, 13, 16 (II, III, V, VIII), 17, 24, 25
Sal ammoniac: refer to “Chloride, ammonium” under Table 3.1b—Salts and alkalis			
Sal soda: refer to “Carbonate, sodium” under Table 3.1b—Salts and alkalis			
Saltpeter: refer to “Nitrate, potassium” under Table 3.1b—Salts and alkalis			
Sauerkraut	a, f	Slow disintegration possible due to lactic acid. Flavor impaired by concrete.	1, 2, 8, 9, 10, 12, 13, 16 (II, III, V, VI), 17, 24, 25
Seawater		Disintegration of concrete with inadequate sulfate resistance and steel attacked in porous or cracked concrete.	1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, (II, III, V, VI), 17, 24, 25
Sewage and sludge		Usually not harmful. Refer to “Hydrogen sulfide.”	
Silage	f	Slow disintegration due to acetic, butyric, and lactic acids, and sometimes fermenting agents of hydrochloric or sulfuric acids. Refer to Table 3.1a—Acids.	3, 4, 8, 9, 10, 12, 16 (II, III, V, VI), 24, 25
Sodium hypochlorite		Slow disintegration	7, 8, 9, 10, 13, 16 (IV, VI), 17, 24, 25 (aliphatic only)
Sugar (sucrose)	a, f	None with dry sugar on thoroughly cured concrete. Sugar solutions could slowly disintegrate concrete.	1, 2, 3, 7, 8, 9, 10, 12, 13, 15, 16 (II, III, V, VI), 17
Sulfite liquor		Disintegration	1, 2, 3, 5, 6, 8, 9, 10, 12, 13, 16 (II, III, V, VI, VIII), 17, 19, 24, 25
Sulfur dioxide	a	None if dry. With moisture, sulfur dioxide forms sulfurous acid.	2, 5, 6, 8, 9, 10, 12, 13, 16 (II, III, V, VI, VII, VIII), 17, 19, 24, 25
Tanning bark		Slow disintegration possible if damp. Refer to “Tanning liquor.”	1, 2, 3, 6, 8, 9, 10, 11, 12, 13, 16 (II, III, V), 17, 24, 25
Tanning liquor		None with most liquor, including chromium. If liquor is acid, it disintegrates concrete.	1, 2, 3, 5, 6, 8, 9, 10, 11, 12, 13, 16 (II, III, V), 17
Tobacco		Slow disintegration if organic acids present	1, 8, 9, 10, 12, 13, 16 (II, III, V, VI), 17
Trisodium phosphate		None	
Urea	a, c	None. Refer to “Deicers and anti-icers.”	
Urine		None, but steel attacked in porous or cracked concrete	7, 8, 10, 12, 13, 16 (II, III, V), 24, 25
Vinegar (refer to acetic acid)	a	Slow disintegration due to acetic acid	9, 10, 12, 16 (II, III, V, VIII), 17, 24, 25
Washing soda (sodium carbonate)		None	
Water, soft (<75 ppm of carbonate hardness)		Leaching of hydrated lime by flowing water in porous or cracked concrete	2, 3, 4, 8, 9, 10, 12, 13, 16 (II, III, V, VI, VIII), 17, 24, 25
Whey	a, f	Slow disintegration due to lactic acid	3, 4, 5, 7, 8, 9, 10, 12, 13, 16 (II, III, V, VI, VIII), 17, 24, 25
Wine	a, f	None, but taste of first wine batch could be affected unless concrete has been given tartaric acid treatment. Solutions from wine-making process can cause slow disintegration.	For fine wines, two or three applications of tartaric acid solution, 1 lb (320 g) tartaric acid in 3 pt (1 L) of water, 2, 8, 10, 12, 16 (II), 20, 24, 25
Wood pulp		None	
Zinc refining solutions		Disintegration if hydrochloric or sulfuric acids present.	8, 9, 10, 12, 13, 16 (II, III, V, VI, VIII), 17, 25
Zinc slag		Zinc sulfate (refer to Table 3.1b—Salts and alkalis) could be formed by oxidation.	8, 9, 10, 12, 13, 16 (II, III, V, VI, VIII), 17, 24, 25

*Impermeable materials, such as most epoxies, should not be used on exterior slabs on ground or other concrete where moisture can freeze under the coating. The freezing water can cause surface delamination under the impermeable coating.

CHAPTER 4—PROTECTIVE TREATMENTS AND SYSTEMS DESCRIPTIONS

4.1—Magnesium fluosilicate or zinc fluosilicate

These chemicals are commonly available as floor hardeners applied to hardened, older concrete. Treatment consists generally of three applications of the same material with the excess removed after each application. Magnesium and zinc fluosilicates are available separately or as a mixture and should be applied as required by the producer. The solution can be applied efficiently with large brushes for vertical surfaces and mops for horizontal ones. Surfaces should be allowed to dry between applications, with approximately 3 to 4 hours required for absorption, reaction, and drying. Brush and wash the surface with water shortly after the last application has dried to remove encrusted salts that could cause white stains. Treatment with fluosilicates reduces dusting and hardens the surface by chemical action. Although this treatment increases resistance to attack from several substances as shown in the previous tables, it does not prevent them. With low-quality concrete, such as concrete that has an unsound, improperly cured, or otherwise deteriorated surface, this treatment is less effective. Fluorosilicates react and harden only the top 1/16 to 1/8 in. (1 to 3 mm) of normal concrete surfaces. Concrete surfaces to be treated with fluosilicates should not contain integral water-repellent agents because these compounds will prevent penetration of the solution. Fluosilicate hardeners should not be used when paints are to be applied because they result in poor adhesion of many coatings. Hardened surfaces are difficult to etch properly as well. Buffing, like polishing, can create sheen but decrease friction, like slip resistance, when wet.

4.2—Alkali silicates, sodium silicate (water glass), potassium silicate, lithium silicate

Among numerous other applications, alkali silicates are widely used in the construction industry as water repellents, curing compounds, and set accelerators for concrete. These chemicals are commonly available as floor hardeners applied to hardened, older concrete. They are manufactured in various grades with different ratios of alkali (sodium, potassium, or lithium) and silicate. Although promoted as water repellents, their efficacy has not been conclusively proven. Sodium, lithium, and potassium silicates are claimed to reduce water absorption of cementitious substrates, mainly concrete, by reacting with portlandite (calcium hydroxide) to form a water-insoluble precipitate. Little data have been published to support these claims despite many years of usage.

Silicates react and harden only the top 1/16 to 1/8 in. (1 to 3 mm) of normal concrete surfaces. This reaction of soluble silicate with calcium hydroxide in concrete also produces alkali metal ions that can be detrimental to concrete if reactive aggregates and moisture are present. There is also potential for the silicate to form efflorescence, which is highest with sodium, lower with potassium, and lowest with lithium. Sodium, potassium, or lithium stabilize and solubilize the silicate so it remains in solution until it has penetrated the

concrete and reacted with the abundant calcium hydroxide in the concrete.

Sodium, potassium, or lithium ions typically do not react in concrete, so they are incidental to the primary benefits. Hydroxides from sodium, potassium, and lithium, in combination with laitance from the scrubbing process, should be removed before they crystallize on the surface. Lithium silicate, when applied in the correct amount, dries to a dust (Nasvik 2008). Considerably more alkaline, lithium raises the pH of the concrete surface and reduces the possibility of alkali aggregate reaction (AAR) (Nixon and Drisko 2001).

Although commercial alkali silicates are available to approximately a 40 mass percent solution, they are viscous and should be diluted with water to secure penetration. Two or three coats are usually sufficient. For tanks and similar structures, progressively stronger solutions are often used for the succeeding coats. Each coat should be allowed to dry thoroughly before the next one is applied. On horizontal surfaces, the solution may be liberally poured and spread evenly with mops, brooms, or brushes. Scrubbing each coat with stiff fiber brushes or scrubbing machines and water after it has hardened will assist penetration of the succeeding application. The treatment can increase resistance to attack from some substances listed in Tables 3.1a through 3.1h, but not prevent it.

4.3—Drying oils

Raw, boiled, and or polymerized linseed oil in various types of solvents, including mineral spirits and kerosene, are available. They are usually sold as solutions composed of equal parts of boiled linseed oil and mineral spirits or kerosene. Two or three coats of linseed oil can be used as a protective treatment and depth of penetration is dependent on the absorptivity of the concrete surface; however, one study reported penetration of a few millimeters (Xie 1995). Boiled linseed oil dries faster and is used more often than raw oil. Soybean oil and tung oil, also called China wood oil, can be used as well. The treatment will increase the resistance to attack from various substances as described in the preceding tables, but it cannot completely prevent such attack. Reapplication on bridge decks every 4 years is recommended in Fowler and Mitchell (1973).

Concrete should be well cured and at least 28 days old before the first application of drying oil. Concrete should be allowed to dry for at least 48 hours. Any crystals formed on the surface should be removed by light brushing. Sometimes a magnesium fluosilicate treatment is also applied to harden the surface before the oil treatment. The oil treatment can be applied with mops, brushes, or spray. The excess oil should be removed with a squeegee before it gets tacky. Do not build up a heavy surface coating to allow for the oil to penetrate the surface. Diluting the oil with turpentine or mineral spirits in equal parts provides a stronger penetration for the first coat; subsequent coatings can be diluted less. Heating the oil or substance/solution to a warm surface also improves the penetration due to high viscosity. Each coat should dry thoroughly for at least 24 hours before the next application. Drying oils tend to darken concrete.

4.4—Coumarone-indene resin

Available in grades from dark brown to colorless, this synthetic resin is soluble in xylol and similar hydrocarbon solvents, and should be powdered to aid dissolving. Two or more coats should be applied to dry concrete. Although these coatings have a tendency to yellow with exposure to sunlight, the yellowing does not appear to affect the protective properties. Recent substitutes include hydrocarbon-resin polymers and rosin-based resins.

4.5—Styrene-butadiene (SBR) copolymer resin

Styrene-butadiene copolymer resins are available in various medium-strength solvents, some faster drying than others. Three coats are generally recommended, with the first coat thinned for better penetration. Allow 24 hours between coats and 7 days for thorough drying before the coated surface is placed in service. These coatings tend to yellow with exposure to sunlight. Because this coating is solvent-borne, it is usually high in volatile organic compounds (VOCs), making it less available because of state and local VOC content limits. Styrene-butadiene resin is also used as a type of waterborne decorative coating that is alkali-resistant and breathable, but is usually not UV-resistant and could yellow. Styrene-butadiene resin-based coatings usually have excellent water resistance but, like other polymer emulsion systems, are not generally considered chemically resistant.

4.6—Chlorinated rubber

Chlorinated rubber is produced by chlorinating isoprene rubber to chlorine content as high as 67 mass percent. The resulting product no longer holds the resiliency and elasticity of the rubber from which it was produced. Materials using chlorinated rubber have excellent resistance to alkalis, moisture, and abrasion, and their adhesion to concrete is good. They are widely used for concrete floor coatings, traffic paints, and swimming pools. They have adequate resistance to a wide range of common acids, aliphatic hydrocarbons, and lower alcohols, but are not resistant to nitric, acetic, and sulfurous acids, or concentrated aqueous ammonia. They are dissolved or softened by aromatic hydrocarbons, fatty acids, and animal and vegetable oils. Chlorinated rubber may be used in water service up to approximately 140°F (60°C). They have limited resistance to heat and will decompose when used above 225°F (107°C). In continuous, direct sunlight, only the pigmented coatings, or those with ultraviolet absorbers, can satisfactorily be used. Chlorinated rubber-derived products may also be elastomeric.

Chlorinated rubber cures by solvent evaporation. Chlorinated rubber surface treatments usually consist of a trowel-applied mastic of heavy consistency up to 1/8 in. (3 mm) thick, or multiple coats of specially formulated lower-viscosity types can be brushed or sprayed on to a maximum thickness of 10 mil (0.25 mm). A minimum of two coats of 5 mil (0.1 mm) dry film thickness is recommended for chemical exposure. In general, concrete should age for 2 months before this treatment. The concrete can be damp but not wet, as excessive moisture could prevent adequate

bonding. Typically, the first coat is thinned using the producer's recommended thinner. A coating dries tack-free in 1 hour, but a 24-hour interval is recommended between coats. The applied coating is odorless, tasteless, and nontoxic after it dries. Solvent-borne coatings are usually high in VOCs, making it difficult formulating coatings that are based on chlorinated rubber resins that comply with state and local VOC content limits. Also, the solvents used in chlorinated rubber coatings could lift and destroy previously painted and aged coatings of oil or alkyd base. More modern surface coating materials have rendered this treatment less common.

4.7—Chlorosulfonated polyethylene (hypalon)

Chlorosulfonated polyethylene elastomers have:

- a) Excellent resistance to ozone, heat, weathering, oxygen, oils, and other fluids
- b) Great colorability and color stability
- c) High tensile strength and abrasion resistance
- d) Excellent electrical insulating properties
- e) Low flammability characteristics once dried

Chlorosulfonated polyethylene elastomers can be cross-linked by peroxides, radiation curing, metal oxides, sulfur-bearing organic compounds, and epoxy resins (Ormonde et al. 2009).

Four coats of 2 mil (0.05 mm) each and an appropriate primer are normally recommended to eliminate pinholes. Thinning is not usually required, except for spray applications. The producer's recommended thinner should be used. Each coat dries dust-free, usually within 10 to 20 minutes, curing completely in 30 days at 70°F (21°C) and 50 percent relative humidity. A fill coat of grout or mortar is required because the paint film will not bridge voids in the concrete surface. Moisture on the surface could prevent good adhesion.

4.8—Vinyls and latex-based materials

Of the vinyls available, polyvinyl chloride, polyvinyl chloride acetate, and polyvinylidene chloride are used extensively in corrosion control. These resins are soluble only in strong solvents. Due to their high viscosity, only solutions of low solids content can be made. Multiple coats are therefore required for adequate film thickness. Vinyls should generally be sprayed onto dry surfaces. The rapid drying of many vinyl materials may make brush application difficult. Vinyl chloride coatings are good top coatings for vinyl chloride acetate and other concrete coatings, but do not adhere well directly to concrete. Polyvinyl acetate latex (waterborne) copolymers, which are also known as dispersions or emulsion polymers, are widely available as decorative coatings. Like other latexes, such as acrylic and SBR types, they are usually inferior to solvent-system coatings for chemical resistance. In addition, the vinyl acetate latexes (waterborne emulsions) are sensitive to the free alkalinity of concrete and eventually break down. Acrylic and SBR dispersion-based coatings range from brittle to elastomeric and can provide some limited protection to concrete from water-soluble contaminants.

4.9—Bituminous paints, mastics, and enamels

Asphalt or coal-tar coatings may be applied cold (paints and mastics in cutback or emulsion form) or hot (mastics and enamels). Two coats are usually applied to surface-dry concrete according to the producer's suggested coverage:

- a) A priming coat to ensure bond
- b) A finish coat

The priming solution is of thin brushing consistency and should be applied to cover the surface completely. Uncoated spots should be touched up. When the primer has dried to a tacky state, it is ready for the finish coat. Multiple coats should be applied at right angles to each other to ensure continuity and avoid pinholes. Emulsions are slower drying, more permeable, and less protective than other coatings. Cutbacks and emulsions, if not completely cured, can impart odor or flavor to materials. The producer's recommendations on service, UV exposure, and application temperatures should be strictly observed.

Bituminous mastics can be applied cold or heated until fluid. Cold mastics are solvent thinned (cutbacks) or emulsions containing finely powdered siliceous mineral fillers or bitumen-coated fabrics. They form a thick, pasty, fibrous mass that increases the coating's resistance to abrasion, flowing, and sagging at elevated temperatures. Multiple thin layers of mastic approximately 1/32 in. (1 mm) thick are troweled on and allowed to dry until the required thickness has been obtained. Hot mastics should be poured and troweled into place in layers 5/8 to 1 in. (16 to 25 mm) thick. Enamels should be melted, stirred, and carefully heated until they reach the required application temperature. Enamel heated above the producer's recommended temperature should be discarded. If application is delayed, the pot temperature should not be allowed to exceed 375°F (190°C). Because it sets and hardens rapidly, the fluid enamel should be applied quickly over tacky cutback primer.

4.10—Polyester and vinyl ester materials

Polyester resins are produced by condensation and polymerization of saturated and unsaturated acids and polyols. The esters formed can be reacted with unsaturated monomers such as styrene to form a three-dimensional network. Bisphenol-types are unsaturated polyester resins based on the reaction of bisphenol A, hydrogenated bisphenol A, or glycols derived from bisphenol A with fumaric acid or maleic anhydride. Halogenated types are normally made with materials including hexachloroendomethylene tetrahydrophthalic anhydride, tetra-bromophthalic anhydride, and other proprietary halogenated acids or glycols. The halogenated materials react with fumaric acid, maleic anhydride, or a glycol and fumaric acid to form the unsaturated polyester. Isophthalic acid types are unsaturated polyester resins based on the reaction of isophthalic acid and propylene or other glycols with fumaric acid or maleic anhydride.

These resins are usually mixed with styrene monomer to improve workability and lower viscosity to approximately 2.2×10^{-5} lb-s/in.² (0.15 Pa-s). Styrene also reacts chemically with polyester resin after the appropriate catalytic hardening or curing agents are added. Liquid resin is converted to a

solid by adding a peroxide initiator such as benzoyl peroxide and an accelerator—sometimes called a promoter—such as dimethyl aniline or cobalt naphthenate. Concentration of the initiator can usually be modified to change the rate of hardening; however, the producer's mixing instructions should be closely followed.

There are two conditions that could prevent polyester resins from hardening completely. Water will inhibit hardening of polyesters; therefore, when they are used, a primer insensitive to water should be applied to the concrete first. Air also inhibits the cure of some polyester, but is usually resolved by applying a final topcoat that contains paraffin or other wax. Wax rises to the surface and prevents direct contact between the polyester surface and air. Without wax in the topcoat, the surface will remain tacky.

These resin coatings are two- and three-part systems consisting of polyester, peroxide catalyst, and sometimes a promoter. The amount of initiator should be carefully controlled because it affects the rate of hardening. The catalyst and promoter are mixed separately into the polyester. Fillers, glass fabrics, or fibers used to reduce shrinkage and coefficient of expansion compensate for the brittleness of resin and increase its strength. Polyesters are usually silica-filled except for hydrofluoric acid service, which requires nonsiliceous fillers such as carbon (NACE SP0892).

Coatings with a 2- to 3-hour pot life generally cure in 24 to 36 hours at 75°F (24°C). Shorter curing periods require reduced pot life because of high heats of reaction. Coatings are sensitive to changes in temperature and humidity during the curing period. Some coatings can be applied to damp surfaces at temperatures as low as 50°F (10°C). The alkali resistance of certain polyesters is limited. Trained personnel should apply the coatings to avoid costly errors. Polyester and filler surfacings should conform to ASTM C722. Higher filler contents are discussed in 4.16. Vinyl esters are thermosetting resins produced by adding an unsaturated acid, such as methacrylic acid, to a polymeric backbone, which is usually an epoxy. Other vinyl esters can be prepared using polyester or urethane backbones and unsaturated acids. Epoxy vinyl ester is primarily used in corrosion protection. Bisphenol A epoxy vinyl esters are characterized by their broad chemical resistance, satisfactory adhesion to substrates, and high resilience. Novolac epoxy vinyl esters have excellent resistance to high-temperature acids and many solvents.

The properties of polyesters and vinyl ester resin that affect their use as coatings are shrinkage, thermal expansion, bond strength, and permeability. When a coating is applied to concrete that has a relatively low tensile strength, shrinkage, expansion, and adhesion can have a great influence on the range of applicability. Shrinkage during curing or from thermal changes can place stress proportional to the coating thickness on the concrete, which can cause fracture of the concrete surface (Nixon and Drisko 2001; Mei and Chung 2000). Thermal stress can build to the point at which it could fracture the concrete. Thermal cycling can also accelerate deterioration of concrete coatings due to stress caused by differences in the coefficient of thermal expansion between the concrete and the coating.

4.11—Polyurethane/urethane

Polyurethane coating, which is also known as urethane coatings, can be one- or two-part systems. They are formed through the reaction of a polyol with an isocyanate. A one-part system can be moisture-cured or oil-modified. Coatings that cure by reacting with the ambient moisture in the air should be used on dry surfaces and protected from contact with liquid water to prevent blistering or foaming during the curing period (*Adhesives and Sealants Council 2012*). Oil-modified coatings dry by air oxidation and generally have the lowest chemical resistance of the urethane coatings. Two types of the two-part system available are:

- a) Catalyzed (fast set)
- b) Polyol cured (slow set)

Catalyzed coatings have limited pot life after mixing and cure rapidly, ranging from a few minutes to an hour, depending on the formulation and environmental conditions (*Meier-Westhues 2007*). Elastomeric urethane topcoats have a quick chemical cure so they can be exposed to fog, rain, chemical splash, or immersion almost immediately after application. Overnight curing is recommended if the coating will be exposed to traffic in service. Several days of curing are required for high-impact or abrasive applications (*NACE SP0892-2007*). For polyol-cured coatings, the mixture is stirred well and allowed to stand for approximately 30 minutes before use, giving it a pot life of approximately 8 to 12 hours. Polyol-cured coatings are generally the most chemically resistant of the polyurethane coatings, but both application and durability properties are formulation dependent.

Two-component polyurethane elastomers are thermoset elastomeric coatings with distinct advantages over rigid floor surfacing. They adhere well to concrete and are flexible and nonshrinking. They can bridge small existing static cracks in the surface, although they typically require additional detailing. New cracks that form after application of the urethane coating often breach the system. The producer's specific recommendations should always be followed. Urethane coatings are easily applied by brush, spray, or roller. Rough or porous surfaces could require two coats. For immersion services in water and aqueous solutions requiring a primer, consult with the urethane producer. For spray-applied polyether polyurethanes, an epoxy coating applied to the surface closes pores before the polyurethane is applied (*Recker 1994*). Satisfactory cure rates of polyurethanes are attained at relative humidities of 30 to 90 percent and temperatures between 50 and 100°F (10 and 38°C). Lower temperatures retard the rate of cure. Follow specific product producer's guidance regarding exposure and immersion.

Aliphatic urethanes have very good abrasion resistance, color and gloss stability, and resistance to ultraviolet light (*NACE SP0892*). The urethane coatings require proper mechanical surface preparation recommended by the producer to ensure adhesion. Difficulty in recoating may be encountered unless the surface has been properly prepared by conventional cleaning and possibly solvent application according to the producer's recommendations. Multiple coats should be used and cracks or voids filled by a compat-

ible material if they are present on the concrete surface; the coatings are not able to span cracks or voids. Dilute solutions of urethane have been used as floor hardeners (*Mailvaganam 1991*).

Mixtures of polyols and amines may be reacted with isocyanates to produce polyurethane/polyurea hybrids. Properties of polyurethane and polyurea coatings range from high strength with relatively good chemical resistance and low flexibility to very flexible with reduced strength and chemical resistance. Aromatic-based polyurethanes may be extended with asphalt or coal-tar to reduce costs and increase water repellency. Aliphatic-based urethanes have better UV resistance than aromatic urethanes but are significantly more expensive. Elastomeric polyurethanes and polyureas are severely swollen by many solvents and are not recommended to contact these materials. In addition, these resins are not resistant to most concentrated acids and alkalis. Polyurethanes and polyureas are usually formulated into high-build, 100 percent solids, aggregate-free coatings that are often spray-applied.

Polyurethane cementitious hybrids are also used to provide chemical and abrasion protection to concrete surfaces. The coefficient of thermal expansion for some of these hybrid materials allows them to tolerate large thermal changes, such as steam cleaning in food processing areas, without delamination.

4.12—Epoxy

Epoxyes are durable and abrasion- and chemical-resistant, which makes them suitable for use as concrete coatings. Epoxyes are resistant to many chemicals and solvents, making them ideal candidates for severe environments. Epoxy coatings are not normally used when the service is highly acidic unless specially formulated for this type of service. Epoxy resins can be used with glass and other nonreactive fillers and fibers to provide dry film properties desirable as coatings for concrete. The dry film thickness should be within the range recommended by the producer.

The most commonly used epoxy resins for coatings are the reaction products of certain bisphenols and epichlorohydrin. These coatings may be formulated with diluents to lower viscosity and sometimes increase flexibility. The degree of chemical and heat resistance depends primarily on the combination of resin type and curing agents used. Multifunctional epoxy resins, such as novolacs, produce coatings exhibiting improved chemical and heat resistance.

Epoxy phenolics are epoxy coatings that have been modified with phenolic resins to improve general chemical and temperature resistance. The phenolic modification could result in a decrease in flexibility. Epoxy phenolics are normally used in areas subject to severe chemical spills and immersion service.

Epoxyes are characterized by lower cure shrinkage than most thermosetting resins. The expansion coefficient is approximately the same as for other thermosets and, in some cases, epoxy coatings withstand high-temperature service. Some mat-reinforced epoxy coatings have withstood short-term temperatures as high as 220°F (104°C) without loss of bond.

Epoxy coatings are generally a two-package system consisting of epoxy resin that can be formulated with flexibilizers, extenders, diluents, and fillers, and a curing agent. The coating properties are dependent on the epoxy resin and type and amount of curing agent used. There are three general classes of epoxy resin: bisphenol A, bisphenol F, and novolac, listed in increasing order of chemical resistance. Reaction of methacrylic acid with an epoxy produces a vinyl ester (4.10). The common curing agents suitable for curing are aromatic and aliphatic, including cycloaliphatic, amines, polyamines, amides, amidoamines amine adducts, polyamides, polysulfides, tertiary amines, and mannich bases. The polyamide-cured epoxies have less chemical resistance but better physical properties (NACE SP0892).

The single-package coatings are epoxy esters that are generally inferior to the two-package epoxies in chemical resistance. They require an alkali-resistant primer and are not recommended for immersion service. Epoxy formulations are either 100 percent solids or solution coatings. Water-based epoxies are designed for use as primers over damp or dry concrete as well as high-gloss topcoats. Solvent-based epoxies are often used as a first coat to penetrate and seal porous concrete. Multiple coats can achieve a dry film thickness of 20 mil (0.5 mm) (NACE SP0892). Two coats, and to a lesser extent one coat, 100 percent solids epoxy systems are frequently recommended as coating systems for concrete in aggressive environments (Society for Protective Coatings Cover 2006). The producer's recommendations should be followed in selecting the appropriate system for the protection needed.

Follow the producer's recommendations for the best application procedures, temperatures, and allowable working life. Epoxies are usually trowel- or roller-applied (NACE SP0892). Usually two coats are applied to eliminate pinholes, especially on rough or porous surfaces. Epoxy toppings can be low- or high-build and with aggregate added, they can be up to 1/4 in. (6 mm) thick (NACE SP0892). Epoxy liners may be formed with reinforcement, such as woven fabrics, mats, or chopped-glass fiber. Apply the epoxy coating with a roller to a film thickness of 10 mil (0.25 mm), spread the fabric over the wet epoxy coating, and press the fabric into it. A second epoxy coating is applied immediately to embed the fabric reinforcement. The surface should be sound and as much contamination as possible removed prior to coating (NACE SP0892).

There are epoxy systems that cure at temperatures as low as 40°F (4°C) single coat, but they require a relatively long cure time. There are epoxy systems that will bond to damp surfaces and will cure when flooded with water immediately after application. Water-based epoxy topcoats can be durable, give off little odor, and are safety oriented and easy to clean.

Epoxies will experience some chalking and yellowing with exposure to ultraviolet light, depending on the resin and curing agent type (NACE SP0892). Diluted epoxy solutions have been used as floor hardeners (Mailvaganam 1991). Contact with epoxy resins or hardeners can cause skin irritation or allergic reactions, so follow the producer's recommended protection. If skin contact occurs, use a dry towel

to wipe epoxy from the skin before washing with soap and water.

Epoxy-and-filler surfacings should conform to ASTM C722. Bond can be checked for adhesion using ASTM C882/C882M, ASTM D7234, and NACE SP0892. Epoxy overlays are used on bridge decks and parking decks (ACI 548.8).

4.13—Neoprene

Neoprene is a synthetic rubber chemically identified as polychloroprene that may be used either exposed or below other wearing surfaces. Neoprene does not have good resistance to strong alkalis or acids, chlorinated aromatic, and nitro hydrocarbons. Neoprene coatings can be one- or two-part systems. The one-part system is used as a thinner film than the two-part and generally has a lower chemical resistance. It cures slowly at room temperature, and some curing agents could limit its shelf life. The two-part system might require a holding period between mixing and application. To allow evaporation of water from the concrete, application of either system should not begin for at least 10 days after removal of the forms. Some coatings require primers while others are self-priming. Adhesion is often improved by application of a diluted first coat to increase penetration of the surface. Each coat should be sufficiently solvent-dry before the next application; however, if it becomes too fully cured, it could swell and lose adhesion. Three coats of 2 to 3 mil (0.05 to 0.08 mm) each are normally recommended to eliminate the possibility of pinholes. For immersion service, minimum dry thickness should be 20 mil (0.5 mm).

4.14—Polysulfide

Polysulfide coatings are formed from the co-reaction of thiol functional polysulfide resins initiated by metal oxides or peroxides. They typically have high flexibility and UV resistance but low strength. Alternately, epoxy/polysulfide hybrid coatings, formed by co-reacting with epoxy or epoxy and amine resins, usually have higher strength and improved adhesion, but reduced flexibility. Polysulfides are used to protect concrete from a variety of mild chemicals and are recommended for petroleum products. Polysulfides, like polyurethanes, are usually formulated into high-build, 100 percent solids, aggregate-free coatings that are often spray-applied. They have a mercaptan odor and are usually solvent-free, enabling high-build applications. Formulas might include fillers as described in 4.26.1. These coatings may be one- or two-part systems. They do not harden with age and remain rubbery over a broad temperature range. Thick coats of 20 to 25 mil (0.5 to 0.6 mm) can be applied at one time. For the one-part system, atmospheric moisture serves as the curing agent; when humidities are low, curing is hastened by fogging with a fine water mist. The two-part system usually has a pot life of 30 to 45 minutes and becomes tack-free overnight.

4.15—Coal tar and coal-tar epoxy

Coal tar is obtained from the destructive distillation of coal that is distilled to produce coal-tar pitches. These materials can be subsequently modified by additional processing or

adding additives, like the asphaltic types, to produce products of various consistencies ranging from thin liquids to heavy mastics, semisolids, or both. Coal-tar-based materials are of the hot- or cold-applied type. Cold-applied coal tar usually contains a solvent known as cutback. Coal-tar emulsions are also available.

The outstanding property of coal-tar pitch-based barrier products is their excellent water resistance. The outstanding property of coal-tar pitch-based barrier products is their excellent water resistance, even in dilute acids and alkalis. They normally do not support bacterial growth. In the hot-applied form or as a solvent cutback, they often form a series of cracks resembling alligator skin (known as alligator cracking) when subjected to weathering, which could limit the use of those particular types of products for above-ground exposure. Coal-tar emulsions, however, do have excellent atmospheric exposure characteristics. Some coal-tar solvents will impart objectionable taste and odor to potable water supplies, so coal-tar-based products should not be used for that purpose without specific recommendations of the producer for the specific application. Coal-tar-derived products may be elastomeric.

Coal-tar pitch derivatives such as cutbacks, emulsions, hot-applied enamels, epoxies, and urethanes, have been in common use in coatings for decades, especially in water-immersion applications. Coal tars are potential carcinogens and possibly severe skin irritants, especially at clothing contact points such as collars and belt lines. Coal-tar coatings, especially those removed by abrasive blasting, can produce a painful reddening of the skin, which occurs frequently in individuals with lightly pigmented or sensitive skin. All workers in the vicinity of coal-tar coating spray applications or abrasive-blast removal should use full-body protection and air-supplied respirators. Coal tar use has been severely restricted in recent years.

Coal-tar epoxy coatings are intermediate in properties between coal tar and epoxy, and are classified in three main types according to epoxy resin content:

- a) Type 1—High-resin coatings for dry thicknesses of 15 mil (0.4 mm)
- b) Type 2—Medium-resin coatings for integral linings of concrete pipe
- c) Type 3—Low-resin coatings for building nonsagging barriers up to 40 mil (1 mm) thick.

Type 1 requires a special primer and its thickness is achieved in two coats. Types 2 and 3 do not require primers. Coal-tar epoxy coatings are a two-package system.

A combination of coal tar, filler, solvent, and epoxy resin may be in one package and the curing agent in the other. Common to this package is amine, polyamine, amine adduct, polyamide, or tertiary amine. These two packages are usually mixed in a ratio of 20:1 or 10:1, although the ratio may be lower. The coal tar, filler, solvent, and curing agent may also be blended together to make one package and the epoxy resin kept separate from the other. The packages should be proportioned correctly to secure proper cure and chemical resistance. Storage life of the blends can vary from 6 months to 2 years, depending on formulation. Make sure

the two packages are thoroughly mixed using power agitation. Mixing small quantities is not advisable. Insufficient mixing is revealed only after the coating has cured. For some coatings, a 30-minute waiting period between mixing and application is desired.

Pot life is generally 3 to 4 hours at 70°F (21°C), but it may vary from several minutes to 8 hours, depending on solvent content and formulation. Some coal-tar epoxy coatings should not be applied at temperatures below 50°F (10°C) or if in danger of becoming wet within 24 hours of application. Although spray applications generally result in better coverage, the sides of a short, stiff bristle brush or a long-nap roller can be used. The second coat should be applied within 48 hours to prevent adhesion problems between coats. If the first coat dries at air temperatures above 75°F (24°C), the producer's maximum recommended time between coats should be observed. Usually these coatings are not put into service until a minimum of 5 days of curing time has elapsed. Coal-tar epoxies are less commonly used today due largely to health concerns over long-term exposure and direct contact by coating applicators to the tar. Cleanup and disposal require special precautions to comply with local, state, and federal regulations.

4.16—Chemical-resistant masonry units, mortars, grouts, and concretes

The chemically-resistant brick barrier is made up of two major components. The primary protective barrier is a chemical-resistant material applied directly to the concrete substrate. The brick with chemical-resistant mortar joints is then applied over the barrier. Because the brick and mortar joints might develop cracks, their primary function is to protect the relatively fragile barrier from damage caused by mechanical abuse and excessive temperature. It is common practice to have a layer of either coating, sheet good, or overlay against the substrate concrete that then may be covered with another layer of chemically-resistant brick or tile that is then grouted with an appropriate material. A coating is essentially a type of barrier that is fluid-applied and bonded to the substrate. A mechanical barrier may or may not be bonded to the substrate and may or may not be supplemented with a fluid-applied bonded material. Overlays can be considered comparatively thick field-applied barriers. Chemical-resistant masonry units, mortars, grouts, and concretes may work for most situations from a mechanical and protection viewpoint; however, weight, dimensional tolerances, and cost consideration may lead to selection of a coating in many environments.

Service temperature and mechanical loading determine thickness of the brick. There are three types of chemical-resistant brick used for this type of barrier.

Chemical-resistant brick and tile are usually solid, kiln-fired masonry units made from clay, shale, or mixtures used for masonry construction. Units can also be made from carbon (ASTM C1106), graphite, or other materials where additional chemical resistance is required. Chemical-resistant brick and tile should conform to ASTM C279. Three types of masonry units are:

1) Type I (formerly Type H) for locations where low absorption and high acid resistance are not required

2) Type II for locations where low absorption and high acid resistance are required

3) Type III (formerly Type L) for locations where minimum absorption and maximum acid resistance are required

ASTM C279 does not specify the composition of the brick, as it will differ depending on the source of the raw materials used to manufacture the brick. The standard does define certain physical properties to which the brick should conform, including strength, water absorption sizes, warpage, and surface texture. Other important properties are porosity, iron content, and thermal shock resistance.

Porosity is a function of the material, like fireclay or red shale, and the method of manufacture. A higher porosity implies that it is easier for liquid to penetrate the brick. A brick with low porosity is therefore more desirable because it minimizes migration of acid to the shell of the vessel. There are some cases where higher porosity is desirable, such as high temperature applications, where brick porosity helps the brick to resist spalling from thermal shock by allowing it to absorb dimensional changes more easily.

Iron content of the brick is an important factor when selecting brick type. Acid absorbed by the brick will react with any iron present to form iron sulfate. The volume of iron sulfate is six to seven times that of iron, resulting in spalling or flaking to the brick surface. The typical iron content of red shale brick can be as high as 7.5 mass percent compared to an iron content of only 1.5 mass percent for clay brick.

Brick spalling can be the result of severe temperature cycling attack, chemical attack, or both. If fluorides are present, they contribute to weakening of the brick leading to spalling of the brick surface.

Thermal shock of the brick can occur when a dry area of brick work is exposed to high-temperature gas that is suddenly cooled by contact with the colder acid. Brick will eventually spall when exposed to these conditions over a long period of time.

Chemical-resistant industrial floor brick should conform to **ASTM C410**. ASTM C410 Type H brick is used where chemical resistance is a service consideration but low absorption is not required. ASTM C410 Type L brick is used where minimal absorption and high chemical resistance are required. Although highly abrasion resistant, Type L brick usually has limited thermal and impact resistance.

A bed of mortar and an impervious membrane lining are usually placed between the masonry lining and concrete. Rubber and vinyl sheets or properly primed and hot-applied 3/8 in. (10 mm) thick asphaltic materials, both plain and glass-cloth reinforced, are preferred for the membrane lining, depending on the corrosive substance. The primer should conform to **ASTM D41/D41M**, but should have high solids content. Floor slabs receiving a masonry lining should have a smooth wood-float finish. A slab having a steel-trowel finish might be too smooth for adhesion of the asphaltic membrane.

Monolithic surfacings, which are often called coatings, toppings, or thin overlays, can also be made with the base materials of cement or resin in 4.16.1 through 4.16.12. Many surfacings, such as epoxy and polyester, are discussed in previous sections. They are used without masonry units to cover a concrete surface. Epoxy, polyester, and other resin and filler monolithic surfacings should meet the requirements of **ASTM C722**.

Chemical-resistant mortar or grout should be used to fill the joints between chemical-resistant brick or tile and will also influence the chemical resistance of the lining. Mortars are troweled on the sides and bottom, or faces to be bonded, of the brick to approximately 1/8 in. (3 mm) thickness before the brick is placed. Grouts are usually applied to joints, approximately 1/4 in. (6 mm) wide, after the masonry units are set in place on the floor. The chemical resistance of mortars or grouts can be evaluated using **ASTM C267** test methods. The most commonly used mortars or grouts are as follows.

4.16.1 Asphaltic and bituminous membranes—For use over a limited range of low temperatures, some are sand filled and can be applied as mastics that depend on evaporation of solvent or as hot-melt compounds. The membrane is usually applied in two coats with a reinforcing fabric between them. Each coat may then be covered with chemical-resistant masonry units and grouted with an appropriate material for the application.

4.16.2 Epoxy-resin mortars or grouts—Two- or three-part systems with amine or polyamide curing agents that should conform to **ASTM C395** or **ASTM C658**. For instructions on their use, refer to **ASTM C399**, **ASTM C723**, or **ASTM C881/C881M**.

4.16.3 Furan-resin mortars or grouts—These mortars or grouts should conform to **ASTM C395** or **C658**. A membrane of 1/16 to 1/4 in. (1.5 to 6 mm) in thickness is applied to concrete and then a furan mortar is used as a bond coat or bed joint. Furan-resin mortars have the broadest range of resistance of all resin mortars to both acid and alkali (pH 0 to 14) and temperatures up to approximately 425°F (220°C) (**Mailvaganam 1991**). For instructions on their use, refer to **ASTM C399** or **C723**.

4.16.4 Hydraulic-cement mortars or grouts—These include the use of portland, blended, and calcium aluminate cements. For instructions on their use, refer to **ASTM C398**.

4.16.5 Phenolic-resin mortars—These mortars should conform to **ASTM C395**. For instructions on their use, refer to **ASTM C399**.

4.16.6 Polyester-resin mortars—These mortars should conform to **ASTM C395**. General-purpose isophthalic resin systems have limited resistance to strong chemicals, but will withstand mildly oxidizing solutions such as bleaches. Other available polyesters are highly chemical resistant, even to strong acids. For instructions on their use, refer to **ASTM C399**.

4.16.7 Silicate mortars—These mortars should conform to **ASTM C466**. For instructions on their use, refer to **ASTM C397**.

4.16.8 Sulfur mortars—These mortars should conform to **ASTM C287**. For instructions on their use, refer to **ASTM C386**.

4.16.9 Vinyl ester-resin mortars—These mortars should conform to [ASTM C395](#). For instructions on their use, refer to [ASTM C399](#).

4.16.10 Sulfur concretes—These should conform to [ASTM C1159](#). A typical mixture design by weight is 38 mass percent coarse aggregate, 38 mass percent fine aggregate, 8 mass percent mineral filler, and 16 mass percent sulfur cement ([McGovern 1992](#)).

4.16.11 Polymer-cement concretes, mortars, and latex-modified materials—The polymer should conform to [ASTM C1438](#) and [ASTM C1159](#). Latex-modified concretes that use styrene butadiene polymer are discussed in [ACI 548.4](#). Much of the instruction in [ACI 548.4](#) is relevant to the use of similar materials in protective systems. Acrylic copolymers may also be added to portland-cement mortars and concretes in breathable overlay systems.

4.16.12 Silicate-based concretes—Class F fly ash or other pozzolan, silicate solution, and an alkaline activator are the most commonly used cementitious materials ([Oswald 1998](#)). These materials are also known as geopolymers. Depending on composition and degree of curing, a wide range of chemical resistance is possible, including acid, alkali, and thermal resistance. Specific chemical resistance should be determined for a given composition and an installation method with an acceptable degree of permeability of the aggressive agent verified.

4.17—Sheet rubber

Soft natural and synthetic rubber sheets 1/8 to 1/2 in. (3 to 13 mm) thick may be cemented to concrete with special adhesives. Sometimes two layers of soft rubber are used as a base, with a single layer of hard rubber over them. Chemical-resistant synthetics available as sheeting are neoprene, polyvinylidene chloride-acrylonitrile, plasticized polyvinyl chloride, polyisobutylene, butyl, nitrile, polysulfide, and chlorosulfonated polyethylene rubbers. Specific chemical resistance depends on the composition of the rubber sheet.

4.18—Resin sheets

Synthetic resins, particularly polyester, epoxy, and polyvinyl chloride, are available as sheet materials. These sheets are not referred to in the guide for selecting protective treatments, but may be used wherever comparable resin coatings are recommended. They are often glass-fiber reinforced and may be cemented to concrete with special adhesives. Types of resin sheets include acrylic, polyethylene and polypropylene, polystyrene, polyvinyl chloride, ABS, fiberglass-reinforced plastic, and polycarbonate. Specific chemical resistance depends on the resin sheet composition.

4.19—Lead sheet

In the United States, lead sheet used for chemical resistance is called chemical lead. The sheets should be as large as possible to minimize the number of joints, but not too heavy to handle; the thinnest sheet can be as large as 8 x 20 ft (2.5 x 6.0 m). Thicknesses range from 1/64 to 1/2 in. (0.4 to 13 mm). Lead may be cemented to concrete with an asphaltic paint or other suitable adhesive resin. Each sheet

should be overlapped and the seam welded by conventional lead-burning techniques. If the lead is subjected to high temperatures, it can be covered with chemical-resistant masonry to reduce thermal stresses.

4.20—Glass

Two types of glass have been used for corrosion resistance—high-silica and borosilicate. Borosilicate glass, the more alkali-resistant material, is recommended because alkalis in concrete can cause glass etching. Glass may be cemented to the concrete using adhesive resins. Thermal shock or impact is often the cause of failure in glass-lined structures.

4.21—Acrylics, methyl methacrylate (MMA), and high-molecular-weight methacrylate (HMWM)

Methyl methacrylates, acrylic polymers, and their modified forms are often applied with squeegees and rollers to concrete to reduce water, chloride-ion, and chemical ingress. They are often used on bridge and parking garage surfaces and architectural concrete. Pure methyl methacrylate systems can be made impermeable or breathable, depending on their formulation.

Much of the instruction in [ACI 548.10](#) is relevant to the use of similar materials as overlays in protective systems. The guidelines of the producer of the material should be followed for required surface preparation. Some formulations are considered both penetrating and crack-repairing. Specialty MMA and HMWM materials are used to flow into and seal substrate cracks. The recommendations of the producer of these specialty materials for surface preparation and crack widths that are appropriate should be followed. Methacrylates are often used in conjunction with nonskid aggregate. Some acrylic formulations are solvent-free, so they experience less shrinkage on curing than solvent-based formulations. Acrylic dispersions and water-based copolymers are discussed in 4.16.12.

Varying the formulations allows for either flexible or hard materials. Some acrylics can be used at temperatures as low as 14°F (−10°C) and cure very quickly at low temperatures ([Mailvaganam 1991](#)). Depending on the porosity of the concrete, penetration depths range from approximately 0.25 in. to greater than 3 in. (6 mm to greater than 80 mm), and full depth penetration of even very fine cracks is possible.

4.22—Silane, siloxane, and siliconates (organosilicon compounds)

Alkyltrialkoxysilanes are composed of an alkyl group that serves as a water repellent and three alkoxy groups for chemical reactivity and bonding, all joined to a silicon atom. The alkyl group can vary from very short, methyl or ethyl, to a longer linear or branched octyl group. The chain length and degree of branching determines the compound's resistance to degradation in an alkaline environment, as well as its ability to repel water. Because alkyltrialkoxysilanes are some of the smallest silicon-based compounds, they tend to penetrate the substrate better than larger siloxanes or polydimethylsiloxanes resins. When treating dense

substrates, such as precast or glass fiber-reinforced concrete, this is advantageous. With more porous materials, such as lightweight concrete masonry units, it could prove to be a disadvantage.

Siloxanes are essentially oligomers, or short chains of silanes, though not manufactured from silanes. As with silanes, they have two different functional groups—silicone and organic—attached to a silicon-oxygen chain. The alkyl groups present on a siloxane could be the same, all ethyls, or could be mixtures such as methyls and butyls. Again, chain length and degree of branching determines some critical performance characteristics. Siloxanes are larger than silanes and tend not to achieve the depths of penetration that silanes will. This can be advantageous on a porous substrate, but cause darkening on a much denser material.

Polydimethylsiloxanes are silicone resins, which cross-link upon contact with moisture to form an elastomeric film. Varying in structure (linear or branched) and molecular weights (size or length), these compounds are much larger in size than a silane or siloxane. Due to their size and relatively few silicon-functional reactive sites, they work best when a cross-linking agent, such as a silane, is incorporated into the product.

Methyl siliconates are water-soluble salts of methyl silanes. These products are formed when methyltrichlorosilane reacts with sodium (or potassium) hydroxide. They chemically bond with silica-containing materials through a reaction with carbon dioxide. Bonding to the substrate occurs slowly in comparison to that of other reactive penetrants because of the small amount of carbon dioxide in the atmosphere. The reaction slows even further in alkaline environments, such as concrete or concrete masonry. For this reason, siliconates are not recommended as sealers for concrete substrates.

Silanes and siloxanes also chemically bond with siliceous materials, attaching a hydrophobic hydrocarbon, the alkyl group, directly to the substrate. The presence of this alkyl group reduces the surface tension of the substrate to a point where it is below the surface tension of water. When this occurs, water cannot wet-out the substrate and, in the absence of continual hydrostatic pressure, will not penetrate into the masonry or concrete. These materials provide no protection against hydrostatic pressure.

The effectiveness of silanes or siloxanes depends on the type of alkyl group in size and branching, the molecular weight, and the reaction rate and surface tension of the silane/siloxane liquid. Silanes that use shorter alkyl chains, such as the methyls and ethyls, tend not to resist alkaline degradation as well as longer alkyl groups. Their small size makes them inefficient water repellents in any environment. Longer chains, such as octyls, and branched chains, such as isobutyls, have much better resistance to alkaline degradation and can provide superior water repellency. This relationship between the alkyl group and efficacy also holds true for alkylalkoxysiloxanes. It is critical that silane and siloxanes penetrate the substrate when durability is required, such as in horizontal applications. The surface layer, only a few molecules thick, could be degraded by UV light or abraded

away. Concrete provides a measure of protection to the silane/siloxanes as much as they do the concrete. Penetration depends on the coverage rate, solvent type, molecular structure in size and reactivity, viscosity, and the presence of catalysts in the formulation. In general, silanes penetrate to greater depths than siloxanes do.

The most commonly used organosilicon compounds are silane, siloxane, and mixtures of the two. They are available in 100 percent active, solvent- or water-borne formulations. Silane- and siloxane-based materials are single-component penetrating materials commonly used to reduce chloride ion and moisture ingress to concrete bridges and parking garages, thereby reducing corrosion of reinforcing steel. They are also used to reduce water permeance on concrete and concrete masonry. They might offer some protection to concrete in sulfate exposures (Stark 1997, 2002). Water repellents could contain a carrier, such as alcohol, and can be classified according to their active ingredient content by weight, up to 100 percent. Performance usually increases with an increase in solids content; however, higher percentages of active ingredients might darken the concrete. Siloxanes are less volatile than silanes, which results in less loss of active ingredient during application. Siloxanes, therefore, are usually used with a lower percentage of active ingredient than silanes.

Silanes and siloxanes are applied with low pressure—15 to 30 psi (100 to 200 kPa)—typically at a rate of 100 to 150 ft²/gal. (2.5 to 3.7 m²/L). They can be applied with brush, roller, or pump-up or airless sprayer. Silanes and siloxanes are breathable materials that allow water vapor to pass through concrete. They usually do not discolor concrete and have no effect on the coefficient of friction—two advantages to their use.

Silanes do require more care during application; they can evaporate under hot or windy conditions, reducing the surface levels and thereby decreasing the effectiveness of the treatment. Siloxanes are heavier, and even warm ambient temperatures or high winds have little effect on the amount that remains on the surface. Siloxanes tend to penetrate less deeply than silanes into concrete, partially because of molecular size. Individual products vary in performance.

Silane penetration depth and waterproofing effectiveness improve as the permeability and water-cementitious material ratio (w/cm) of the concrete decreases. Silanes do not require dilution with alcohol; 100 percent silanes without carrier penetrate better and can be more effective sealers than 40 mass percent silane sealers. Surfaces can be retreated with silane; the penetration depth generally improves if the concrete has had sufficient time to dry (Carter 1994). Salt-exposed concrete of high quality should have increased service life when sealed with 100 percent silane materials. Silanes are not the best choice for concrete subjected to prolonged submerged conditions in the presence of freezing and deicing chemicals. Because these water repellants do not form films, they provide limited protection to existing, narrow, partial-depth cracks, and no protection to cracks that form after application. Cracks formed after the water repellent is applied allow water to penetrate through the treated substrate.

4.23—Metalizing

Corrosion-resistant metals can be applied to concrete surfaces by using flame- or arc-spray techniques. The flame-spray process melts the metalizing wire with a combustible gas, and compressed air atomizes the molten metal and projects the metal spray onto the prepared concrete surface. The liquid metal is impinged on the concrete and cools. After cooling, the metal can be ground, polished, and finished as desired.

Thermal-arc spraying uses an electric arc to melt the metalizing wire. The molten metal is then blown onto the concrete surface by compressed air to form the metal coating. Aluminum, copper, bronze, stainless steel, chrome, nickel, monel, tin, zinc, and other metals and alloys can be used. Ceramics such as zirconium oxide can also be applied. The most common metalizing process used for concrete is to surface deposit zinc, aluminum, or other alloys for galvanic cathodic protection. The deposited metal is connected to the reinforcing steel imbedded in the concrete and sacrificially corrodes to protect the steel. [AWS C2.20/C2.20M](#) is a reference specification for this process. Thermal spray zinc has also been used to control zebra mussel accumulation in marine environments.

Metalizing using other materials to provide a barrier coating is less common, primarily due to cost and difficulty achieving an intact film over the porous concrete.

4.24—Crystalline coatings and admixtures

Crystalline modifications of concrete, either as a coating system or admixture, add the same protective mechanism to concrete. In both systems, a chemical is added to the cement matrix that promotes the development of additional gel or other precipitate within concrete voids. Coating systems rely on prewetting the substrate concrete followed by chemical diffusion to the pore water. Admixtures are an addition of similar chemicals to the wet concrete with sufficient mixing to ensure homogenous distribution of chemicals throughout the concrete prior to pouring.

Coatings are applied by brush or low-pressure sprayer. A minimal surface profile is usually required. The substrate concrete should be saturated surface-dry and coatings misted for several days to be kept moist during the initial diffusion period. Although the crystal structure does not fully block pores, microcracks, or macrocracks, it does waterproof the concrete by making the pathway for liquid water through the pore structure of the concrete so torturous that liquid water is not able to pass, slowing the ingress of water-borne deleterious substances to the concrete. This crystallization process is also reported to heal small cracks; these treatments, however, are not flexible. Most crystalline protective systems apparently slow the surface attack of concrete from mildly aggressive liquids, including weak acids, but cannot stop it as they are not surface barrier systems.

Several manufactures of crystalline waterproofing chemicals exist. All producers' formulations are proprietary, so it is recommended to test each product to substantiate the waterproofing and chemical protection properties of a specific material.

While crystalline modification of concrete will not fully protect it from attack of high- or low-pH liquids, it is often a second level of defense below a topical barrier system.

4.25—Polyurea

Polyurea is a similar coating to polyurethane. Polyurea normally uses polyamines, such as an amine-terminated polyether ester, to react with isocyanates and therefore does not require a catalyst. Polyurea is distinguished by its extremely fast gel time, which can be as low as 3 seconds for a quick-setting polyurea. As a result of rapid set time, polyurea coatings are less sensitive to moisture and humidity and can be applied in conditions of high ambient humidity. Bond to the substrate, however, may be impeded by the rapid-setting polyurea materials. It is recommended that bond to the substrate be evaluated to confirm bond strengths are in compliance with producer's and specifier's requirements. They should not, however, be applied to fresh concrete. Although trapped moisture will not react with the coating as it sets, it will impair adhesion and ultimately lead to coating failure. Polyurea coatings tend to have a very limited pot life and their recoat time becomes a problem in cases when multiple coats occur ([Kenworthy 2003](#)). Polyurea systems can require heated application equipment to reduce viscosity of the components. A variety of aromatic, aliphatic, and single-component systems are available. The bulk of polyurea material is two-component. High heat-of-deflection temperature and a wide range in glass transition temperature makes this elastomer utilitarian in coating at low temperatures and where service requires heat resistance to 350°F (177°C). Joint sealant, joint filler, repair material, and coating systems are available. Polyurea contains no solvents, diluents, or plasticizing agents. Polyurea can be VOC-compliant and has excellent resistance to most common hydrocarbons and a wide range of corrosive attack between pH 4 and 12. Shrinkage is experienced with spray systems due to material cooling from normal installation temperatures in excess of 160°F (71°C). Colored pigments may be added. Polyurea may be reinforced and nonskid aggregates incorporated with the material. Nonskid is often achieved for traffic-bearing applications by stippling the product, which is a spray technique. Polyureas can be applied in extreme conditions of humidity and temperature and will cure at temperatures as low as -4°F (-20°C) ([Kenworthy 2003](#)).

Polyureas are thermoset coating and lining systems used in concrete protection. They are typically plural component (two-part) systems derived from the reaction of a modified isocyanate component and a resin-blend component of formulated amine-terminated resins. These systems, considered autocatalytic, do not require use of a catalyst.

They can be aromatic-based, which are not color-stable, or aliphatic-based, where color- and gloss-retention are observed in UV exposure. Due to a quick reaction gel and set times (3 to 20 seconds), polyurea systems are commonly applied using high-pressure, high-temperature plural-component equipment fitted with impingement mixture spray guns. Some slower-set polyurea systems are applied using plural-component, low-pressure, static mixture

delivery. Both the high- and low-pressure-processed polyureas are designed for thick film application—for example, 10 to 125 mil (250 to 3.2 μm) or thicker—and might not contain solvents or VOCs. Slower polyurea systems are also common for decorative application work or topcoats and are commonly called polyaspartic polyureas. These systems typically contain solvents and are applied by spray, brush, roller, or squeegee at a film thickness of approximately 10 mil (250 μm). While sometimes compared to polyurethanes, polyurea systems have similar characteristics but noted faster cure (faster return to service), higher thermal resistance, and are more hydrolytically stable. Polyureas can be applied in extreme conditions of humidity and temperature as compared to polyurethanes, and will cure at temperatures as low as -4°F (-20°C) (Primeaux 1989). Due to the fast set and cure, a penetrating primer system is usually suggested for concrete applications to ensure performance.

4.26—Adjunct additives

Additives, reinforcements, and fillers can be added to most resin systems. These are adjuncts to the binder and are excluded in the tables as an alternative method.

4.26.1 Fillers—Second only to the resin system, the choice of reinforcing filler is critical to establishing the desired low permeability and mechanical properties required of the coating. Fillers reduce shrinkage and promote a coefficient of thermal expansion that more closely approximates that of concrete, thereby reducing stress at the interface of the two surfaces. Fillers are also selected to enhance handling and application properties. The choices are numerous, but selection can be limited to a few broad categories such as geometry, size, and chemical resistance. Spherical or particulate fillers or aggregates are some of the best known resin modifiers. Those in wide use are based on crushed silica or washed and dried silica sands. In addition to silica, particles based on carbon, aluminum oxide, zirconium oxide, silicon carbide, glass beads, or any of a number of naturally occurring corrosion-resistant minerals could lend unique properties to the composite.

Aside from the reinforcement and permeation resistance imparted by fillers, some materials provide special chemical-resistance or electrical conductivity. For example, most silicates, including glass, can be chemically attacked by hydrofluoric acid and strong alkalis, whereas aluminum oxide has good resistance at operational temperatures lower than 160°F (71°C), and carbon fillers are virtually inert.

Carbonaceous fillers are also useful in applications involving sodium hydroxide or strong oxidizing agents. Strong crystalline structures in aluminum oxide, silicon carbide, and zirconium oxide also find applications in abrasion-resistant composites.

4.26.2 Reinforced coatings—Fibers are known to be among the best reinforcing fillers. They occur naturally in many mineral forms or as the product or by-product of a synthetic operation. Corrosion-resistant glass fibers are available in several forms, including woven fabrics, randomly oriented chopped-strand mat, or as independent short fibers. Because of their reinforcing quality, fiber

selection plays a key role in enhancing the mechanical properties of the coating. Inclusion of the chemically-resistant woven fabric increases the strength of the composite, lowers the thermal expansion, and helps to distribute localized stresses due to minor crack movements in concrete substrates. Multiple-layer application also ensures the best resistance to pinholes.

Fabric-reinforced coating can be based on epoxy, polyester, or vinyl ester resin, filled with silica or carbon, and reinforced with either fiberglass or synthetic fabric. The reinforcement layer is normally placed between two layers of filled resin. This type of coating normally consists of three layers: a trowel-applied filled base coat, a resin-saturated reinforcement layer, and a trowel- or spray-applied filled topcoat.

Another general coating design involves the use of chopped-strand mat as the primary reinforcement. This type of coating simulates inner construction and chemical resistance of an all-fiberglass tank. Typical specifications include one or two layers of chopped strand mat, which can be sealed with a resin-saturated chemical-grade surface veil or pure resin. A significant improvement in the performance of mat-reinforced coatings is the inclusion of a silica-filled resin basecoat. This basecoat contributes to a substantially lower permeation rate that enables the mat to be easily supported on walls and ceilings. Better continuity is achieved between the mat layers and the often-rough concrete surface, because mat layers are somewhat rigid and do not easily conform to an irregular contour.

4.26.3 Flake-filled coatings—These composites are generally filled with 5 to 40 mass percent flakes by weight, depending on the size and aspect ratio of the flake. These coatings are either spray- or trowel-applied in at least two coats with a final thickness of 25 to 150 mil (0.64 to 3.8 mm), depending on the type of service. Glass and mica are the most common flakes in use, although graphite also finds some applications requiring HF-resistance or electrical conductivity.

CHAPTER 5—REFERENCES

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ACI 201.2R-08—Guide to Durable Concrete

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ACI 548.8-07—Specification for Type EM (Epoxy Multiple-Layer) Polymer Overlay for Bridge and Parking Garage Decks

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As ACI begins its second century of advancing concrete knowledge, its original chartered purpose remains “to provide a comradeship in finding the best ways to do concrete work of all kinds and in spreading knowledge.” In keeping with this purpose, ACI supports the following activities:

- Technical committees that produce consensus reports, guides, specifications, and codes.
- Spring and fall conventions to facilitate the work of its committees.
- Educational seminars that disseminate reliable information on concrete.
- Certification programs for personnel employed within the concrete industry.
- Student programs such as scholarships, internships, and competitions.
- Sponsoring and co-sponsoring international conferences and symposia.
- Formal coordination with several international concrete related societies.
- Periodicals: the ACI Structural Journal and the ACI Materials Journal, and Concrete International.

Benefits of membership include a subscription to Concrete International and to an ACI Journal. ACI members receive discounts of up to 40% on all ACI products and services, including documents, seminars and convention registration fees.

As a member of ACI, you join thousands of practitioners and professionals worldwide who share a commitment to maintain the highest industry standards for concrete technology, construction, and practices. In addition, ACI chapters provide opportunities for interaction of professionals and practitioners at a local level.

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Guide to Selecting Protective Treatments for Concrete

The AMERICAN CONCRETE INSTITUTE

was founded in 1904 as a nonprofit membership organization dedicated to public service and representing the user interest in the field of concrete. ACI gathers and distributes information on the improvement of design, construction and maintenance of concrete products and structures. The work of ACI is conducted by individual ACI members and through volunteer committees composed of both members and non-members.

The committees, as well as ACI as a whole, operate under a consensus format, which assures all participants the right to have their views considered. Committee activities include the development of building codes and specifications; analysis of research and development results; presentation of construction and repair techniques; and education.

Individuals interested in the activities of ACI are encouraged to become a member. There are no educational or employment requirements. ACI's membership is composed of engineers, architects, scientists, contractors, educators, and representatives from a variety of companies and organizations.

Members are encouraged to participate in committee activities that relate to their specific areas of interest. For more information, contact ACI.

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