Engineering Journal of Qatar University, Vol. 1, 1988.

"CORROSION FAILURES: IDENTIFICATION, DIAGNOSIS & REMEDIES"

By

G.S.A. Shawki & **A.Y. Kandeil**
Professor & Dean, Associate Professor,

Faculty of Engineering, Qatar University,
Doha, Qatar, Arabian Gulf.

ABSTRACT

This paper deals with the nature, typical surface features and common forms of corrosion. It also reports corrosion rates in various locations and under differing environmental conditions, viz. tropical, marine, urban and industrial.

Rates of corrosion failures may well overweigh those of mechanical failures. Measures taken to control corrosion, mainly include proper selection of materials, application of suitable protective coatings, alteration of environment and careful design of components and assemblies. These remedies no doubt exert differing influences on part life and economy. Correct diagnosis of failures would evidently help in making the right decision as to the most effective protective measures to be taken.

1. INTRODUCTION

Corrosion may be defined as the gradual undesirable destruction or breakdown of a solid material (e.g. metals and rocks) under the action of an unintentional chemical and/or electrochemical attack which usually starts at the surface. Such reaction alters the corroding metal in such a way that often makes it useless. Corrosion in iron and steel is known as rusting (oxidation).

Gases such as sulphur dioxide in smoke sometimes cause corrosion. Metals laid underground (e.g. electric cables) are liable to corrode by chemicals present in the soil. Component failure due to corrosion may be catastrophic, e.g. gas pipes and high pressure boilers.

Several ways have been devised for corrosion prevention or corrosion control (1-5); these include:

a) Protection of surfaces by metallic or non-metallic coatings (e.g. paints, plastics, elastomers, non-corroding metals etc.).

b) Adding alloying elements with a view to producing alloys with enhanced corrosion resistance.

c) Using inhibitors to reduce the corrosive action of the environment.

d) Proper design of components and assemblies taking into consideration intermaterial influences as well as the deterioration of material properties and service life under corrosive conditions.

e) Application of certain methods of protection such as "Cathodic Protection" for buried pipe lines.

2. TYPES OF SERVICE DAMAGE

Deterioration of components in service may be caused by physical factors only such as by abrasive wear, or by chemical and/or electro-chemical influences, these being aggravated or assisted by physical conditions which may comprise one or more of the following factors:

1. Loading, presence of static and/or dynamic stress.

2. Low pressure, eventually leading to cavitation.

3. Repeated relative motion or displacement between the interfaces of components in service, e.g. fretting corrosion.

4. Heating, this may lead to thermogalvanic corrosion or to high temperature corrosion.

Table (1) presents a summary of the most common types of service damage. Deterioration due to physical influences is herein referred to for comparison only. Typical forms of corrosion as aggravated by loading are displayed in Figure (1), while the nature and mechanism of damage emanating from the collapse of vapour-filled bubbles due to low pressure are illustrated in Figure (2). Repeated relative motion may lead, under corrosive environment, to corrosionerosion, corrosive wear or to fretting corrosion, Figure (3). Typical forms of corrosion, as influenced by thermal effects are shown in Figure (4). Chemical and/or electro-chemical attack can result in a variety of types of surface damage, notable among which are galvanic corrosion, hydrogen damage, crevice corrosion, intergranular corrosion and pitting damage, Figures (5) and (6).

Oxidation-reduction reactions can take place under various conditions, with galvanic cells assuming some three types, namely cells involving unlike electrodes, stress cells and solution concentration cells (6).

Experience gained in the failure of various forms of titanium heat exchangers in chemical plant has recently been reported by Liening (7). Figure (7) indicates the boundary lines for the development of crevice corrosion, also for hydrogen pickup (8).

Surface failure as resulting from corrosive action may assume various forms (9), e.g. spread damage, localized damage, highly localized damage (pitting) and cracking, Table (2) and Figure (8).

One of the serious types of corrosion is the microbial or bacteria-induced corrosion which has recently received careful attention, yet bacterial involvement in the corrosion process is not, however, at present completely understood (10). Corrosion failures are strongly related to corrosion rates of materials i.e. higher corrosion rates normally resulted in accelerated failure of engineering components. Therefore, before discussing corrosion failures, corrosion rates for various materials will be presented.

Table (1): Most common type of service damage.

Deterioration by	Aggravated or accompanied by		Typical Forms of Damage
Physical causes only (This type of deterioration is not corrosion)	Absence of chemically active media		Loss of dimensions (and consequently weight): — Erosion, — Wear (abrasive) or Galling
Chemical &/or electrochemical attack (by virtue of inherent or induced difference of electric potentiality of mating components)	Physical conditions: one or combination of:	Loading	— Stress corrosion cracking (Presence of tensile stress) — Corrosion Fatigue
		Low pressure	— Cavitation corrosion (or Damage)
		Repeated relative motion (displacement) between interfaces	— Corrosion-erosion — Corrosive wear — Fretting corrosion
		Heat	— Thermogalvanic corrosion — High temperature corrosion
	Chemical conditions e.g. attack by acids, etc.		— Galvanic corrosion — Hydrogen damage (due to admission of hydrogen into metal-Hydrogen Embrittlement) — Crevice corrosion (due to oxygen concentration cells) — Intergranular corrosion

Continued

Deterioration by	Aggravated or accompanied by	Typical Forms of Damage
Chemical &/or electro chemical attack (continued)	chemical conditions e.g. attack by acids etc. (continued)	— Pitting corrosion — Microbial corrosion — Selective attack (Leaching) — Electrolytic corrosion (due to uncontrolled direct current flow) — Uniform (or general) corrosion (Anodes and cathodes are inseparable)

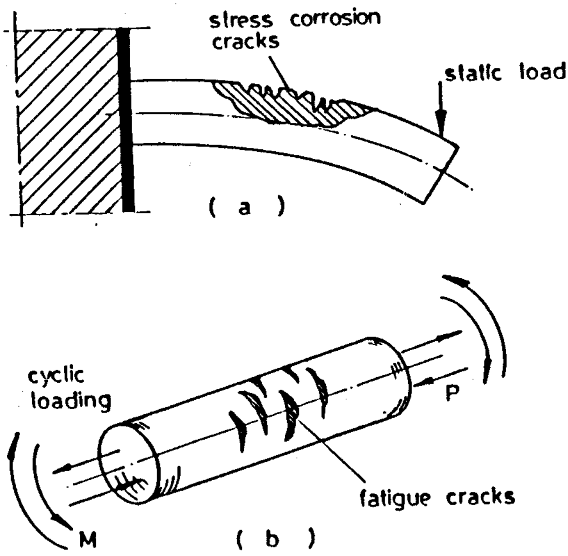


Fig. (1): Typical forms of corrosion as aggravated by loading.

(a) Stress corrosion cracking (presence of static tensile stress)

(b) Corrosion fatigue (presence of cyclic loading)

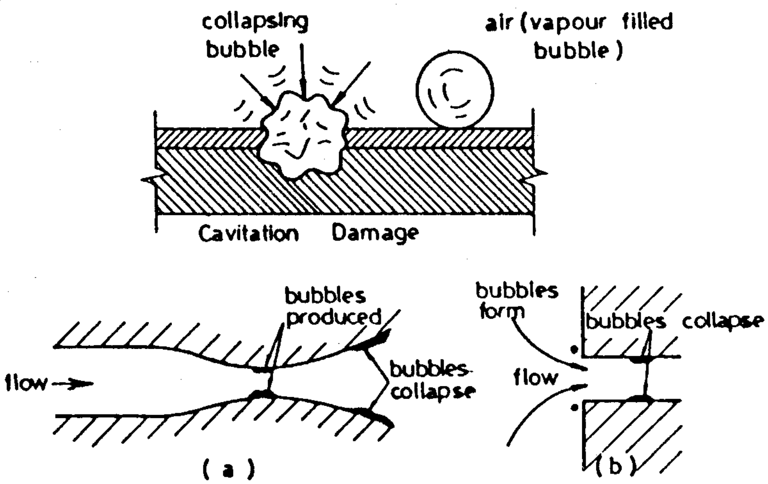


Fig. (2): Nature and mechanism of cavitation corrosion (collapse of vapour filled bubbles).

(a) Damage occurring in a curved channel

(b) Damage emanating from sudden change of cross section of flow

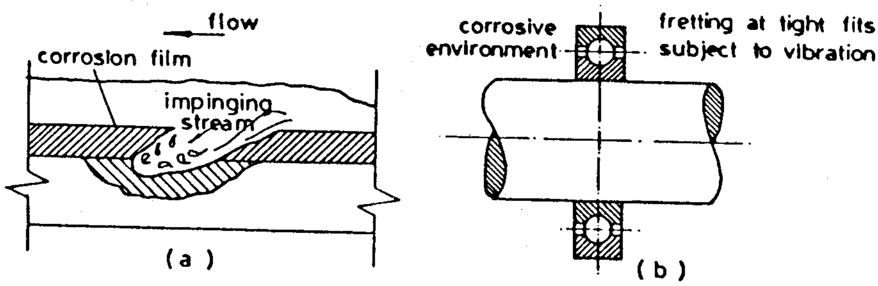


Fig. (3): Some typical forms of corrosion as aggravated by repeated relative motion (displacement) of interfaces:

(a) Corrosion-erosion

(b) Fretting corrosion

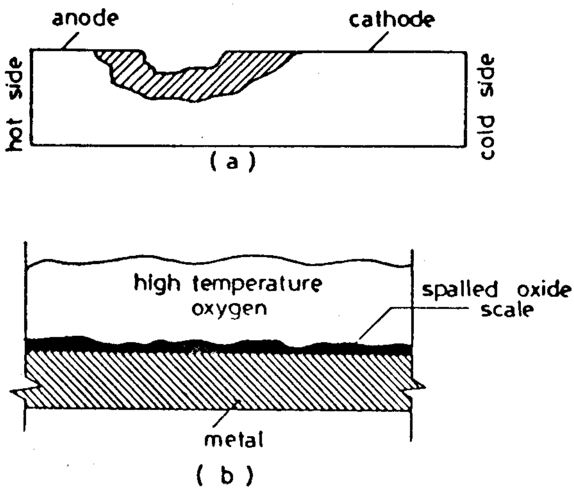


Fig. (4): Some typical forms of corrosion as aggravated by repeated relative motion (displacement) of interfaces:

(a) Thermogalvanic corrosion

(b) High temperature corrosion

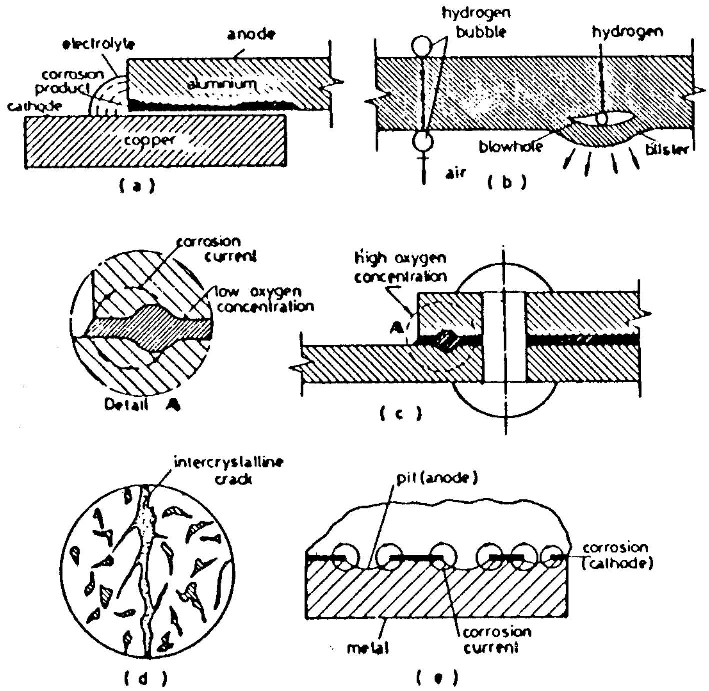


Fig. (5): Typical forms of corrosion resulting from chemical &/or electro-chemical attack:

(a) Galvanic corrosion
(b) Hydrogen damage (embrittlement)
(c) Crevice corrosion
(d) Intergranular corrosion
(e) Pitting corrosion

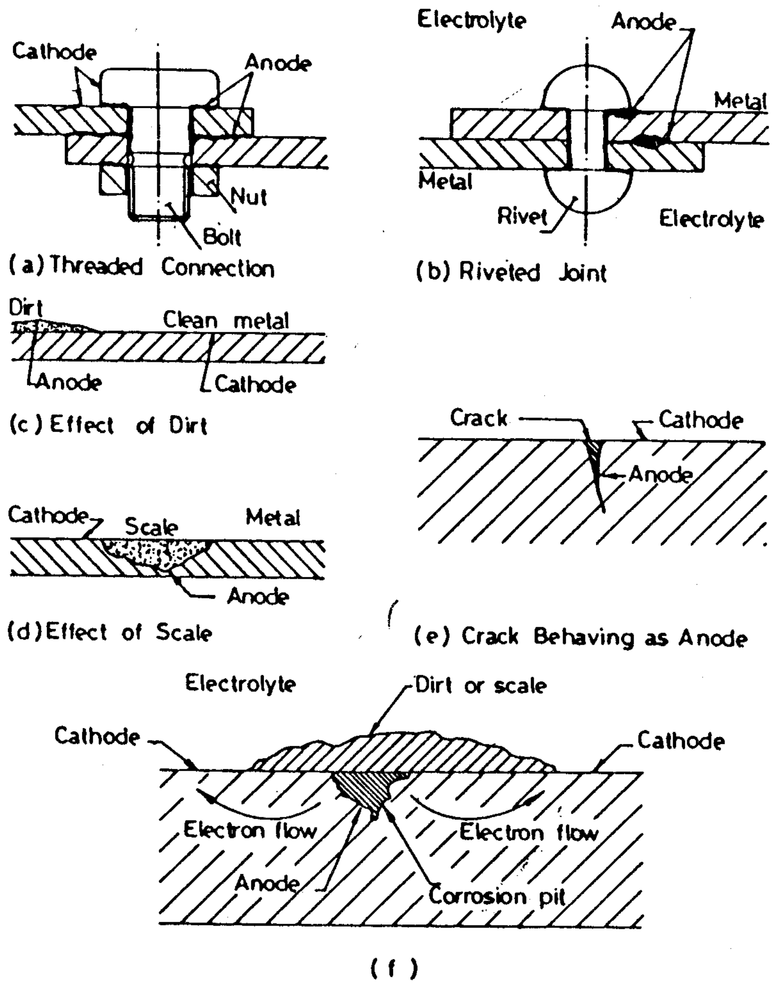
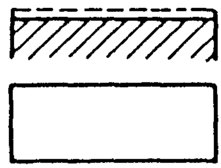
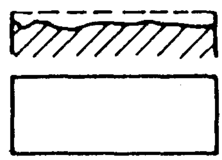
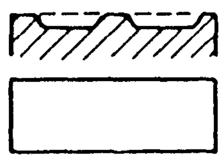
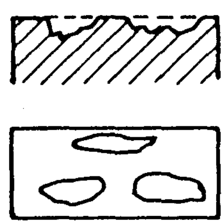


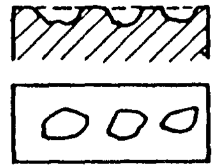
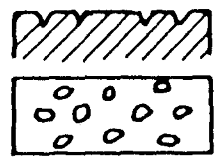
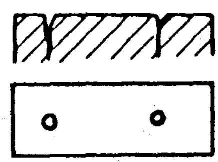
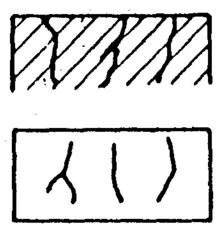
Fig. (6): Crevice corrosion emanating local variations in oxygen concentration. Inaccessible locations & interfaces with low oxygen concentration become anodic in polarity.

Table (2): Surface features of the more common forms of corrosion damage.

TYPE OF DAMAGE		CONFIGURATION (SEC. ELEV. & PLAN)
general corrosion: spread damage (e.g. oxidation & tarnishing)	even general corrosion	
	uneven general corrosion	
localized corrosion (e.g. crevice corrosion, intergranular corrosion, also cavitation damage, corrosion erosion, fretting corrosion etc.)	even localized corrosion	
	uneven localized corrosion	

Continued

Table (2): Surface features of the more common forms of corrosion damage (continued).

TYPE OF DAMAGE		CONFIGURATION (SEC. ELEV. & PLAN)
pitting: highly localized attack (e.g. pitting of passive metals such as stainless steel & aluminum alloys)	wide pits	
	medium size pits	
	narrow & deep pits	
cracking (e.g. stress corrosion, cracking, sulphide stress cracking)		

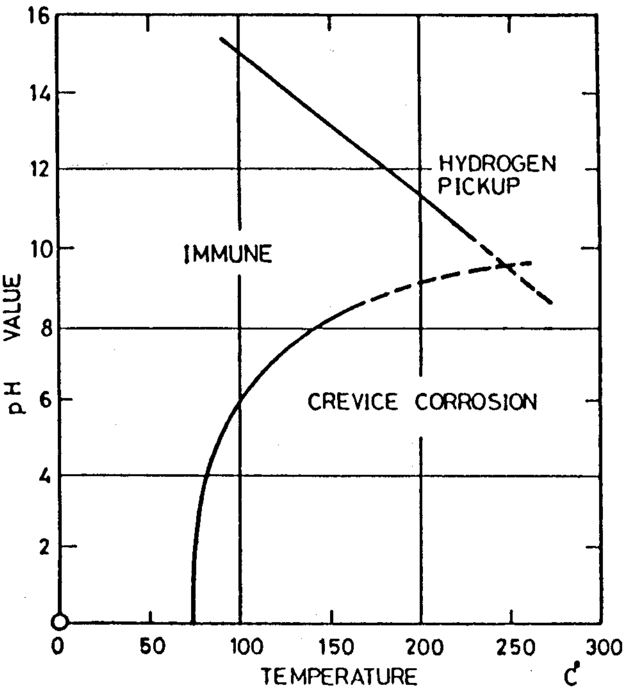


Fig. (7): Temperature and PH value boundaries for crevice corrosion of grade 2 titanium in Na C1 brine (based on data taken from Timet (8).

Table (3): Typical corrosion rates for mild steel outdoors*.

Environment	Site	Average Corrosion Rate (mm/year)
Rural or Suburban	Khartoum Delhi Berlin-Dahlem Teddington, G.B.	0.003 0.008 0.053 0.070
Marine	Basrah, Iraq Singapore Brixham, G.B. Calshot, G.B. Sandy Hook, N.J., U.S.A.	0.015 0.015 0.053 0.079 0.084
Industrial	Pittsburgh, Pa., U.S.A. Sheffield, G.B. Derby, G.B.	0.108 0.135 0.170
Marine Industrial	Congella, South Africa	0.114
Marine, Surf beach	Lagos, Nigeria	0.615

*** Based on data from Shreir (9).**

3. CORROSION RATES

Corrosion rates have been shown to depend on a number of factors, among which are the following:

1) Environmental and working conditions, e.g. rural or suburban, industrial and marine environments, Table (3).

2) Time of the year. By way of example, the rate of rusting of steel varies from a minimum value of some 0.064 mm/year during the month of March to a maximum value of some 0.094 mm/year attained during the month of September (9).

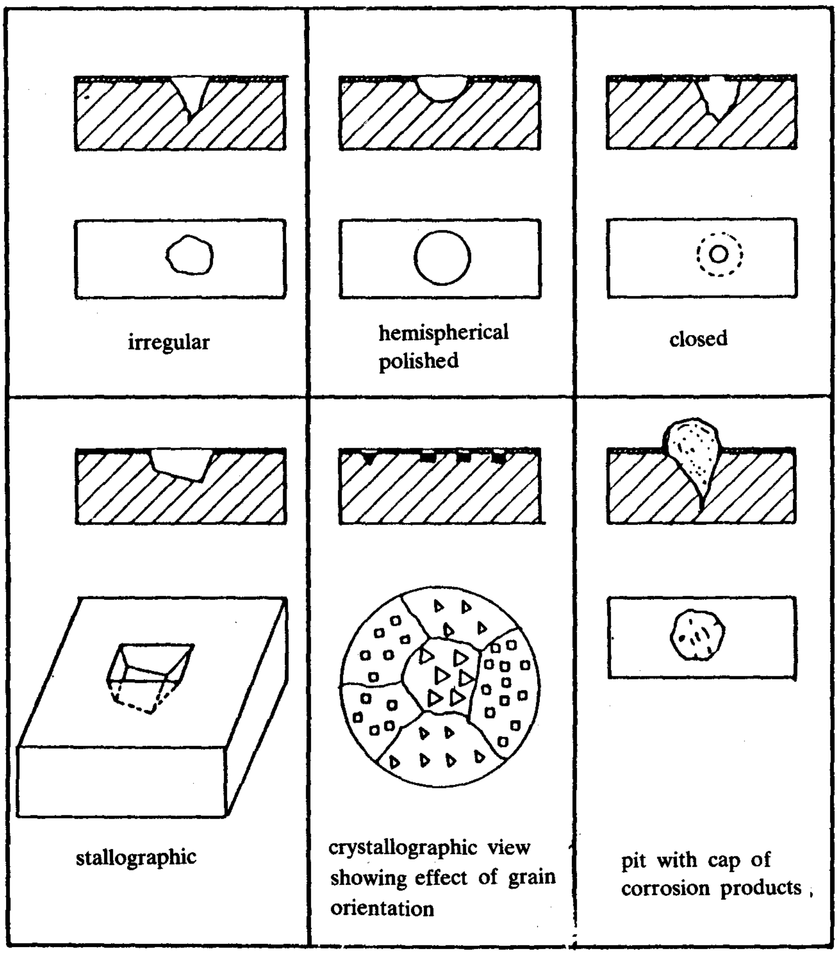


Fig. (8): Some typical forms of pitting damage.

3) Degree of purity of the metal; relative corrosion may well increase considerably with degradation of purity. A 99.2% A1 shows a corrosion rate 30,000 times that displayed by 99.998% pure aluminium (4).

4) Type of material exposed to corrosive environment. Figures (9) and (10) show typical weight loss and general penetration in corrosion respectively for some steels, cast iron and brass (3, 9). It can be readily seen from Figure (9) that the weight loss for brass is more than seven fold that exhibited by 18-8 CrNi steel after a period of exposure of two hours. This is the reason underlying the use of this type of steel as facing material for water turbine blades. Figure (10) shows how low-alloy additions can seriously add to the corrosion resistance of steel.

5) Time of exposure to corrosion. Figure (11) shows, by way of example, that for both ferrous and non-ferrous metals, while the average corrosion rate assumes quite a high value at the beginning of exposure, it drops drastically to an asymptotically declining value after a period of exposure of some two years.

6) Velocity of flow. Figure (12) shows that higher velocity of moving fluids give rise to enhanced corrosion rates (3).

7) Working temperature. An 18-8 CrNi steel exposed to 65% Nitric Acid displays, for example, at a temperature of 190°C a corrosion rate 250-fold that experienced by same steel under same conditions, but at a temperature of only 120°C.

4. CORROSION FAILURES

Experience accumulated over the years indicates that failures due to corrosion may well overweigh mechanical failures. Table (4) shows that while corrosion failures occur at a frequency of some 57%, mechanical failures seem to take place at a lower frequency, namely 43%, i.e. corrosion failures may be encountered some 33% more than mechanical failures. This points out to the reason underlying contemporary intensive interest in corrosion and corrosion failures.

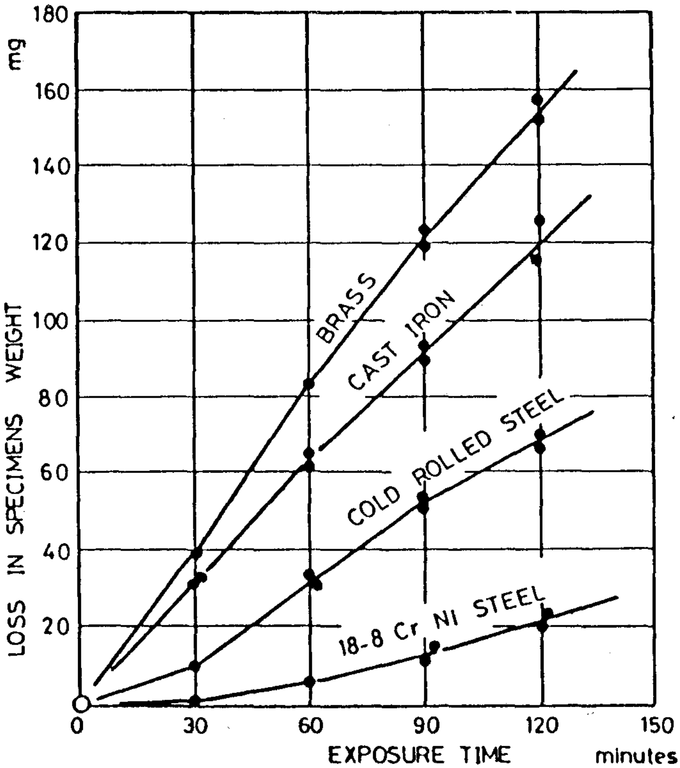


Fig. (9): Resistance of various metals to corrosion erosion (laboratory) tests in cambridge water at room temperature.

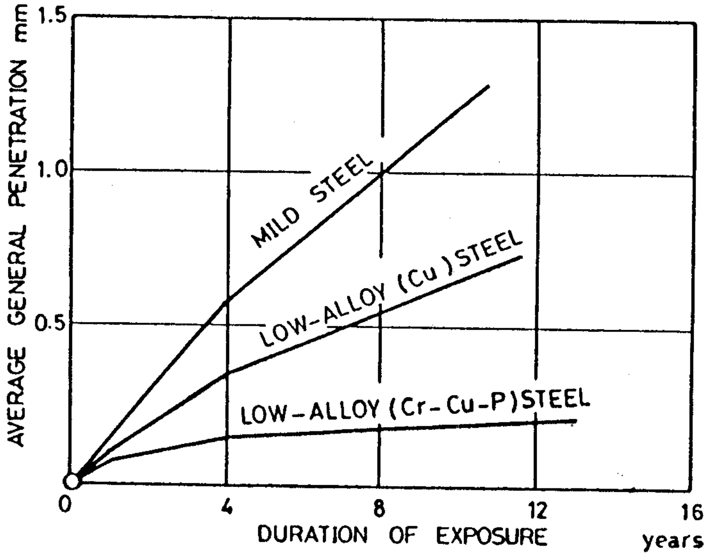


Fig. (10): General penetration as influenced by low-alloy additions for steel subject to corrosion under outdoor environment.

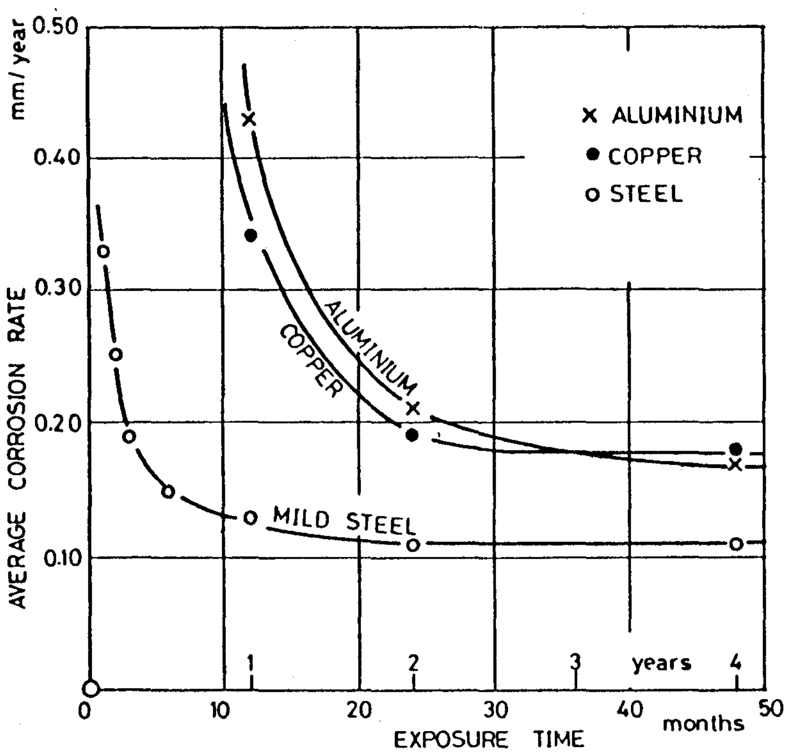


Fig. (11): Variation of average corrosion rate with exposure time for mild steel, copper & aluminium.

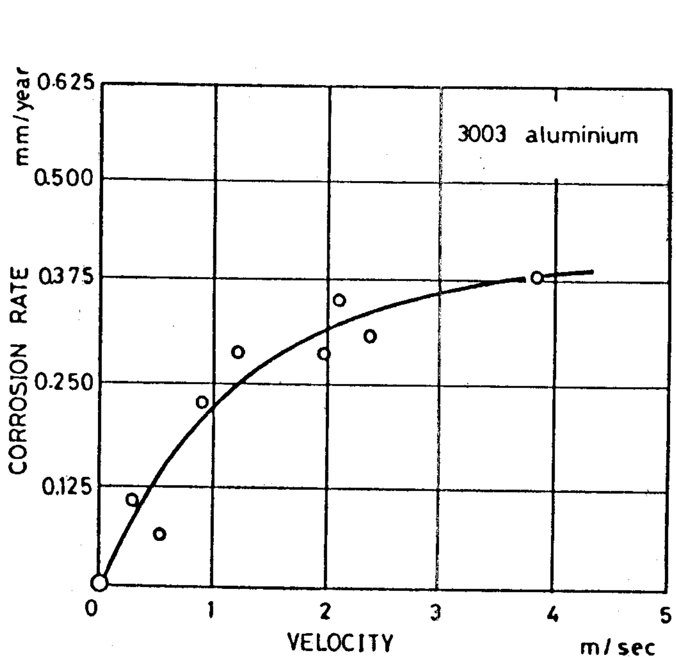


Fig. (12): Corrosion-erosion of 3003 aluminium subjected to white fuming nitric acid at 42°C (corrosion rate taken as the average of 4 tests each of 24 hr duration).

A breakdown of corrosion failures by type is further presented in Table (5) which clearly shows that of all types of corrosion failures, both general corrosion and stress corrosion cracking are responsible for the majority of corrosion failures. On the other hand, pitting and intergranular corrosion failures are expected to be met in only one fourth of failure cases. Other types of corrosion failure have been found to occur at a much lower frequency.

5. SUMMARY AND CONCLUSION

Types, features, causes and rates of corrosion failures are herein thoroughly reviewed. Should these failures be carefully identified, effective remedies can be prescribed.

For maximum reliability, the use of materials with enhanced corrosion resistance is recommended. If this merit criterion is not of prime importance, the optimum choice of relevant protective control of corrosion would be governed by economical considerations.

Table (4): Comparison between frequency values of corrosion versus mechanical failures over a two-year period*.

Category	Type of Failure	Frequency of Failures %	
Corrosion Failures	General corrosion	17.92	
	Stress corrosion cracking & corrosion fatigue	13.32	
	Pitting corrosion	8.93	
	Intergranular corrosion	5.80	
	Cavitation corrosion (or damage) Erosion corrosion Fretting corrosion	5.12	45.97
	Thermogalvanic corrosion	1.31	
	High temperature corrosion	1.31	
	Weld corrosion	1.31	
	Hydrogen damage (Embrittlement)	0.29	
	Crevice corrosion	1.02	
	Selective attack (Leaching)	0.57	
			56.9
Mechanical	Mechanical failures		43.1

*** Based on Data from Du Pont Company's Reports.**

N.B. Considerable deviations from above percentage may be encountered depending on environmental and working conditions.

Table (5): Corrosion failures analysed by type*.

Type of Corrosion	Average Rate	Failure %
General corrosion	30.4	56.6
Stress corrosion cracking	26.2	
Pitting corrosion (Highly localised damage)	15.8	27
Intergranular corrosion	11.2	
Erosion corrosion	7.6	12.6
Weld corrosion	5.0	
All other types of corrosion	3.8	3.8
		100%

*** Based on Data from Du Pont Company's Reports.**

6. REFERENCES

1. **Shreir, L.L.:** "Corrosion Handbook — Corrosion Control", Vol. 2, Newnes, Butterworths, 1979.

2. **Pludek, V.R.:** "Design and Corrosion Control", The MacMillan Press Ltd., 1979.

3. **Uhlig, H.H.:** "Corrosion and Corrosion Control — An Introduction to Corrosion Science and Engineering", John Wiley & Sons Inc., 1971, pages 105, 109 & 112.

4. **Fontana, M.G.** and **Green, N.D.:** "Corrosion Engineering", McGraw-Hill Book Company, 1978.

5. **Barrett, C.R., Nix, W.D.** and **Tetelman, A.S.:** "The Principles of Engineering Materials", Prentice-Hall, Inc., 1973.

6. **Van Vlack, L.H.:** "Materials Science for Engineers", Addison-Wesley Publishing Company, 1970, Ninth Printing, 1982.

7. **Liening, E.L.:** "Unusual Failures of Titanium Equipment in Chemical Processing", International Forum on Corrosion, Anaheim, California, April 1983, Paper No. 15, 25 pages.

8. **Timet,** "Corrosion Resistance of Titanium", Pages 7 and 8.

9. **Shreir, L.L.:** "Corrosion Handbook — Metal/Environment Reactions", Vol. 1, Newnes-Butterworths, 1979.

10. **Stoecker, J.G.:** "Guide for the Investigation of Bacteria-induced Corrosion", International Forum on Corrosion, Anaheim, California, April 1983, Paper No. 245, 17 pages.