

IV. ORGANIC CHEMICALS AND FUELS

Zinc is used in contact with many organic chemicals during the handling, packaging, and storage of commercial products. Many organic liquids are inert in contact with zinc. Table 5.5 gives a guide to some that have been stored successfully in galvanized containers and are even more likely to be satisfactory in contact with sheet zinc or with castings in zinc or ZA alloys. Interpretation of test results requires care since, although total corrosion may be small, either the resultant contamination of the liquid may be unacceptable or small amounts of solid zinc corrosion products may cause problems (e.g., by preventing the free action of valves in a circulating system). Corrosion may arise when material is moist or water is present as a contaminant in the liquid.

Table 5.6 summarizes the results of a comprehensive evaluation of the behavior of galvanized steel in contact with synthetic organic chemicals. These data, furnished through the cooperation of the Union Carbide Corporation, Chemicals Division, are the results of Union Carbide's evaluation of materials for storage and packaging of the synthetic organic chemicals they produce or supply.

The tests were on hot dip galvanized steel strips exposed to commercially pure chemicals in stoppered bottles for a minimum of 100 days at ambient temperature with part of the sample being fully immersed and part exposed to vapors; the compatibility (i.e., the effect of contact with zinc on the chemical properties of the test chemical) is observed. In Table 5.6, most of the chemicals listed are rated as less than 13 $\mu\text{m}/\text{year}$ (<0.5 mm/year), which was regarded as low enough to show that zinc is compatible with the chemical involved; further investigation may be necessary to determine whether the rates were in fact much lower and the chemical suitable for use with relatively thin zinc coatings.

Relatively few organic chemicals in the group are rated as unsuitable for use in contact with zinc.

Information on organic chemicals from other tests is given in Table 5.7. The corrosion of zinc in primary alcohols has been studied by Heitz et al. (1970) in relation to alcohol chain length.

Air entrapped during encapsulation and vapor from polymeric materials such as epoxy resin can cause corrosion. The corrosive effect of vapors from plastics, rubber, and wood on zinc and cadmium has been tabulated by Knotkova-Cernakova and Vickova (1971); other work, including electroplated zinc-nickel alloys, has been discussed by Donovan and Stringer (1971).

Also, at 85°C and 95% relative humidity, zinc can deteriorate in contact

Table 5.5 Some Chemicals That Have Been Successfully Stored in Galvanized Containers

Hydrocarbons	Esters	Butyl	Amines and amine salts
Benzene (benzole)	Allyl	butyrate	Pyridine
Toluene (toluole)	butyrate	isobutyrate	Pyrolidine
Xylene (xylene)	caproate	caproate	Methylpiperazine
Cyclohexene	formate	propionate	Dicarbethoxypiperazine
Petroleum ethers	propionate	succinate	1-Benzhydryl-4-methylpiperazine
Heavy naphtha	Ethyl	titanate*	2:4-Diamino-5-(4-chlorophenyl-6-ethylpyrimidine)
Solvent naphtha	butyrate	Propyl	Hydroxyethylmorpholine (hydroxyethyl-diethylenimine oxide)
Alcohols	isobutyrate	butyrate	<i>p</i> -Aminobenzenesulfonyl-guanidine
Methyl paralytol (methyl pentynol)	caproate	isobutyrate	Butylamine oleate
Morpholinoisopropanol	caprylate	caproate	Piperazine hydrochloride monohydrate
Glycerol (glycerin)	propionate	formate	Carbethoxypiperazine hydrochloride (dry)
Halides	succinate	propionate	Amides
Carbon tetrachloride	isobenzate	isobenzate	Formamide
Amyl bromide	Butyl	Butyl	Dimethylformamide
Butyl bromide	butyrate	butyrate	Miscellaneous
Butyl chloride	isobutyrate	caproate	Glucose (liquid)
Cyclohexyl bromide	caproate	isobenzate	Benzilideneacetone
Ethyl bromide	caprylate	Propyl	<i>p</i> -Chlorbenzophenone
Propyl bromide	Methyl	caproate	Sodium azobenzenesulfonate
Propyl chloride	butyrate	formate	Melamine resin solutions
Trimethylene bromide (1,3-dibromopropane)	propionate	propionate	Crude cascara extract
Bromobenzene	succinate	Cyclohexyl butyrate	
Chlorobenzene	Benzyl	Phenols	
Aroclors and Pyroclors (chlorobiphenyls)	butyrate	Phenol	
Nitriles (cyanides)	isobutyrate	Cresols (methylphenols)	
Diphenylacetonitrile	propionate	Xylenols (dimethylphenols)	
<i>p</i> -Chlorobenzoyl cyanide	succinate	Biphenol (dihydroxybiphenyl)	
	Octyl	2,4-dichlorophenol	
	butyrate	<i>p</i> -chloro- <i>o</i> -cresol	
	caproate	Chloroxylenols	

*And other unspecified titanates.
Source: Galvanizers Association.

able 5.6 Corrosion of Galvanized Steel in Contact with Organic Chemicals

ecimens of galvanized steel partially immersed in commercially pure test chemicals at ambient perature for a minimum of 100 days; corrosion rate based on total area of specimen.

Corrosion rate		Corrosion rate	
Corrosion media	mils/year (1 mil/year = 25 μm/year)	Corrosion media	mils/year (1 mil/year = 25 μm/year)
Aldehydes			
acetic	a	Formaldehyde	<0.5
opionic	a	Normal pentaldehyde	2.4
ityric	a	Paraldehyde	2.5
leric	5.0	Propionaldehyde	a
Methylpentanoic	a	Valeraldehyde	1.5
Ethylbutyric	a	2-Ethylbutyraldehyde	b
Ethylhexoic	a	2-Ethylhexaldehyde	b
decanoic	a	Methacrolein	<0.5
(2-ethylhexyl) phosphoric	a	Crotonaldehyde	1.5
rylics	a	Acrolein dimer	c
rylic acid	a	Glutaraldehyde-25% aq. soln.	3.5
yl acrylate	<0.5	2-Hydroxyadipaldehyde-25% aq. soln.	1.0
yl acrylate	<0.5	Alkanolamines	
ethylhexyl acrylate	<0.5	Monoethanolamine	a
yl acrylate	<0.5	Diethanolamine	a
cidyl acrylate	<0.5	Monoisopropanolamine	a
Alcohols			
anol, 190 proof	1.0	Diisopropanolamine	<0.5
opropanol (19 vol %)	<0.5	Triisopropanolamine	<0.5
opropanol (anhyd)	<0.5	Alkyl amines	
anol	<0.5	Ethylamine-(69%)	0.5
utanol	<0.5	Diethylamine	<0.5
ntanol	<0.5	Triethylamine	<0.5
ethyl-1 butanol (commercial)	<0.5	Propylamine	<0.5
ethyl-1 butanol	<0.5	Dipropylamine	<0.5
ary amyl alcohol	<0.5	Isopropylamine	<0.5
exanol	<0.5	Diisopropylamine	<0.5
exanol	<0.5	Butylamine	<0.5
yl amyl alcohol	<0.5	Dibutylamine	<0.5
yl butanol	<0.5	Amylamine	<0.5
yl hexanol	<0.5	Diamylamine	<0.5
l-Trimethyl-1 pentanol	<0.5	Hexylamine	<0.5
tanol	<0.5	2-Ethylhexylamine	<0.5
butyl carbinol	<0.5	N-Methylbutylamine	<0.5
		N-Ethylbutylamine	<0.5

Table 5.6 Continued

Corrosion rate		Corrosion rate	
Corrosion media	mils/year (1 mil/year = 25 μm/year)	Corrosion media	mils/year (1 mil/year = 25 μm/year)
Isodecanol	<0.5	Esters	
2,6,8-Trimethyl-4 nonanol	<0.5	Ethyl acetate	<0.5
Tridecanol	<0.5	Propyl acetate	<0.5
Alkylene amines		Isopropyl acetate	<0.5
Ethylenediamine (98%)	a	Butyl acetate	<0.5
Diethylenetriamine	<0.5	Isobutyl acetate	<0.5
Propylenediamine	1.5	Primary amyl acetate	<0.5
1,3-Diaminopropane	<0.5	Methyl amyl acetate	<0.5
Dimethylaminopropylamine	0.5	2-Ethylhexyl acetate	<0.5
Diethylaminopropylamine	0.5	Methylcellosolve acetate	a
Imino-bispropylamine	1.5	Cellosolve acetate	4.0
Tetramethyl-1,3-butanediamine	<0.5	Butylcellosolve acetate	0.5
N-Methyl-bis (aminopropyl)-amine	0.5	Carbitol acetate	<0.5
Aryls		Butylcarbitol acetate	<0.5
Phenol	<0.5	Glycol diacetate	3.5
Butylphenol	<0.5	Diethyl sulfate	<0.5
Amylphenol	<0.5	Ethyl silicate (condensed)	0.5
Nonylphenol	<0.5	Tetraethyl orthosilicate	<0.5
Dodecylphenol	<0.5	Tetra (2-ethylhexyl) orthosilicate	<0.5
Ethylbenzene	<0.5	Ethers	
Styrene, monomeric	<0.5	Dimethyl ether	<0.5
Acetophenone	<0.5	Ethyl ether	<0.5
α-Methylbenzyl ether	<0.5	Isopropyl ether	<0.5
Phenyl methyl carbinol	<0.5	Butyl ether	<0.5
Chlorine compounds		1,4-Dioxane	<0.5
Butyl chloride	<0.5	Glycol and triols	
2-Butyl chloride	<0.5	Diethylene glycol	<0.5
2-Ethylhexyl chloride	<0.5	Triethylene glycol	<0.5
Ethylene dichloride	<0.5	Tetraethylene glycol	<0.5
Propylene dichloride	<0.5	1,3-Propanediol	<0.5
1,1,2-Trichloroethane	<0.5	Propylene glycol	<0.5
1,2,3-Trichloropropane	<0.5	Dipropylene glycol	<0.5
Dichloroethyl ether	<0.5	Hexylene glycol	<0.5
Dichloroisopropyl ether	<0.5		
Triglycol dichloride	<0.5		
Ethylene chlorhydrin	<0.5		
Epichlorhydrin	<0.5		

Table 5.6 Continued

Corrosion media	Corrosion rate		Corrosion media	Corrosion rate	
	(1 mil/year = 25 $\mu\text{m}/\text{year}$)	mils/year		(1 mil/year = 25 $\mu\text{m}/\text{year}$)	mils/year
Glycol ethers			Morpholines		
Methylcellosolve	<0.5		Morpholine (tetrahydro-1, 4-oxazine)	<0.5	
Cellosolve solvent	<0.5		2,6-Dimethylmorpholine	0.5	
Butylcellosolve	<0.5		N-Methylmorpholine	<0.5	
Isobutylcellosolve	<0.5		N-Ethylmorpholine	<0.5 ^d	
Dibutylcellosolve	<0.5		Nitriles		
Hexylcellosolve	<0.5		Acetonitrile	<0.5	
Methylcarbitol	<0.5		Butyronitrile	<0.5	
Carbitol solvent	<0.5		Acrylonitrile	<0.5	
Butylcarbitol	<0.5		Ethylene cyanohydrin		
Butoxytriethylglycol	<0.5		Oxides		
Methoxytriethylglycol	<0.5		Ethylene oxide	<0.5	
Ethoxytriethylglycol	<0.5		Propylene oxide	<0.5	
Ketones			Butylene oxide	<0.5	
Acetone	<0.5		Styrene oxide	<0.5	
Methyl ethyl ketone	<0.5		Plasticizers		
Methyl propyl ketone	<0.5		Dibutyl phthalate	<0.5	
Methyl isobutyl ketone	<0.5		Diocetyl phthalate	<0.5	
Methyl <i>n</i> -amyl ketone	<0.5		Polyethylene glycols		
Methyl butyl ketone	<0.5		Polyethoxyethylene glycols	<0.5	
Diisobutyl ketone	<0.5		Polymethoxyethylene glycols	<0.5	
Mesityl oxide	<0.5		Polypropylene glycols	<0.5	
Isophorone	<0.5		Pyridine and piperazines		
Diacetone alcohol	<0.5		α -Picoline	<0.5 ^d	
Latexes			γ -Picoline	<0.5 ^d	
Acrylic latex			2-Methyl-5-ethylpyridine	<0.5 ^d	
Styrene-butadiene latex			N-Hydroxyethylpiperazine	0.5 ^e	
Polyvinyl acetate latex			N-Aminoethylpiperazine	<0.5	
Vinyl acetate-acrylic copolymer latex			Vinyl ethers		
Monomers			Vinyl ethyl ether	<0.5	
Acrylonitrile	<0.5		Vinyl butyl ether	<0.5	
Styrene, monomeric	<0.5		Vinyl isobutyl ether	<0.5	
Vinyl acetate	<0.5		Vinyl 2-chlorethyl ether	<0.5	

^aCoating completely destroyed.^bZinc coating partly removed.^cIncomparable—causes polymerization^dProduct contaminated.^ePartially dissolved.

Source: Union Carbide, Chemicals Division.

Table 5.7 Corrosion Data for Zinc and Zinc Coatings with Organic Chemicals

Some references that occur frequently (and are mainly tabular summaries) are referred to in this table by letter code:

A	=	Helwig and Bird (1973)
B	=	Ritter (1958)
C	=	Ried (1964)
D	=	Dechema (1953)
E	=	Bauer and Schikorr (1934)
G	=	Wiederholt (1976)
I	=	International Nickel Co. (direct data)
J	=	Fuller (1927)
N	=	New Jersey Zinc Co. (direct data)
R	=	Clarke and Longhurst (1961)

Corrosive medium	Time (days, except as otherwise indicated)	Temperature (°C)	Corrosion rates		General suitability ^a	Remarks	Ref.
			$\text{g}/\text{m}^2/\text{year}$	$\mu\text{m}/\text{year}$			
Abletic acid					d	In conifers	D
Acetates					d		Marassi (1969)
Molten Li-Na-K		197-247					
Acetic acid							
0.1 g/L vapor	8	30	2,520	350	d		I
0.005 ppm vapor	21	30	33	5	b	100% RH over water	R
0.05 ppm vapor	21	30	78	11	b	100% RH over water	R
0.5 ppm vapor	21	30	945	132	d	100% RH over water	R
2.0 ppm vapor	21	30	4,300	600	d	100% RH over water	R
3.5 ppm vapor	21	30	5,250	735	d	100% RH over water	R
5.0 ppm vapor	21	30	7,050	990	d	100% RH over water	R
20.0 ppm vapor	21	30	2,015	282	d	100% RH over water	R
35.0 ppm vapor	21	30	1,305	183	d	100% RH over water	R
50.0 ppm vapor	21	30	1,415	198	d	100% RH over water	R
500.0 ppm vapor	21	30	3,125	440	d	100% RH over water	R
1% in water vapor	6	30	7,960	1,115	d	72% RH	R
0.5% in saturated Na acetate vapor	42	30	200	28	c	100% RH	R
pH 3.8 vapor	8	RT	290	40	c		Gilbert and Hadden (1950)

A = Helwig and Bird (1973)
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Acetylene				b		C
60%	20			a	Transported in galvanized containers	B, D, E, F, Tödt (1961)
Pure dry				c		
Moist				d	Attack more than with propionic acid	
Acrylic acid						
Alcohols				a		B
Pure dry				c		B
50% solution				d		B
Aldehydes						
Aromatic					Are destroyed	Minnesota Mining & Manufacturing Co.
Algae				a	Paint vehicle	D, G
Alkyd resins				a	In zinc silicate paints	MacLeod (1966), Bullett (1969)
Alkyl silicates				d		D
Allyl chloride				b	Often an inhibitor	Liddell (1961)
Amides				b	Often an inhibitor	
Amines				b		Grigorev and Kuznetsov (1969)
Amino acids						
Amyl alcohol				a	Stored in galvanized containers	D
Pure dry				a	Inhibitor in H ₂ SO ₄	D
Aniline	20			d		D
Aniline sulfate				d		D
Aniline sulfide				a	If acid-free	D
Anthracene				d		D
Ascorbic acid					Influence corrosion mechanism (soils)	Ehlert (1970) Guillaume (1970) MacDougall (1969)
Bacteria				c		D
Beeswax						
Benzaldehyde				a-b		D, E
Solution	40	15-250	2-35	d		B, C
100%	80			a		D
Benzidine				a-d	Depending on S content	D, Radtke (1969)
Benzine/benzol						
Benzoic acid						

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Corrosive medium	Time (days, except as otherwise indicated)	Temperature (°C)	Corrosion rates		General suitability*	Remarks	Ref.
			g/m ² /year	μm/year			
Vapor					d		Gmelin (1956)
100%		60			d		C, D
Binders					b		G (many)
Butane					a		
Butyl alcohol							
100%		80			b	Can use galvanized drums	C, D
Caprylic alcohol							
Pure, neutral					b	Sent in galvanized drums	D
Carbon tetrachloride							
Dry		20	13,870	1,940	c	Only for short contact: other hydrocarbons better	Bukowiecki (1968), B, D
(C ₂ HCl ₃ or C ₂ Cl ₄)			510	71	b		Bukowiecki (1968), B, D
Castor oil					b	Binder	Van Eijnsbergen (1967)
Cellulose acetyl							
Neutral, moist					b	Stored in galvanized drums	D
Cellulose nitrate					b	Sent in galvanized drums	D
Chlorinated phenols							
Pure, dry		20			a	Sent in galvanized drums	D
Moist					d		Dirkse (1970)
Chloroform							
Pure, dry, neutral		20			a	Sent in galvanized drums	D, E
Citrates					d		
Citric acid							
2%	21	RT			d	Specimen dissolved	I
<0.64% air-free					b	3-5 times more than tartaric acid	B, D, G
<0.64% aerated					d		
Cork							
Pure, dry					a		F
m-Cresol							
Pure, dry	100	25	5	0.7	a		I
Pure, dry - vapor	100	Hot	High	High	d		I
Pure + 10% water	100	25	9	1.3	a		I
Pure + 10% water - vapor	100	Hot	10,300	1,440	d		I
o-Cresol							
Pure, dry	100	25	9	1.3	a		I
Pure - vapor	100	Hot	9,900	1,390	d		I
Pure + 10% water	100	25	3	0.4	a		I
Pure + 10% water - vapor	100	Hot	2,050	287	d		I
Cyclohexanol					a		D
Dextrin					a		D
Diphenyl					a		D
Ethane							
Ethanol						Higher than methanol	Lechner-Knoblach and Heitz (1987)
200 proof	Also down to 25 v/o in DW	13 months	RT	0	0	a	N
190 proof	45 v/o in tap water	8 months	RT	39	5	a	N
190 proof	45 v/o in tap water; 8 h hot, 16 h cold daily	5	bp	8	1.1	a	
190 proof: vapor	40 v/o + 5 v/o methanol in tap water	5	bp	160	22	b	N
190 proof		8 months	RT	141	20	b	N
190 proof		5	bp	378	53	c	N

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Corrosive medium	Time (days, except as otherwise indicated)	Temperature (°C)	Corrosion rates		General suitability ^a	Remarks	Ref.
			g/m ² /year	μm/year			
190 proof + formic acid (e.g., to 0.1 mg KOH/g)	7	30	120	17	b		Schlapfer and Bukowiecki (1948)
190 proof + 5% water	7	30	0	0	a		Schlapfer and Bukowiecki (1948)
Ethanolamine					d		D
Ether							
Pure		20			c		B, G
Ethyl acetate + 5% water	7	30	1,350	189	d		Schlapfer and Bukowiecki (1948)
+ formic acid (e.g., to 0.1 mg KOH/g)	7	30	18	2.5	a		Schlapfer and Bukowiecki (1948)
Ethyl chloride		20			d		C, D, E
100%							
Ethyl mercaptan						For example, in crude oils: with water, corrosion increases	D
Ethylene					a		D
Ethylene glycol							
50% solution	14	24	120	17	b		
50% solution	14	-7	59	8	a		
50% solution	14	-23	15	2	a		
50% solution	14	77	1,354	190	d		
50% + 1% borax	14	24	243	34	c		
50% solution + 1% borax	14	-7	610	85	c		
50% solution + 1% borax	14	-23	288	40	c		
50% solution + 1% borax	14	77	0	0	a		
50% solution + 1% NaNO ₂	14	-7	31	4	a		
50% solution + 1% NaCO ₃	14	-7	9	1.3	a		
50% solution + 1% acetate	14	-7	106	15	b		
50% solution + 1% sodium benzoate	14	-7	148	21	b		
Fatty acids							C
C ₆ upward: 100%		75			d		
Formaldehyde							D, E
Pure, dry		20			b		B, D, E, G
Moist					d		I
0.1 g/L vapor 90% RH	8	30	183	25	c		
Formic acid							A
2.5% vapor	30	RT	840	118	c	With chromate film containing 0.02, 1.3, and 2.2 μg/dm ² , respectively	
			250	35	c		
			160	22	b		
4.6% solution	4 h	100	219,000	30,670	d		A
0.1 g/L vapor: 90% RH	8	30	30,660	4,300	d		I
pH 3.8 vapor: 100% RH	8	RT	77	11	b		Gilbert and Hadden (1950)
Gasoline							
Untreated	180	RT	31	4	a		N
+ 40 ppm lecithin	180	RT	5	0.7	a		N
+ 40 ppm + 10% water	180	RT	137	19	c	Corroded in water layer	N
+ 10% water	180	RT	246	35	c	Pitted in water layer	N
Glues							
12.5% pH 5.6	69	50	3,030	425	c-d	Inhibitor in H ₂ SO ₄	D, G, I
Glutaminic acid					d		D
Glycerine							
Pure, dry, neutral	240	RT	0	0	a		D

Table 5.7 Continued

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Corrosive medium	Time (days, except as otherwise indicated)	Temperature (°C)	Corrosion rates		General suitability ^a	Remarks	Ref.
			g/m ² /year	μm/year			
Glycol							
10% solution		40			d	Fire extinguisher use	C
50% solution		-6	58	8	b		D
50% solution + 1% borax	Hot	-6	610	85	c		D
Glycolic acid							
7.6% solution	4 h	100	1,314,000	184,000	d		I
37% solution		20			d		D, Gmelin (1956)
Glycol diacetate			610	85	b		
Hydrazine							
Water-free					b		B, D, E
Impregnating oils							
Water-free, neutral					b	Stored in galvanized containers	D
Moist					d		D
Isobutanol							
+ formic acid (e.g., to 0.1 mg KOH/g)	7	30	15	2	a		Schlapfer and Bukowiecki (1948)
+ 5% water	7	30	0	0	a		Schlapfer and Bukowiecki (1948)

Jute							
Unrotted					b		D
Rotted					d		D
Kerosene					a		Gmelin (1956)
Ketones							
Pure, neutral					a		
Lactic acid							
10%		40			d	More attack than butyric acid	C, Gmelin (1956)
Maleic acid							
100%		40			d		C, D
Mercaptans							
Dissolved in naphtha					b		D
Water solution					d	Two-liquid phase	D
Methane							
100%		80			a		C, D
Methanol (commercial)						Lower than ethanol	Lechner-Knoblach and Heitz (1987), Teeple (1952)
Immersed	180	RT	0	0	a		
Vapor	30	bp	0	0	a		
Methanol 100%							
Immersed	240	RT	29	4	a		N
Methanol 35% in tap water							
Immersed	240	RT	101	14	b		N
Vapor	5	bp	39	5	a		N
Methanol 30% in tap water							
Immersed	30	bp	355	50	b	AC-41A die casting	N
Immersed	365	RT	296	41	b	AC-41A die casting	N
Methanol 100%							
Immersed		60-70				Transported in galvanized containers	D
Methanol, impure							
Moist					d	Dissociates	D
Methyl acetate							
Pure, dry, neutral					a		D
Moist					d		D
Methyl bromide							
Pure, 0.08% H ₂ O					a	Transported in galvanized containers	D
Moist					d		D

Table 5.7 Continued

Some references that occur frequently (and are mainly tabular summaries) are referred to in this table by letter code:

A	=	Helwig and Bird (1973)
B	=	Ritter (1958)
C	=	Ried (1964)
D	=	Dechema (1953)
E	=	Bauer and Schikorr (1934)
G	=	Wiederholt (1976)
I	=	International Nickel Co. (direct data)
J	=	Fuller (1927)
N	=	New Jersey Zinc Co. (direct data)
R	=	Clarke and Longhurst (1961)

Corrosive medium	Time (days, except as otherwise indicated)	Temperature (°C)	Corrosion rates		General suitability ^a	Remarks	Ref.
			g/m ² /year	μm/year			
Methyl chloride							
Dry, pure					d	But if water-free can be transported in galvanized containers	D
Methyl ethyl ketone							
+ 0.03% acetic and 0.2% water	128	10	190	27	b	Some agitation	I
+ trace acetic and 0.1% water	30	10	37	5	a		I
+ trace acetic + heptane	142	24	22	3	a	Moderate agitation	I
Methylamine					d		D
Milk							
pH 4.03		20	9,930	1,380	d	Unsuitable because of effect on the milk anyhow	Gmelin (1956)
		97	9,200	1,280	d		Gmelin (1956)
pH 6.6		20	22	3	a		Gmelin (1956)
		75	11	1.5	a		Gmelin (1956)
Naphtha							
Immersed	50	155	1,124	157	d		I
Vapor			347	49	c		I
Nitrobenzene					d		B, C, D
Nitrotoluene					b		D
Oil							
No. 6 fuel	267	RT	14	2	a		I
Crude, light: immersed	55	RT	9	1.3	a		I
Crude, light: vapor	55	RT	11	1.5	a		I
Neutral, light: immersed	55	RT	1,836	257	c		I
Neutral, light: vapor	55	RT	54	8	a		I
Oxalates							
With phosphates						Indicative of protective layer	G
Oxalic acid							
0.01–0.01% solution		20			c		C, D, F, Huber (1968)
10% solution			24,090	3,375	d		D
Paraffin							
Pure, dry					a		
Perchloroethylene							
Vapor	64	127	4,300	600	c		I
Immersion	64	151	14,874	2,080	d		I
Phenol							
Pure, dry	100	25	5	0.7	a		Rhodes et al. (1934)
Pure, dry: vapor	100	bp	High	High	d		
+ 10% H ₂ O	100	25	6	0.8	a		
+ 10% H ₂ O vapor	100	bp	544	76	c		
0.1 g/L 90% RH vapor	8	30	46	6	b		
Phenol formaldehyde							
Resins					a		Kloetz (1963), Grauer (1966)
Phenol-formalin-water mixture	184	27	620	87	c		Rhodes et al (1934)
Phenolsulfuric acid					b		
Phosgene							
Pure, dry		20			a		B, D, F
Moist					d		B
n-Propanol							
+ 5% H ₂ O	7	30	11	1.5	a		Schlapfer and Bukowiecki (1948)
+ formic acid (equivalent to 0.1 mg KOH/g)	7	30	11	1.5	a		Schlapfer and Bukowiecki (1948)
Rape oil		100			c		Gmelin (1956)
Shellac					b		

Table 5.7 Continued

Some references that occur frequently (and are mainly tabular summaries) are referred to in this table by letter code:

A	=	Helwig and Bird (1973)
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G	=	Wiederholt (1976)
I	=	International Nickel Co. (direct data)
J	=	Fuller (1927)
N	=	New Jersey Zinc Co. (direct data)
R	=	Clarke and Longhurst (1961)

Corrosive medium	Time (days, except as otherwise indicated)	Temperature (°C)	Corrosion rates		General suitability ^a	Remarks	Ref.
			g/m ² /year	μm/year			
Soya oil					b		White and Deanin (1965)
Tannic acid							
50% solution			20	2.8	d		G
Tartaric acid							
10% solution		60	36,135	5,060	d		G, Gmelin (1956)
Thiourea					b		G
Trichloroacetic acid + nitrobenzene					d	Very strong attack	F, Gmelin (1956)
Trichlorethylene							
Immersed	41 h		10,549	1,480	d	In storage tank	I
Vapor	41 h	45	380	53	b	In dryer	I
Vapor	41 h	84	496	69	b	In exhaust duct	I
Vapor			13,760	1,925	d	In still	I
With water					b	Attack in water layer	N
Turpentine					b		
Urethanes					a	Paint vehicles	Van Oeteren (1967)
Vinyl acrylic resins					a	Zinc dust paint vehicles	Labrenz (1970)
Waxes					a		G

^aRatings: a = little attack (<10 μm/year), very useful; b = attack (10–100 μm/year), but may be useful; c = heavier attack (100–3000 μm/year), not usually suitable; d = rapid attack, unsuitable for use.

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with polystyrene, polyethylene, phenol formaldehyde, and Perspex (Bora, 1974).

Lechner-Knoblach and Heitz (1987) have studied the effect of impurities such as chlorides and organic acids on the corrosion rate in CH₃OH and C₂H₅OH, both at 50°C and at room temperature. At acid contamination levels of 0.1 mol/L, corrosion rates could reach 1 μm/h or more, but at 0.01 mol/L, 0.03 μm/h was more typical (Table 5.8). It has also been shown that the presence of water may cause a marked increase in the corrosion of zinc in organic chemicals. Therefore, the possible effect of moisture contamination should be considered in using the data from Table 5.6. Constantinescu and Heitz (1976), in tests on formic, acetic, propionic, and butyric acids, showed that water has a significant effect on the corrosion by monocarboxylic acids with three or more carbon atoms.

The suitability of zinc castings, especially ZA-8, ZA-12, and ZA-27, for use in engines and equipment has led to many tests—largely by Noranda (1993)—on their suitability with fuels, oils, and so on of different types.

A. Gasoline

ZA alloys as cast, when totally immersed in any of the six fuel mixtures (except ethanol-based gasohol) given in Table 5.9, did not corrode significantly when water-free. In hydrated fuel mixtures, however, the corrosion products formed both on zinc alloys and on 384 aluminum alloy might, in some cases, interfere with the functioning of fuel systems; the possible benefits of chromating are being investigated (Noranda, 1992). In two-phase solutions, voluminous white corrosion products formed at the fuel–water phase interface. With contaminated water additions (giving a two-phase liquid), steel, aluminum, and zinc alloys performed in static fully immersed tests as shown in Table 5.9. The unleaded high aromatic fuel (HAF) gasoline is ASTM reference fuel C, recommended for studies involving automotive fuels.

The use of zinc die castings with methanol/petrol mixtures was studied by Zinkberating (1979), which concluded that chromated castings were suitable for use with single-phase solutions (even with 0.03% acetic acid present); if a second phase is present (especially when fuel additions based on ethanol are used), however, some problems in use may recur.

Protective coatings are, therefore, usually applied over zinc or ZA alloys when these materials are used in contact with fuels.

In developing a dual-fuel engine—to use alcohol as an alternative to gasoline—researchers in Brazil have found that nickel-plated zinc is a reliable material for the carburetor, resisting the ethanol fuel. Knowledge of this property opens the way for possible use of the ZA alloys.

Table 5.8 Corrosion Rates ($\text{g/m}^2/\text{h}$)^{a,b} of Zinc in Contaminated Methanol and Ethanol

Concentration (mol^{-1})	Room temperature									50°C			
	H ₂ O			CH ₃ OH			C ₂ H ₅ OH			CH ₃ OH		C ₂ H ₅ OH	
	N ₂	O ₂	Air	N ₂	O ₂	Air	N ₂	O ₂	Air	N ₂	O ₂	N ₂	O ₂
Without contamination			0.09	0.01	0	0	0	0	0	0	0	0	0
50 ppm Cl ⁻	0.01	0.18		0.14	0.01		0	0					
CH ₃ COON ₂													
0.1	0.02			0.38	0.67		0.03	0.03		0.73	1.60	0.37	0.01
CH ₃ COOH													
0.1	1.29			4.2	7.0	11.7	0.17	2.8	3.51	0.43	6.28	0.1	6.19
0.05				0.87	3.93		1.06	2.8					
0.01				0.62	0.28		0.43	0.62					
0.005					0.16		0.21	0.29					
0.001					0.15		0.03	0.02					
HCOON ₂													
0.1				0.46	0.3		0.01	0		0.48	0.56	0.01	0.02
HCOOH													
0.1				3.9	5.5	9.7	0.17	0.08	0.13	0.14	0.12	0.14	0.18
0.05							0.24						
0.01							0.20						
0.005							0.29						
0.001							0.07						

^aCorrosion rates in grams per square meter per hour nearly correspond to millimeters per year; $1 \text{ g/m}^2/\text{h} = 1217 \text{ } \mu\text{m}/\text{year} = 3.3 \text{ } \mu\text{m}/\text{day}$.

^bZero corresponds to weight loss rates less than $0.01 \text{ g/m}^2/\text{h}$.

Source: Lechner-Knoblach and Heitz (1987).

Table 5.9 Results of Visual Examination Carried out on As-Cast ZA-8 and ZA-27 Samples and on Control Materials After 3200 hours of Total Immersion in Various Fuel Mixtures Containing Corrosive Water^a

Test fuel (mixed 1:1 with corrosive water)	Material ^b				
	No. 3 Zn alloy	ZA-8	ZA-27	No. 384 Al alloy	1008 Steel
Unleaded HAF gasoline	Light film of white c.p.	Light film of white c.p.	No c.p.	No c.p.	Rust pinpoints on almost 20% of the surface
Leaded gasoline	No c.p.	No c.p.	No c.p.	No c.p.	No c.p.
90% HAF + 10% ethanol	No c.p.	Superficial dark stains	No c.p.	Superficial corrosion	Rust pinpoints plus superficial staining
85% HAF + 15% methanol	No c.p.	No c.p.	Superficial dark stains	Corroded spots	Superficial rust staining
93% HAF + 7% MTBE	Light film of white c.p.	No c.p.	Light film of white c.p.	No c.p.	Rust pinpoints covering 75% of the surface
90.5% HAF + 4.75% methanol + 4.75% TBA	Numerous corroded spots with significant c.p.	Small corroded spots	Dispersed numerous superficial dark spots	Localized corrosion affecting less than 1% of the surface	Rust pinpoints on 20% of the surface

^aCorrosive water is distilled water containing 100 ppm each Cl⁻, SO₄²⁻, and HCO₃⁻ ions.

^bCorrosion products designated by c.p.

Source: Noranda (1992).

B. Diesel and Fuel Oils

Zinc, including ZA alloys, is not corroded by refined oils, but sulfur or water in ordinary fuel oils may form compounds with zinc which can clog small orifices. Chromating of castings may be helpful; zinc anodizing or chrome plating should provide more than adequate protection.

Tests involving galvanized steel were made by Kruse (1984). Small reservoirs for heating (fuel) oil, made from 3 mm steel sheet, were constructed and tested as follows: (a) hot dip galvanized, 50 μm coating thickness; (b) hot dip galvanized, 100 μm coating thickness; (c) ungalvanized steel with scale; and (d) ungalvanized steel, grit-blasted. After 2 years of testing in various fuels, the following conclusions were drawn.

The ungalvanized grit-blasted specimens showed pitting corrosion in various degrees, with occasionally a corrosion rate exceeding 1.5 mm/year. The ungalvanized specimens with scale did not show much pitting corrosion; however, after breakdown of the inhibitive action, rust spread extensively and there was pitting up to a depth of 1 mm. The galvanized test specimen showed voluminous zinc corrosion products. However, the underlying steel was not attacked. The 100 μm thick coatings behaved better than the 50 μm ones.

Further testing was carried out on large tanks, as used in practice. To the fuel in these tanks, 1 L of 3% sodium chloride solution was added, and corrosion was tested in tanks with stagnant fuel and with flowing fuel.

After 4 years of use, all insides of the ungalvanized tanks showed large formations of rust in the lower third of the interior. All galvanized tanks remained completely free from rust, and there was no blocking of oil filters or burner nozzles.

C. Miscellaneous Organic Chemicals

Gear Oils

ZA-12 and ZA-27 do not react with SAE 90 gear oil at 82°C, but oil breakdown and associated corrosion occurs at 149°C in a stirred beaker test.

Lubricants and Hydrocarbons

Heavy oil or greases, particularly the extreme pressure type, produce smooth, light etching and form a natural protective coating. Lubricants should be stable and free from acidity. Lubricants of mineral origin are completely satisfactory. Those containing animal or vegetable oils or fats should be avoided.

Hydraulic Fluids

No apparent reaction occurs on ZA 27 after 2 weeks at 49°C in a static test of three fluids: Shell Tallus T-15, Shell Decol T-23, and Shell Aircraft Hydraulic Fluid 4.

Glycerin

Pure glycerin has a limited smooth etching action on zinc and is quite satisfactory as hydraulic fluid in door stops. Similarly, glycerin-alcohol mixtures are practically inert to zinc, provided the mixture is pure and free of water. Water or low grade glycerin may cause some pitting.

Engine Coolants

After 32 days at 88°C in 33% Prestone II (a commercial engine coolant solution that contains silicate inhibitors), ZA-8 and Alloy 3, either as-cast or polished, showed no corrosion. Dynamic tests confirmed the suitability of ZA-8 at 118°C. ZA-27 displayed intergranular attack when tested as-cast but not when its surface was polished before testing. Possibly, the soft, zinc-rich phase had been smeared over the whole surface during polishing.

Dynamic, as well as static, tests with a ZA-8 pump prototype gave a top ASTM D-2809 rating even though inadequate inhibitor was present and, consequently, copper (from the tubing) deposited onto the alloy surface. Intergranular corrosion was minimal, with pits no more than 100 μm deep after a 300-hour test (Noranda, 1992).

Domestic Uses

Domestic use of chemicals is also significant, but ZA alloys are not recommended for alcohol-water mixtures represented by beverages. Pure alcohols are considerably less corrosive than water, but mixtures of water and alcohol are more corrosive than water alone.

Refrigerants

Freon 22 is inert and stable in contact with zinc alloys. Naphtha-based refrigerant oils are similarly inert and stable.

V. CONCRETE, CEMENT, AND PLASTERS

Unprotected steel reinforcing bars can corrode in certain environments as moisture penetrates into concrete through cracks and pores. Because the rust has a larger volume than the steel from which it is formed, the cover layer over the reinforcing bars can burst and flake off.

Partially grouted-in, poorly rust-protected steel, such as bolts and edge guards, can cause unsightly rust staining on a concrete surface. This type of damage can be avoided if the reinforcing steel is hot dip galvanized (ILZRO, 1981; Porter, 1985). Galvanizing of concrete reinforcement gives increased structural life, makes the placement of reinforcement less critical, and allows the use of steel protrusions with much reduced risk of cracking, rust staining, and spalling. A number of positive advantages arise; for example, for architectural uses, facades, etc., the thickness of the cover layer over the reinforcing bars can be reduced, resulting in a lighter weight structure, which can then be made slimmer and more elegant. Many publications are issued by the market development associations on the subject, and therefore it is not covered in this book. Yeomans (1991) said that in Australia, the use of galvanized steel adds about 6.5% to the typical cost of reinforcement of concrete; this is less than 2% of the building costs of a typical project and, with selective use of galvanized reinforcement, the extra cost is only 0.5–1% of the building costs. Among concerns of users satisfactorily answered by research on zinc-coated steel (Swamy, 1990) are the following: the effects of galvanizing on static strength even after deformation (no adverse effect); bond strength (similar to galvanized and ungalvanized when the usual modest levels of chromate are present, i.e., greater than about 20 ppm); fatigue strength in wet conditions (10% higher for galvanized than ungalvanized according to work done in Kari, Finland, but 25% lower in the less significant dry conditions); and effects of possible cracks in the galvanizing after bending (with 40–70 mm concrete cover, galvanized was less pitted after 3 years outdoors or in accelerated tests). In Holland, galvanized rebars are also used in concrete sewer water pipes, church (Apeldoorn), lock walls in the Delta port area (Rotterdam), Andoc offshore platform, façade elements in the walls of bank offices, cooling water ducts in Delfsylv, swimming pools, support columns of motorway viaducts, and bridges and balcony floor elements. Table 5.11 lists some case histories of galvanized reinforcement that has been in place for more than 15 years. Recent Australian examples include the Intercontinental Hotel in Sydney, the new Parliament House in Canberra, and the ASER Hotel and Convention Complex in Adelaide, which had followed such well-publicized long-term examples as the Sydney Opera House. In Delhi, India, the Bahai Temple—which looks like lotus petals—needed galvanized reinforcement for the thin concrete sections made necessary by the design.

Hot dip galvanized reinforcing bars or mesh are valuable in precast façade units to ensure that rust will not discolor the façade.

Table 5.10 Corrosion Data for Zinc in Contact with Some Building Materials

Corrosion medium	Time (days)	Temperature (°C)	Corrosion rates	
			g/m ² /year	µm/year
Data from Ritter (1958) ^a				
Quartz sand	30	19	4	0.6
Fibrolite	30	19	1	0.1
Asbestos cement	30	19	1	0.1
White granulated slag	30	19	11	1.5
Red brick	30	19	15	2.1
Mineral wood	30	19	18	2.5
Asbestos	30	19	29	4
Portland cement/sand mortar	30	19	77	11
Gypsum plaster	30	19	95	13
Silica brick	30	19	270	38
Data from Bauer and Schikorr (1934) ^b				
Wood from linden tree	61	RT	178	25
Wood from linden tree	61	RT	142	20
Wood from pine tree	61	RT	100	14
Wood from pine tree	61	RT	144	20
Wood from beech tree	61	RT	92	13
Wood from beech tree	61	RT	84	12

^aDirect contact.

^bIn contact under water.

In the case of deformed bar, the stress when 0.1 mm of slip occurs between the steel and the concrete is approximately:

Untreated steel	150 MPa
Hot dip galvanized steel	160 MPa
Hot dip galvanized and chromated steel	190 MPa

When the concrete is poured, its pH is around 13. In solutions with such a high pH, zinc is attacked and hydrogen is evolved, which could give rise to poor adhesion. However, the attack ceases as soon as the concrete has hardened.

Corrosion tests show that zinc-coated steel has a higher tolerance to moderate chloride levels in concrete than black steel (Yeomans, 1991).

Research in Germany has shown the benefit of galvanized steel in mortars even with substantial amounts of chloride present (Hildebrand and Schwenk, 1986). Both galvanized and ungalvanized (pickled) steel sheet specimens were embedded in Portland cement mortar with various cement/water ratios and curing conditions. Then these specimens were dipped in a 0.5 mol sodium chloride solution for 1–5 years. The fully immersed steel samples have very negative free corrosion potentials and, for that reason, cannot act as a cathode in corrosion cells, and the steel sheet within the cement does not corrode. Partially immersed specimens, however, showed very noble potentials. The galvanized steel sheet potentials are also shifted to the same positive values during exposure time. Localized corrosion generally occurs at the air-water line. With the ungalvanized specimens, cracking of the cement occurs as a result of the formation of voluminous rust. Corrosion is retarded significantly by galvanizing. Based on these extensive tests, the authors give detailed information on the use of galvanized steel in mortars, as rebars, and as coatings for salt-carrying pipelines.

Simm (1984) has studied the conjoint action of carbonation and chloride ions on the corrosion of zinc in mortar. Highly concentrated, high chloride mortars at 100% RH and 25°C can corrode zinc at 100 µm/year, but high carbonation or high chloride on its own causes a loss of zinc of only 5 µm/year. With neither chloride nor carbonation, no corrosion occurred. Sergi et al. (1985) have electrochemically looked at zinc in solutions pH 9.0–14.0 in relation to the use of galvanized steel in concrete.

Most types of cement contain small quantities of chromates. These chromates passivate the zinc surface, which is then not attacked by fresh concrete. If the cement contains less chromate than will give at least 20 ppm in the final concrete mix, the hot dip galvanized bars can be dipped in a chromate solution or chromates can be added on the basis of twice the minimum required. Avoid handling the chromates directly, for this can cause dermatitis: hexavalent chromate is a toxic substance.

Nürnberg (1986) in a summary report notes that galvanized rebars and other galvanized steel parts in contact with concrete will initially react with strongly alkaline mortars. The reaction between zinc and calcium hydroxide results in the formation of calcium hydroxyzincates: $\text{Ca}[\text{Zn}(\text{OH})_3] \cdot 2\text{H}_2\text{O}$. This type of coating protects the zinc layer. Hydrogen development during this

reaction is counteracted by the presence of very small quantities of hexavalent Cr ions (approximately 0.02%–0.012% CrO_4^{2-}) present on the galvanized rebar or in the mortar, or both. The corrosion of the zinc layer remains between 2 and 10 µm during the first weeks or months; after which it stops. Only when mortar pH exceeds 13.3 is corrosion accelerated and, consequently, no efficient protection occurs. Blast furnace—and molten clay-based—cements cause even less corrosion than Portland cement because of lower concentrations of calcium chloride during hydration. Under conditions of high humidity and wetness and thin concrete covering layers, the corrosion of zinc in carbonated concrete will be higher than in alkaline concrete. In practice, an 80–100 µm thick zinc coating will delay corrosion for very long periods. When high concentrations of chlorides occur, such as in silos for road salts, galvanized steel has a higher corrosion resistance than ungalvanized steel, especially at chloride concentrations above 1%. However, the zinc coating offers protection during shorter periods only. Galvannealed steel has larger corrosion losses than galvanized steel, where zinc and Zn/Fe alloy layers are present. Because zinc corrosion products are much less voluminous (a factor 2–3 times less) than rust, the danger of spalling concrete layers is practically nil with galvanized rebars. This property is especially valuable when concrete cover is (or must be, because of weight or aesthetic considerations) rather small.

Care must be taken not to allow contact between galvanized steel parts outside a concrete construction (e.g., underneath moist insulation materials) with ungalvanized (black) rebars in the concrete. The chance of corrosion of ungalvanized and galvanized steel parts is summarized as follows:

Contact of Metals		
In concrete	Outside concrete	Chance of corrosion
Ungalvanized	Ungalvanized*	Possible
Galvanized	Galvanized	None
Galvanized	Ungalvanized	None
Ungalvanized	Galvanized*	Possible
Galvanized*/ungalvanized	—	Possible
—	Galvanized*/ungalvanized	Possible

*Areas especially sensitive to corrosion

Even at elevated temperatures (60°C), galvanized rebars do not corrode in concrete. This behavior is in contrast to the corrosion caused by change of potential in hot water between 60 and 90°C.

Contact between zinc and gypsum-containing building materials, especially in moist conditions, results in corrosion of zinc. This often occurs in practice during the building period [e.g., when new galvanized roofing comes in contact with gypsum dihydrate crystals ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$)]. Magnesia cement causes severe corrosion of galvanized parts in contact therewith.

Galvanized parts in sand do not corrode very much. In unaerated and/or contaminated sand, corrosion may occur: always, however, very much less than on ungalvanized steel. Excessive and retained moisture present between galvanized steel parts and other building materials, such as isolating strips, bituminous coatings, and asphalt materials, must be avoided. If this is impossible, other building materials should be used.

Franque and Huppatz (1986) studied the corrosion behavior of nonferrous metal structural elements in contact with building materials. They confirmed that metals like zinc and aluminum (unlike lead, copper, and tin) rapidly form a surface layer of oxide or insoluble salts when exposed to moist air in buildings. Zinc is much more resistant than lead. It also is only superficially attacked in mortars containing no sodium chloride, because insoluble zincates are formed. In contact with magnesia cement and "stone wood," a building material made from wood chips and a magnesia cement binder, zinc is attacked by the very hygroscopic magnesium chloride and chloride ions. Also, zinc is attacked by gypsum under moist conditions. When zinc or galvanized steel is present, care should be taken not to use acidic materials (e.g., from acidifying stone walls).

Laboratory tests on plasters and cements are of limited value but can indicate trends. Lodder and Baumgarten (1951) looked at corrosion in damp gypsum plaster at room temperature. With only 0.046% chloride, corrosion was about 8 $\mu\text{m}/\text{year}$ in a 203-day test, even if the partly embedded rolled sheet was kept dry; the steel was perforated in 52 days if kept damp. Chromating (Cronak process) virtually stopped attack (only 1.5 $\mu\text{m}/\text{year}$).

When 1.5% sodium chloride was added to the gypsum, significant pitting occurred at the interface on partially embedded samples that were kept moist; chromating (Cronak process) virtually prevented attack in tests up to one year, but phosphating allowed corrosion to continue at the interface.

Heavy attack (around 500 $\mu\text{m}/\text{year}$) also occurred with surface contact alone when the area was kept damp, but the Cronak treatment again prevented corrosion (about 5 μm in a year).

Bauer and Schikorr (1934), in 71-day tests at room temperatures in plaster of paris, showed that when the water content of the plaster was 28%, corrosion on partly embedded samples was about 10 $\mu\text{m}/\text{year}$; if the water content was only 15%, localized pitting occurred and corrosion rates of around 100 $\mu\text{m}/\text{year}$ were found in specimens kept in a dessicator over water.

Just by keeping the samples damp, pitting attack was avoided, although the corrosion rate increased up to 200 $\mu\text{m}/\text{year}$. The same investigators also tested cement in similar sets of conditions and found attack of 1.1–1.5 μm in 62 days (annualized rate if linear: 5–8 $\mu\text{m}/\text{year}$).

In general with alkaline building materials, attack on zinc occurs when the pH is above about 12.5. As is seen from the tests quoted, more water will often reduce the alkalinity to levels at which zinc is resistant to attack. In border line cases, the protective film is broken locally to give pitting; in such cases, a surface film containing chromate can be very beneficial. At lower pH values, caution is needed with materials such as fly-ash cement, where it is easy for substantial amounts of aggressive materials to be leached from the cement; attack is then similar to that in polluted fresh water.

The ZA alloys, especially ZA 27, may corrode more than zinc when in contact with fresh concrete, plaster, and other alkaline materials, but then they are better than aluminum.

VI. BITUMEN

The use of bitumen in contact with zinc roofing sheet led to a comprehensive study of the corrosion that may occur. The work was written in German by Witt and Haller (1977) as Part 4 of *Corrosion Behavior of Zinc*. A brief summary follows (the original book contains 35 references and a list of about 40 other relevant articles).

Bituminous materials will form acidic products when affected by light and/or heat. Also, degradation products of additives and hydrolysis of catalysts used in flowing bituminous materials will cause the formation of compounds that may be detrimental to zinc. The use of herbicides and fungicides to prevent growths on roofs covered by bituminous materials results in attack on zinc; pentachlorophenol is especially implicated in this regard. When zinc is exposed to moist air ($\text{RH} > 70\%$) and acidic products from applied bituminous coatings, corrosion is accelerated. To avoid this, it is necessary to (a) use stable materials that do not release acidic products upon weathering, (b) cover bituminous roofing with a protective paint, and (c) avoid contact of zinc with nearby bituminous layers. To select suitable bituminous materials, UV-radiation tests in moist air are recommended. Bituminous materials degrade 200 times quicker in sunlight than in dark areas.

Rückert et al. (1983) note that rainwater dripping from galvanized gutters had pH values of 6.0–6.5, whereas water from bituminous roof claddings had pH values of 5.5–6.5. These authors discuss the influences of intermittent attack and the humidity of the air.

Bitumen-based coatings for cold application in uses involving contact with water are standardized in BS 3416: 1991 (potable water) and BS 6949: 1991 (other waters).

Russian work on zinc as a filler in bituminous coatings (Tomashov and Leonov, 1965) reflects interest in a type of protection not much used elsewhere. These investigators tested films with various concentrations of zinc filler (0–30% by volume, which corresponds to a presence of 0–80% by mass in the coating). The coatings were applied by slow withdrawal of the specimens from the corresponding primer solutions. The film thickness (0.5–500 μm) was regulated by the viscosity and rate of withdrawal of the specimens. The zinc particles apparently dissolve to some extent but can be seen as discrete areas in a section. At the higher concentration, the coating has some degree of electrical continuity. Figure 5.2 gives electrical capacity and resistance measurements for one zinc loading. After testing, a hydrated zinc oxide forms on the surface. The authors conclude that in thin coatings (≤ 10 –20 μm), zinc essentially fulfills the role of protector, but the service life of such a coating is limited by the time for dissolution of the zinc. In thicker coatings, the zinc filler protects the basis metal initially by its protective action and, thereafter (for a longer time), by consolidation of the surface layer of the coating by corrosion-resistant zinc corrosion products.

VII. OTHER BUILDING MATERIALS

Zinc and zinc–aluminum alloys and coatings are suitable for contact with most building materials. Corrosion problems have been surveyed by Jones

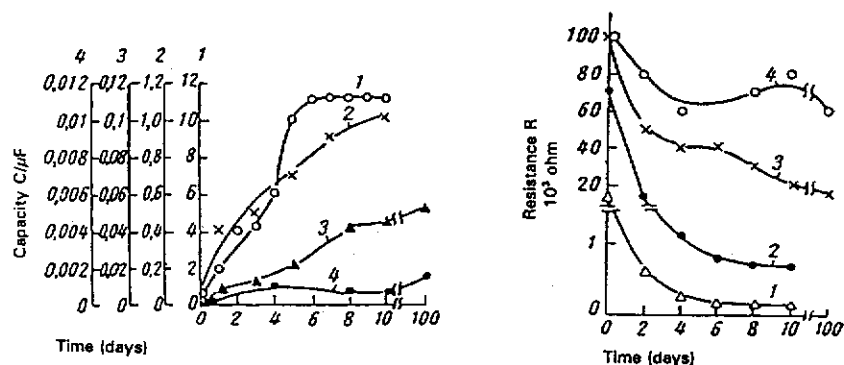


Fig. 5.2 Change of electrical capacity and resistance with time for an iron electrode insulated by a bituminous primer containing zinc filler for various coating thicknesses: 1 = 2 μm ; 2 = 5 μm ; 3 = 10 μm ; 4 = 100 μm (Tomashov and Leonov, 1965).

Table 5.11 Galvanized Rebar: Selection of Uses: More Than 10 Years of Satisfactory Performance

Building or structure	Location	Reference*
Buildings: in situ construction, cladding panels or window frames		
National Theatre	London	GA
Opera House	Sydney	GAA
Dome of New Hall	Cambridge	GA
Sports Hall	Birmingham University	GA
Civic/council buildings	Newham, Woking, Exeter	GA
Civic Centre	Johannesburg	SAHDGA
Examples since 1930	Bermuda	GA
Barclays Bank DCO Tower	London	GA
Civic buildings, police station, library	Sittingbourne, Kent	GA
Parliament Buildings	Wellington, New Zealand	GAA
Bank of Hawaii	Waikiki, Honolulu	FCP/JvanE
Congress Theatre	Eastbourne	GA
HUD (Housing and Urban Development) offices	Washington, D.C.	AGA
Church roof	Tromsø, Norway	JvanE
Flowers Brewery	Luton	GA
University buildings	York	GA
Collegiate buildings, University College	London	GA
Former GLC offices (south of Westminster Bridge)	London	GA
Civil engineering structures		
Bridges in Michigan, Vermont, Pennsylvania, Connecticut, and Massachusetts, including		
Boca Chica bridge	Florida	ILZRO
Ames bridge	Iowa	ILZRO
Hershey bridge	Pennsylvania	ILZRO
Tioga bridge	Pennsylvania	ILZRO
Athens bridge	Pennsylvania	ILZRO
Croaopolis bridge	Pennsylvania	ILZRO
Bridges in Ontario and Quebec, including		
Vimont Overpass	Canada	
Power station cooling ducts	Netherlands	SDV
Andoc oil storage tanks	Bed of North Sea	SDV
Docks	Bermuda	GA
Onomachi Pier	Japan	JGA
300-foot chimney	Japan	JGA
Toutry Viaduct	Côte d'Or, France	Galvazinc
Pont d'Ouche Viaduct	Côte d'Or, France	Galvazinc
St. Nazaire bridge	Loire-Atlantique	Galvazinc
Coke ovens-quenching tower	Dunkirk	Galvazinc
Concrete yachts	United Kingdom	GA

*GA = Galvanizers' Association; GAA = Galvanizers Association of Australia; SAHDGA = South African Hot Dip Galvanizers Association; FCP = F. C. Porter; JvanE = J. F. H. Van Eijnsbergen; AGA = American Galvanizers Association; ILZRO = International Lead Zinc Research Organization; SDV = Stichting Doelmatig Verzinken; JGA = Japanese Galvanizers Association.

In addition, see information in the text and also Fe + Zn 12, 16, and 21 published by the European General Galvanizers' Association and the various national galvanizing association publications. F. C. Porter and J. F. H. van Eijnsbergen also have additional information.

and Brinn (1983). Care is needed when there is long-term contact with water, which has leached chlorides, sulfates, and other salts from brickwork and other materials. Table 5.10 gives results of some tests, but it must be remembered that most building materials are very variable in composition and texture. Protection of the zinc is usually desirable when the metal is in contact with pervious materials that are wet for long periods; if such materials are normally dry, however, there is no problem. Thus, the performance of wall ties has been studied by Moore (1981) for 18 locations and up to 50 years of service. In general, the galvanizing in the space between the inner and outer walls sustained no apparent attack. The damper outer wall caused most attack, but the amount of corrosion varied considerably because of different locations and installation conditions and ranged from less than 1 $\mu\text{m}/\text{year}$ to 12 $\mu\text{m}/\text{year}$.

Zinc can be used in contact with most woods, but some corrosion will occur with Western red cedar and other acid woods. Generally speaking, galvanized fasteners (e.g.) are not attacked by wood or by insulation foams (e.g., polyurethane and polystyrene foams). Heavy corrosion may also arise if the wood rots and forms a wet poultice against the zinc alloy. The survey by Jones and Brinn (1983, pp. 56–72) gives details of woods and treatments but concludes that there are wide differences of view on performance or likely performance and calls for more in situ investigations.

Wood preservatives containing copper salts, and any that produce acid solutions, will cause corrosion, particularly on fasteners or connecting pieces if these have only a thin zinc coating. The Greater London Council in the United Kingdom (1981) have particularly cautioned against copper–chrome arsenate wood preservatives, and work by Simm and Button (1985) showed local and general attack in 30-month tests; Duncan (1988) in his work confirmed the corrosivity and indicated that in the worst places, powder-coated galvanized steel would be a cheaper solution than stainless steel or silicon bronze bolts. If, however, the moisture content of the wood can be kept low—Cross and Bailey (1989) suggest below 19%—severe corrosion does not occur.

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