



*excellence*

**KOROSI**

**BAHAN TEKNIK 1**



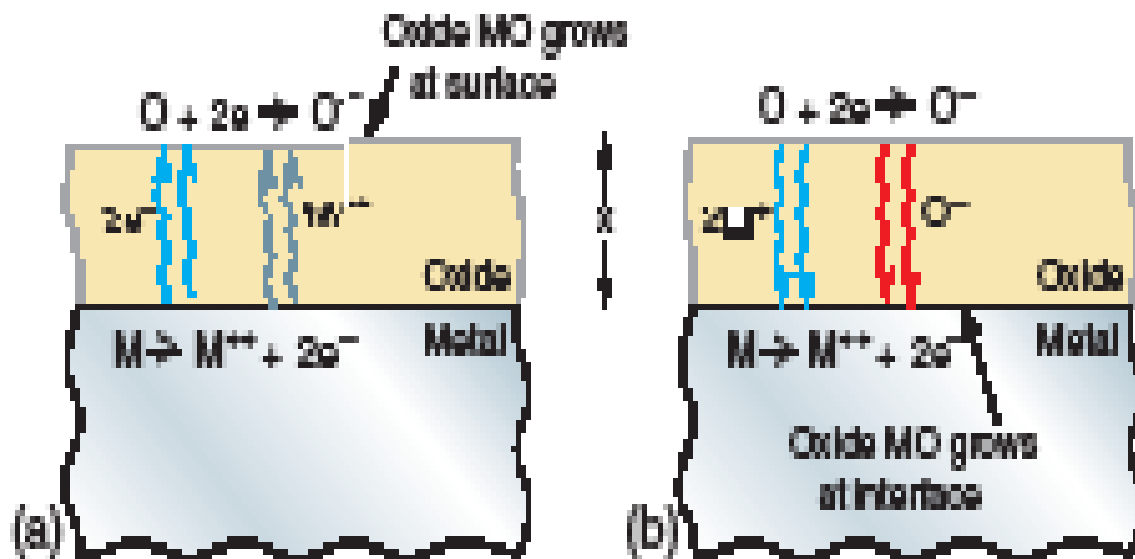
# KOROSI



**Korosi : Peristiwa perusakan atau degradasi material logam akibat bereaksi secara kimia dengan lingkungan**



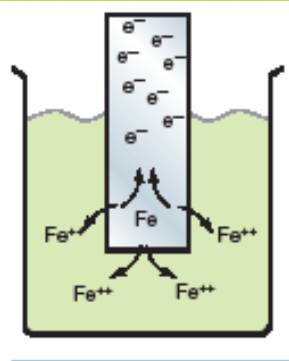
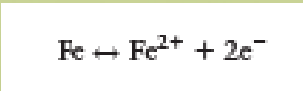
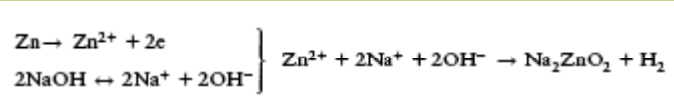
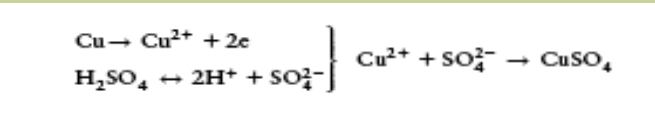
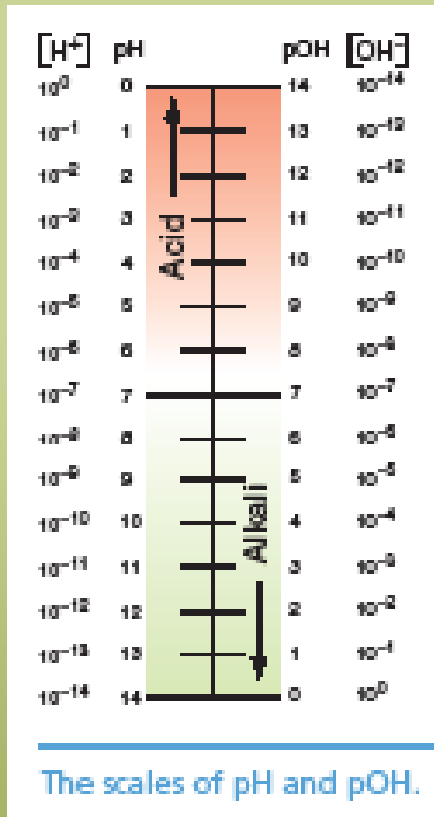
# Fenomena Oksidasi



Oxidation mechanisms. (a) Growth by metal diffusion and electron conduction  
(b) Growth by diffusion of oxygen and holes.



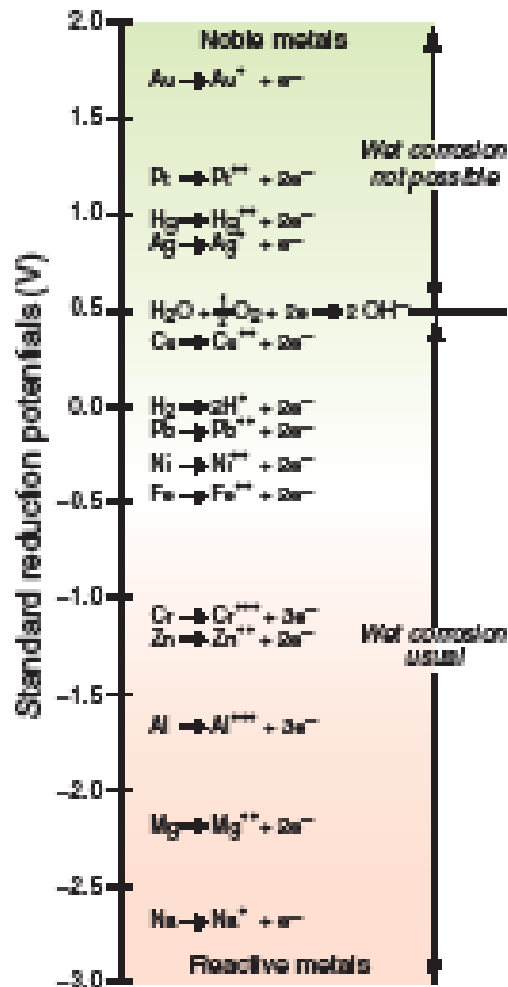
# Tingkat keasaman



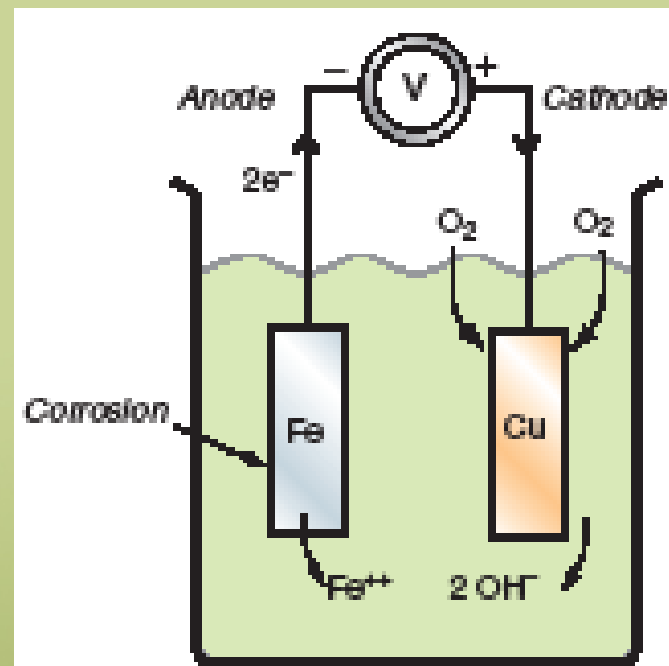
Ionization.



# Standar Induksi Potensial



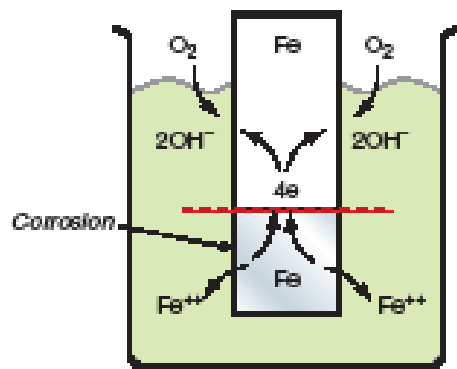
Standard reduction potentials of metals.



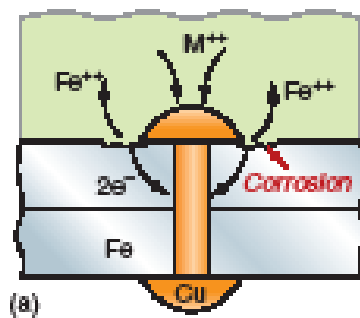
A bit-metal cell containing pure water in which oxygen can dissolve.



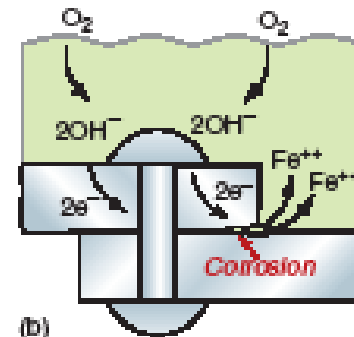
# Peristiwa korosi dan penangkalan



A corrosion cell created by differential access to oxygen.

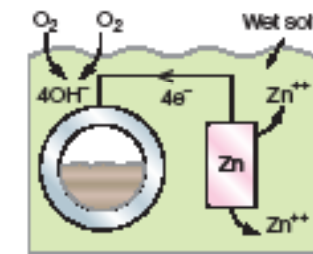


(a)

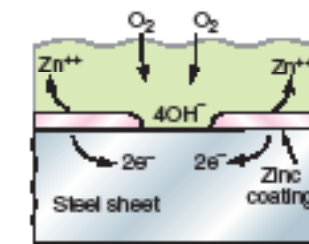


(b)

(a) Electrochemical corrosion where two different metals are in electrical contact. (b) Crevice corrosion caused by differential access of oxygen.



(a)

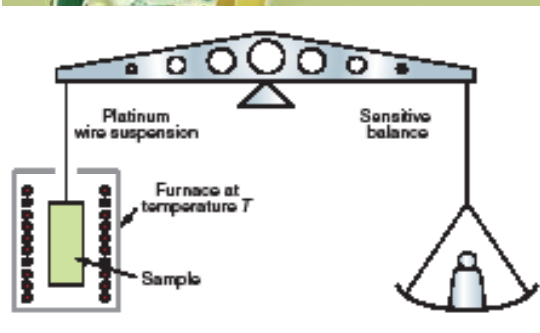


(b)

(a) Protection of steel pipes by a zinc sacrificial anode. (b) Galvanized steel plate; the zinc protects the steel even when scratched.



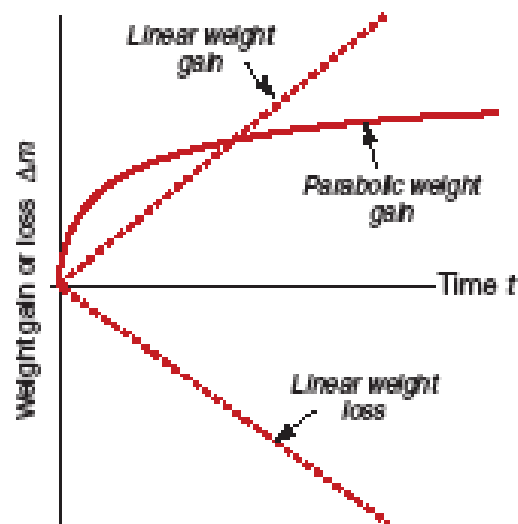
# Laju Korosi



Measuring oxidation rates.

$$\frac{dm}{dt} = k_t \quad \text{giving} \quad \Delta m = k_t t$$

$$\frac{d(\Delta m)}{dt} = \frac{k_p}{\Delta m} \quad \text{giving} \quad \Delta m^2 = k_p t$$



Oxidation rates: linear weight gain, parabolic gain and linear loss.

$$\text{CPR} = \frac{KW}{\rho A t}$$

corrosion penetration rate (CPR)

Corrosion penetration rate—as a function of specimen weight loss, density, area, and time of exposure

where  $W$  is the weight loss after exposure time  $t$ ;  $\rho$  and  $A$  represent the density and exposed specimen area, respectively, and  $K$  is a constant, its magnitude depending on the system of units used. The CPR is conveniently expressed in terms of either mils per year (mpy) or millimeters per year (mm/yr). In the first case,  $K = 534$  to give CPR in mpy (where 1 mil = 0.001 in.), and  $W$ ,  $\rho$ ,  $A$ , and  $t$  are specified in units of milligrams, grams per cubic centimeter, square inches, and hours, respectively. In the second case,  $K = 87.6$  for mm/yr, and units for the other parameters are the same as for mils per year, except that  $A$  is given in square centimeters. For most applications a corrosion penetration rate less than about 20 mpy (0.50 mm/yr) is acceptable.

$$r = \frac{i}{n\mathcal{F}}$$

Expression relating corrosion rate and current density

Inasmuch as there is an electric current associated with electrochemical corrosion reactions, we can also express corrosion rate in terms of this current, or, more specifically, current density—that is, the current per unit surface area of material corroding—which is designated  $i$ . The rate  $r$ , in units of  $\text{mol/m}^2\text{-s}$ , is determined using the expression

where, again,  $n$  is the number of electrons associated with the ionization of each metal atom, and  $\mathcal{F}$  is 96,500 C/mol.





# Oksidasi dan Reduksi

Oxidation reaction  
for metal M



in which M becomes an  $n+$  positively charged ion and in the process loses its  $n$  valence electrons;  $e^{-}$  is used to symbolize an electron. Examples in which metals oxidize are



**anode**

The site at which oxidation takes place is called the **anode**; oxidation is sometimes called an anodic reaction.

**reduction**

The electrons generated from each metal atom that is oxidized must be transferred to and become a part of another chemical species in what is termed a **reduction** reaction. For example, some metals undergo corrosion in acid solutions, which have a high concentration of hydrogen ( $H^{+}$ ) ions; the  $H^{+}$  ions are reduced as follows:

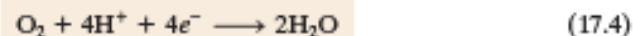
Reduction of  
hydrogen ions in  
an acid solution



and hydrogen gas ( $H_2$ ) is evolved.

Other reduction reactions are possible, depending on the nature of the solution to which the metal is exposed. For an acid solution having dissolved oxygen, reduction according to

Reduction reaction  
in an acid solution  
containing dissolved  
oxygen



will probably occur. Or, for a neutral or basic aqueous solution in which oxygen is also dissolved,

Reduction reaction  
in a neutral or basic  
solution containing  
dissolved oxygen



Any metal ions present in the solution may also be reduced; for ions that can exist in more than one valence state (multivalent ions), reduction may occur by

Reduction of a  
multivalent metal  
ion to a lower  
valence state



in which the metal ion decreases its valence state by accepting an electron. Or a metal may be totally reduced from an ionic to a neutral metallic state according to

Reduction of a metal  
ion to its electrically  
neutral atom







**Figure 17.1** The electrochemical reactions associated with the corrosion of zinc in an acid solution. (From M. G. Fontana, *Corrosion Engineering*, 3rd edition. Copyright © 1986 by McGraw-Hill Book Company. Reproduced with permission.)

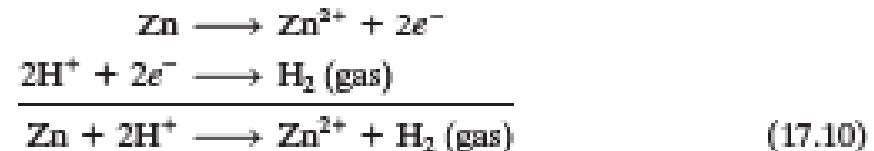
For example, consider zinc metal immersed in an acid solution containing  $H^+$  ions. At some regions on the metal surface, zinc will experience oxidation or corrosion as illustrated in Figure 17.1, and according to the reaction



Since zinc is a metal, and therefore a good electrical conductor, these electrons may be transferred to an adjacent region at which the  $H^+$  ions are reduced according to



If no other oxidation or reduction reactions occur, the total electrochemical reaction is just the sum of reactions 17.8 and 17.9, or



Another example is the oxidation or rusting of iron in water, which contains dissolved oxygen. This process occurs in two steps; in the first, Fe is oxidized to  $Fe^{2+}$  [as  $Fe(OH)_2$ ],



and, in the second stage, to  $Fe^{3+}$  [as  $Fe(OH)_3$ ] according to



The compound  $Fe(OH)_3$  is the all too familiar rust.



# Standar EMF (Electromotive Force)

**Table 17.1** The Standard emf Series

	<i>Electrode Reaction</i>	<i>Standard Electrode Potential, <math>V^0(V)</math></i>
	$\text{Au}^{3+} + 3e^- \longrightarrow \text{Au}$	+1.420
	$\text{O}_2 + 4\text{H}^+ + 4e^- \longrightarrow 2\text{H}_2\text{O}$	+1.229
	$\text{Pt}^{2+} + 2e^- \longrightarrow \text{Pt}$	~+1.2
	$\text{Ag}^+ + e^- \longrightarrow \text{Ag}$	+0.800
	$\text{Fe}^{3+} + e^- \longrightarrow \text{Fe}^{2+}$	+0.771
	$\text{O}_2 + 2\text{H}_2\text{O} + 4e^- \longrightarrow 4(\text{OH}^-)$	+0.401
	$\text{Cu}^{2+} + 2e^- \longrightarrow \text{Cu}$	+0.340
	$2\text{H}^+ + 2e^- \longrightarrow \text{H}_2$	0.000
	$\text{Pb}^{2+} + 2e^- \longrightarrow \text{Pb}$	-0.126
	$\text{Sn}^{2+} + 2e^- \longrightarrow \text{Sn}$	-0.136
	$\text{Ni}^{2+} + 2e^- \longrightarrow \text{Ni}$	-0.250
	$\text{Co}^{2+} + 2e^- \longrightarrow \text{Co}$	-0.277
	$\text{Cd}^{2+} + 2e^- \longrightarrow \text{Cd}$	-0.403
	$\text{Fe}^{2+} + 2e^- \longrightarrow \text{Fe}$	-0.440
	$\text{Cr}^{3+} + 3e^- \longrightarrow \text{Cr}$	-0.744
	$\text{Zn}^{2+} + 2e^- \longrightarrow \text{Zn}$	-0.763
	$\text{Al}^{3+} + 3e^- \longrightarrow \text{Al}$	-1.662
	$\text{Mg}^{2+} + 2e^- \longrightarrow \text{Mg}$	-2.363
	$\text{Na}^+ + e^- \longrightarrow \text{Na}$	-2.714
	$\text{K}^+ + e^- \longrightarrow \text{K}$	-2.924

↑  
Increasingly inert  
(cathodic)

↓  
Increasingly active  
(anodic)



# Galvanic series

**Table 17.2** The Galvanic Series

	Platinum
	Gold
	Graphite
	Titanium
	Silver
	316 Stainless steel (passive)
	304 Stainless steel (passive)
	Inconel (80Ni-13Cr-7Fe) (passive)
	Nickel (passive)
	Monel (70Ni-30Cu)
	Copper-nickel alloys
	Bronzes (Cu-Sn alloys)
	Copper
	Brasses (Cu-Zn alloys)
	Inconel (active)
	Nickel (active)
	Tin
	Lead
	316 Stainless steel (active)
	304 Stainless steel (active)
	Cast iron
	Iron and steel
	Aluminum alloys
	Cadmium
	Commercially pure aluminum
	Zinc
	Magnesium and magnesium alloys

Increasingly inert (cathodic)



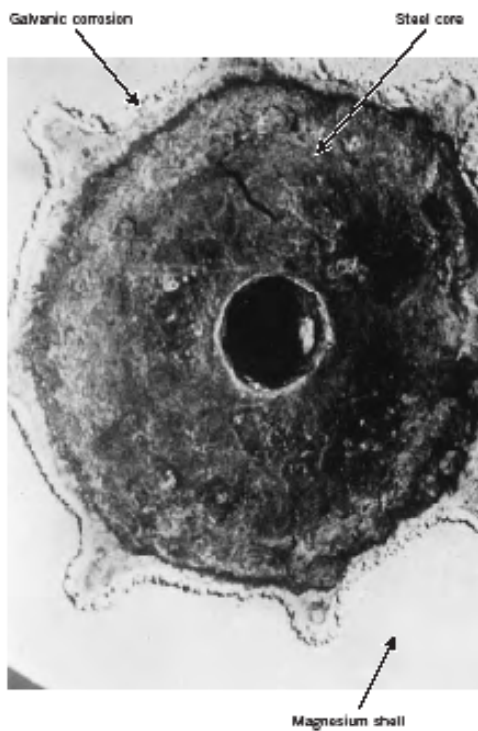
Increasingly active (anodic)



Source: M. G. Fontana, *Corrosion Engineering*, 3rd edition. Copyright 1986 by McGraw-Hill Book Company. Reprinted with permission.



# Macam-macam Korosi

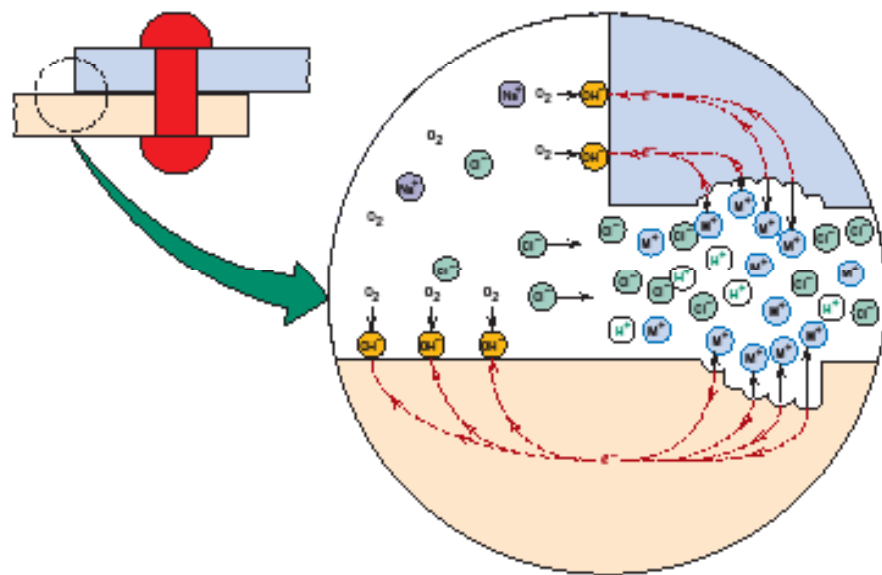


**Figure 17.14** Photograph showing galvanic corrosion around the inlet of a single-cycle bilge pump that is found on fishing vessels. Corrosion occurred between a magnesium shell that was cast around a steel core. (Photograph courtesy of LaQue Center for Corrosion Technology, Inc.)

**Figure 17.15** On this plate, which was immersed in seawater, crevice corrosion has occurred at the regions that were covered by washers. (Photograph courtesy of LaQue Center for Corrosion Technology, Inc.)



**Figure 17.16** Schematic illustration of the mechanism of crevice corrosion between two riveted sheets. (From M. G. Fontana, *Corrosion Engineering*, 3rd edition. Copyright © 1986 by McGraw-Hill Book Company. Reproduced with permission.)

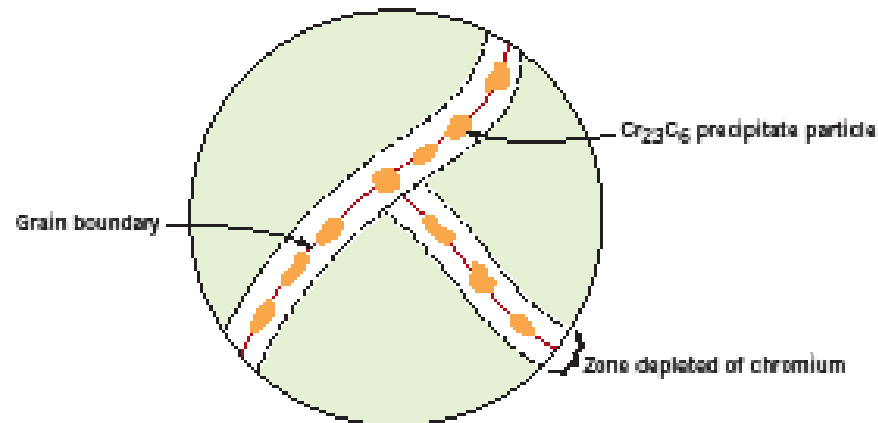




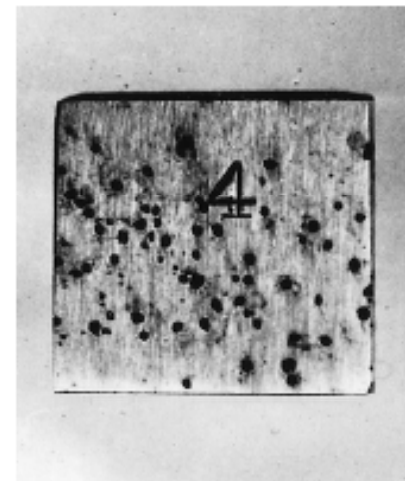
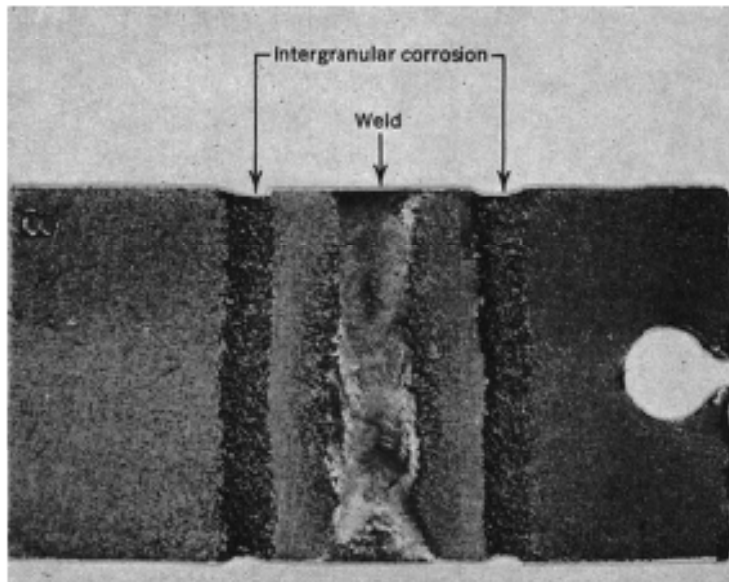
# Macam-macam Korosi

**Figure 17.18**

Schematic illustration of chromium carbide particles that have precipitated along grain boundaries in stainless steel, and the attendant zones of chromium depletion.



**Figure 17.19** Weld decay in a stainless steel. The regions along which the grooves have formed were sensitized as the weld cooled. (From H. H. Uhlig and R. W. Revie, *Corrosion and Corrosion Control*, 3rd edition, Fig. 2, p. 307. Copyright © 1985 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.)



**Figure 17.17** The pitting of a 304 stainless steel plate by an acid-chloride solution. (Photograph courtesy of Mars G. Fontana. From M. G. Fontana, *Corrosion Engineering*, 3rd edition. Copyright © 1986 by McGraw-Hill Book Company. Reproduced with permission.)

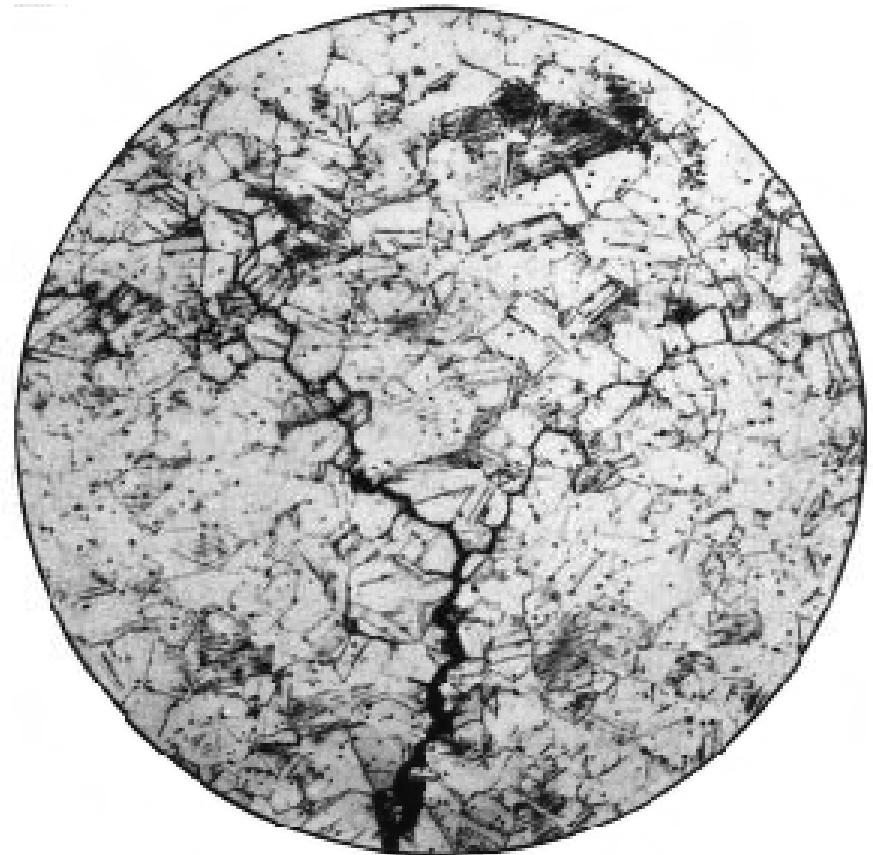


# Macam-macam Korosi



**Figure 17.20** Impingement failure of an elbow that was part of a steam condensate line. (Photograph courtesy of Mars G. Fontana. From M. G. Fontana, *Corrosion Engineering*, 3rd edition. Copyright © 1986 by McGraw-Hill Book Company. Reproduced with permission.)

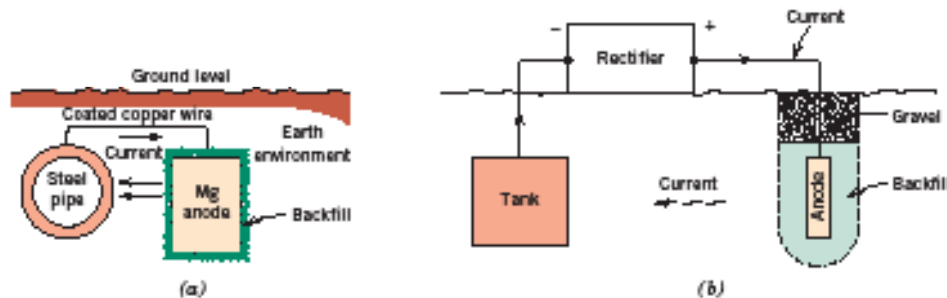
**Figure 17.21**  
Photomicrograph showing intergranular stress corrosion cracking in brass. (From H. H. Uhlig and R. W. Reiss, *Corrosion and Corrosion Control*, 3rd edition, Fig. 5, p. 335. Copyright 1985 by John Wiley & Sons, Inc. Reprinted by permission of John Wiley & Sons, Inc.)



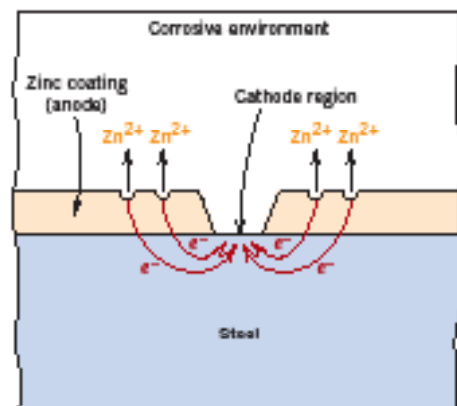




# Pencegahan Korosi



**Figure 17.22** Cathodic protection of (a) an underground pipeline using a magnesium sacrificial anode, and (b) an underground tank using an impressed current. (From M. G. Fontana, *Corrosion Engineering*, 3rd edition. Copyright © 1986 by McGraw-Hill Book Company. Reproduced with permission.)



**Figure 17.23** Galvanic protection of steel as provided by a coating of zinc.

**Table 17.3** Pilling–Bedworth Ratios for a Number of Metals

Protective		Nonprotective	
Ce	1.16	K	0.45
Al	1.28	Li	0.57
Pb	1.40	Na	0.57
Ni	1.52	Cd	1.21
Be	1.59	Ag	1.59
Pd	1.60	Ti	1.95
Cu	1.68	Ta	2.33
Fe	1.77	Sb	2.35
Mn	1.79	Nb	2.61
Co	1.99	U	3.05
Cr	1.99	Mo	3.40
Si	2.27	W	3.40

Source: B. Chalmers, *Physical Metallurgy*. Copyright © 1959 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.



# Degradasi Polimer

**Table 17.4** Resistance to Degradation by Various Environments for Selected Plastic Materials<sup>a</sup>

Material	Nonoxidizing Acids (20% H <sub>2</sub> SO <sub>4</sub> )	Oxidizing Acids (10% HNO <sub>3</sub> )	Aqueous Salt Solutions (NaCl)	Aqueous Alkalies (NaOH)	Polar Solvents (C <sub>2</sub> H <sub>5</sub> OH)	Nonpolar Solvents (C <sub>6</sub> H <sub>6</sub> )	Water
Polytetrafluoroethylene	S	S	S	S	S	S	S
Nylon 6,6	U	U	S	S	Q	S	S
Polycarbonate	Q	U	S	U	S	U	S
Polyester	Q	Q	S	Q	Q	U	S
Polyetheretherketone	S	S	S	S	S	S	S
Low-density polyethylene	S	Q	S	—	S	Q	S
High-density polyethylene	S	Q	S	—	S	Q	S
Poly(ethylene terephthalate)	S	Q	S	S	S	S	S
Poly(phenylene oxide)	S	Q	S	S	S	U	S
Polypropylene	S	Q	S	S	S	Q	S
Polystyrene	S	Q	S	S	S	U	S
Polyurethane	Q	U	S	Q	U	Q	S
Epoxy	S	U	S	S	S	S	S
Silicone	Q	U	S	S	S	Q	S

<sup>a</sup> S = satisfactory; Q = questionable; U = unsatisfactory.

Source: Adapted from R. B. Seymour, *Polymers for Engineering Applications*, ASM International, Materials Park, OH, 1987.



# Degradasi Elastomer

**Table 17.5** Resistance to Degradation by Various Environments for Selected Elastomeric Materials<sup>a</sup>

<i>Material</i>	<i>Weather Sunlight Aging</i>	<i>Oxidation</i>	<i>Ozone Cracking</i>	<i>Alkali Dilute/ Concentrated</i>	<i>Acid Dilute/ Concentrated</i>	<i>Chlorinated Hydrocarbons, Degreasers</i>	<i>Aliphatic Hydrocarbons, Kerosene, Etc.</i>	<i>Animal, Vegetable Oils</i>
Polyisoprene (natural)	D	B	NR	A/C-B	A/C-B	NR	NR	D-B
Polyisoprene (synthetic)	NR	B	NR	C-B/C-B	C-B/C-B	NR	NR	D-B
Butadiene	D	B	NR	C-B/C-B	C-B/C-B	NR	NR	D-B
Styrene- butadiene	D	C	NR	C-B/C-B	C-B/C-B	NR	NR	D-B
Neoprene	B	A	A	A/A	A/A	D	C	B
Nitrile (high)	D	B	C	B/B	B/B	C-B	A	B
Silicone (polysiloxane)	A	A	A	A/A	B/C	NR	D-C	A

<sup>a</sup> A = excellent, B = good, C = fair, D = use with caution, NR = not recommended.

Source: *Compound Selection and Service Guide*, Seals Eastern, Inc., Red Bank, NJ, 1977.