Summary of Technical Characteristics of the Metal alloys Hastelloy C-276 and Titanium grade 2.

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Great Plains Stainless

Foreword

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Choice of Corrosion Resisting Material in Mining.

r recovery of different metals from metallic es, chemical and pyro-metallurgical treatments, ch as roasting, smelting and leaching are rformed under varying conditions of nperatures, pressures and corroding media. ıce the economics of the process are influenced the life of the equipment, materials for nstruction thereof are selected so as to possess quired resistance to corrosion and abrasion. etallurgical practice for the extraction of metals n be divided mainly into the following steps:

Concentration of ore;

Roasting of the ores or concentrate in lphides and arsenides;

(a) Smelting the ores or roasted concentrates to ude metals or metals in case of pyrometallurgy;

Leaching with acids or alkalies for selective lution of the required metal in pyrometallurgical ocesses. The leached solutions are further rified for the production by electrolysis of pure etal or pure compounds, which are treated to duce them to metallic state;

Purification of crude metal by electrolysis or rometallurgical processes.

us for the recovery of metal from the ores, rious steps are to be performed under different nditions of temperature, pressure and rroding media. The proper selection of aterials for the construction of equipment in a ant is directly dependent on (i) the mechanical operties at working temperature e.g. strength, eep, ductility etc; (ii) resistance to corrosion by e gasses, acids, alkalies, liquid metal etc. at fferent working temperatures and pressure; (iii) erall economy. Various metals and alloys have

1.Technical Specification

The following specifications cover:			
Hastelloy C276		Titanium Grade 2	
ASTM B366	ASTM B574	AMS 4902	AMS 4941
ASTM B575	ASTM B619	AMS 4942	ASTM B265
ASTM B622	ASTM B626	ASTM B337	ASTM B338
ASTM F467	ASTM F468	ASTM B348	ASTM B348 (2)
DIN 2.4819	UNS N10276	ASTM B381	ASTM F468 (2)
		ASTM F67	ASTM F67 (2)
		DIN 3.7035	MIL T-9046
		MIL T-9047	UNS R5040
		ASTM F467 (Ti-2)	

Table 01 - Equivalence specifications.

2.Chemical Composition

Alloy (wt. %)		Ni	Co	Cr	Mo	W	Fe	Si	Mn	C	V	P	S
Hastelloy® C 276	Min.	Balance	2.5	14.5	15.0	3.0	4.0	0.08	1.0	0.01	0.35	0.025	0.010
	Max.		Max.	16.5	17.0	4.5	7.0	Max.	Max.	Max.	Max.	Max.	Max.

Table 02 – Chemical Composition Alloy Hastelloy C-276.

Alloy (wt. %)		Ti	N	C	H	Fe	O
Titanium grade 2	Min.	Balance	0.03	0.10	0.015	0.30	0.25
	Max.		Max.	Max.	Max.	Max.	Max.

Table 03 – Chemical Composition Titanium grade 2.

3. Aplications

Hastelloy® C-276: having perhaps the broadest general corrosion resistance of all commonly used alloys. It was developed initially for use with wet chlorine, but it also offers excellent resistance to strong oxidizers such as cupric and ferric chlorides, and to a variety of chlorine compounds and chlorine contaminated materials. Because of its broad chemical resistance, Alloy C-276 is the second most popular alloy, following T316SS, for vessels used in research and development work.

Titanium grade 2: proves useful in chemical processes, since it is highly resistant to chemical environments including oxidizing media, alkaline media, organic acids and compounds, aqueous salt solutions and hot gases. Its corrosion resistance holds up in liquid metals, nitric acid, mildly reducing acids and wet chlorine or bromine gas. Titanium grade 2 is also used to manufacture heat exchangers and cryogenic vessels. Marine: In seawater, Grade 2 is fully resistant to corrosion at temperatures up to 600 F, rendering it ideal for a variety of marine uses. It is suitable for condensers and evaporators, as well as the titanium tubing and tube headers in desalination plants.

4. Maximum operating temperature

Generally the first thing we think of is the material of construction required for the application desired. We then must consider the maximum allowed working temperature of a vessel required. We assume everyone knows that the maximum operating pressure of a vessel is reduced as the strength of the construction material falls of at elevated temperatures. There is a maximum temperature for each material we use. The allowable strength for these metals falls off rapidly as they reach maximum operating temperature. Finally, the difficulties encountered with components operating at high temperatures.

Hastelloy® C-276: 427°C (800°F)

Titanium grade 2.: 315°C (600°F)

5. Why is resistant to corrosion in these Metal_alloys

Hastelloy® C-276: corrosion resistance in nickel alloys is due to the formation of a film of oxide or hydrated oxide. Both in alkaline solution and in acidic solution, support the existence of surface oxide films on passive nickel several nanometres thick.

Titanium grade 2: is intrinsically very reactive, so that whenever the metal surface is exposed to air, or to any environment containing available oxygen, a thin tenacious surface film of oxide is formed. This oxide, which is present on fabricated titanium surfaces at normal or slightly elevated temperatures, has been identified as

6. Crevice Corrosion

Definition: often occurs within narrow openings and gaps (such as those found under gaskets, washers, etc.). Large surface areas will become cathodic and the crevices will become anodic, and thus will corrode (fig.01). The crevices create an environment that traps pollutants, concentrates corrosion products and excludes oxygen which in turn accelerates the rate of corrosion.

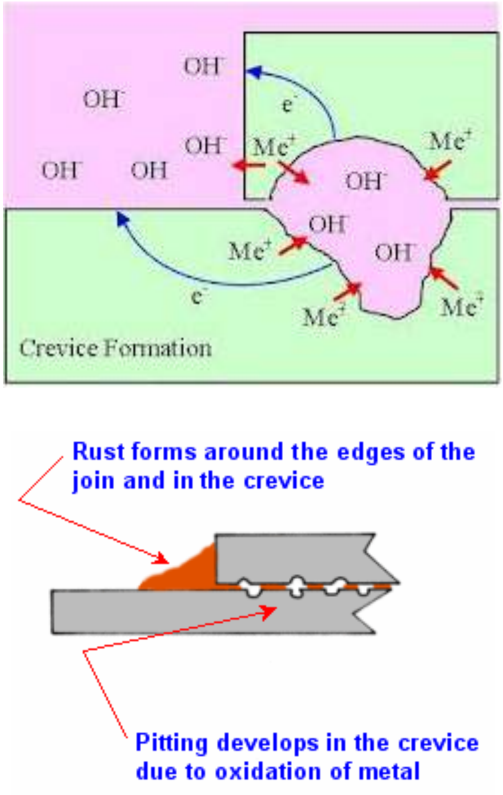

Fig. 01 - Crevice Formation

Figures 02 and 03 show a sample of crevice corrosion parts.

Hastelloy® C-276: Ni-Cr-Mo alloys are among the most resistant of metallic materials to crevice corrosion,although their resistance may be impaired if intergranular precipitates of molybdenum rich carbide are allowed to form. In cast materials at least, solution heat-treatment of the Hastelloy C 276 type of alloy is beneficial and if such a heat-treatment is given.

Titanium grade 2: Although the titanium crevice corrosion is most common in warm chloride solutions, it can also occur in solutions of bromide, iodide, and sulfate. The corrosion susceptibility increases with increasing temperature and concentration of chloride ions and decreases with decreasing pH, and dissolved oxygen concentration, which is the biggest problem of use this material and its alloys.

Titanium is more resistant to crevice corrosion than most conventional metals and alloys, particularly where differential aeration is involved, e.g. it is very resistant to crevice attack in sea water at normal temperatures This form of corrosion becomes more severe when acidity develops in a crevice and this is more prone to occur under conditions of heat transfer. Under these circumstances, especially in the presence of strong aqueous halides at temperatures in excess of 130 °C. This limiting temperature can be raised with additional alloys or by coating with noble metals.

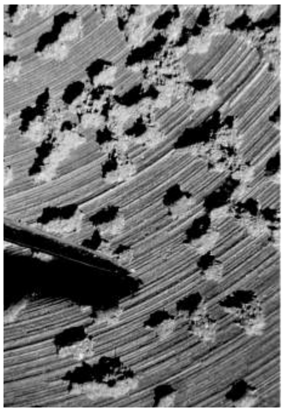

Fig.02- Crevice corrosion propagation process

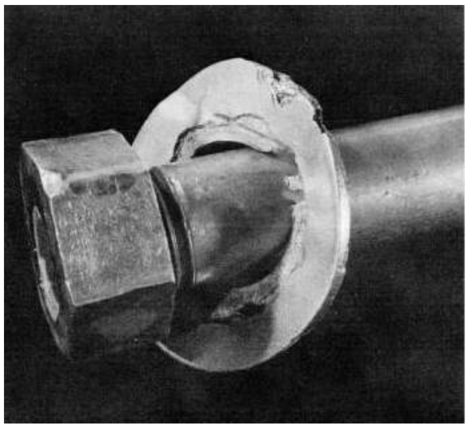

Fig. 03 - Part damaged by crevice corrosion.

7. Pitting

Difinition: is very similar to crevice corrosion with the main difference being that corrosion will occur at locations of dissimilarity in the metal rather than inside a crevice. Once a pit is formed from localized corrosion, the pit continues to act as the anode (losing electrons and mass) while the cathodic reaction remains $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$(Fig. 04). Corrosion products (scale) often form chimneys that cover the pits and lead to an increased rate of corrosion as the corrosive products become trapped within the pit. The mechanism for pitting corrosion is extremely similar to that of crevice corrosion.

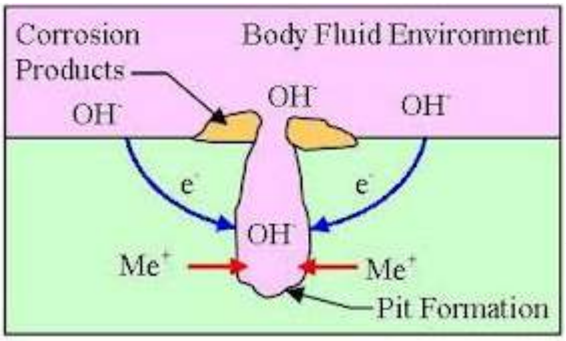

Fig. 04 – Pitting Formation.

Hastelloy® C-276: in practice, pitting of nickel and nickel alloys may be encountered if the corrosive environment contains chloride or other aggressive ions and is more liable to develop in acidic than in neutral or alkaline solutions. In acidic solutions containing high concentrations of chloride, however, passivity is likely to break down completely and corrosion to proceed more or less uniformly over the surface. For this reason nickel and those nickel alloys which rely on passivity for their corrosion resistance are not resistant to HCl.

Titanium grade 2: to decrease the susceptibility to corrosion anodization is carried out after titanium manufacturing or installation equipment in order to remove particles of iron and thicken the passive film. In the titanium, in the presence of Cl^-,occurs in very high potential and difficult to be attained spontaneously..

The presence of TiO_2 is a formidable barrier to uniform corrosion, but it can fail and lead to localized corrosion, including pitting, in the presence of aggressive anion species. Aggressive anion species, especially halide ions such as Cl^-, cause pitting.

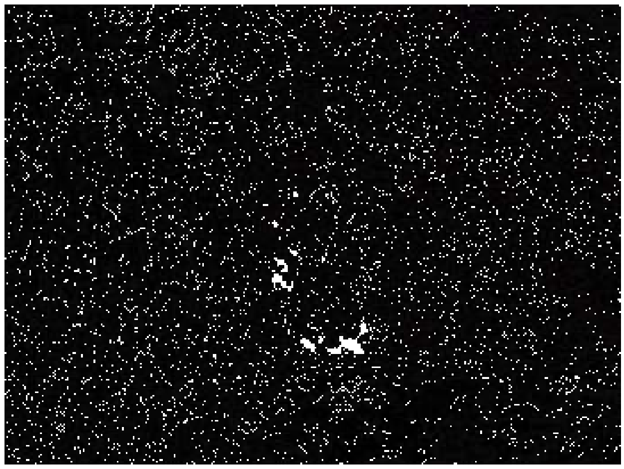

Fig. 05 -Sample Pitting.

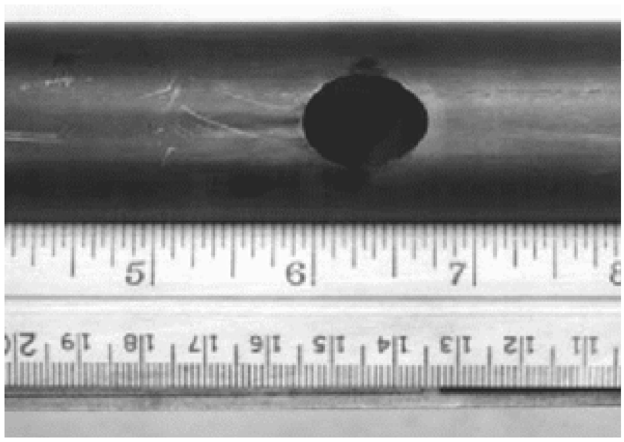

Fig.06 – Unalloyed titanium tube perforated by pitting in hot brine.

7. Conclusion

The choice of such alloys against corrosion is essential for a particular structural implementation. Corrosion can reduce the load capacity of a component by reducing their size (cross section) or localized attack (pitting, crevice, etc.) which also reduces the cross section of the attacked area may increase the stress crack formation starting .

All preventive measures that prevent or eliminate the corrosion will increase component life and reliability. The metal alloys Hastelloy C-276 and Titanium Grade 2 has a wide industrial application and there is an intersection of choice for the same work in the field. Factors to consider for selection of the alloy corrosion protection are:

- Environmental conditions;
- Cost;
- Degree of protection necessary;
- Failure consequences unforeseen work.

8. Reference Bibliography

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- Corrosion Resistance of HASTELLOY®Alloys Databook;
- Corrosion: Understanding the Basics, Joseph R. Davis, ASM International, 2000;
- Corrosion Volume 1 Metal/Environment Reactions / Corrosion Volume 2 Corrosion Control Edited byL. L. Sheir, PhD, CChem, FRIC, FIM, FICorrT,FIMF, OBE R. A. Jarman, MSc, PhD, CEng, FIM, MIEE, FWI G. T. Burstein, MSc, PhD, MA;
- Failure Analysis and Prevention Volume 11 ASM Handbook;
- Oxides formation and characterization grown on anodized Ti and Ti6Al4V";
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- Titanium: A Technical Guide, 2nd Edition By Matthew J. Donachie;
- Uhlig's corrosion handbook / edited by R. Winston Revie. — 2nd ed.;

9. Supplemental Reading

http://www.nickelinstitute.org/

http://www.titanium.org/

http://en.wikipedia.org/wiki/Corrosion

http://corrosionjournal.org/

Supplementary Information

Table 04 – Advantages, Disavantages and warnings

Alloy	Advantages	Disavantages and warnings
Hastelloy® C-276	• Broad range of general corrosive resistance for commonly used alloys, corrosive resistance in high pressure and temperature ranges, • Excellent Resistance to hydrogen embrittlement. • The corrosion resistance of Hastelloy may also be improved by_passivating the surface to remove contaminates which adversely affect its corrosion resistant properties. • Effective survival under high temperature • High stress service in moderately to severe corrosive or erosion prone environments	• Sensitive to strong oxidizing conditions.
Titanium grade 2	• Excellent for use with oxidizing agentes.Compared with SUS316 and Hastelloy C, titanium is superior in resistance to almost all corrosion media. • Low specific weight	• Not suitable for welding, it burns in the of presence oxygen at elevated temperatures. • Poor Resistance to hydrogen embrittlement. • The passivation of titanium does not affect or improve its corrosion resistant oxide layer. However, passivation of titanium does remove iron and other surfaces contaminates. • low elongation and low flexibility

Table 05 - Comparison for different environment.

Comparison of Corrosion Resistance of Hastelloy C 276 and Titanium grade 2					
	Name of Chemical	Concentration (%)	Temperature (°C)	Titanium Grade 2	Hastelloy C 276
Inorganic Acids	Hydrochloric Acid	1	Room Temperature	A	A
			Bolling	B	C
		5	Room Temperature	A	B
			Bolling	C	C
		10	Room Temperature	B	B
			Bolling	C	C
		20	Room Temperature	C	B
			Bolling		C
		35	Room Temperature	C	A
			Bolling		C
	Hydrochloric Acid + Nitric Acid	1::3	Room Temperature	A	
		2::1	Room Temperature	A	
		3::1	Room Temperature	A	
		4::1	Room Temperature	A	
		7::1	Room Temperature	A	
		20::1	Room Temperature	A	
	3.5% HCl + 0.5% HNO3		Room Temperature	A	
	3.5% HCl + 0.5% FeCl3		Room Temperature	A	
	Sulfuric Acid	5	Room Temperature	A	A
			Bolling	C	B
		10	Room Temperature	B	A
			Bolling		C
		60	Room Temperature	B	A
			Bolling		C
		80	Room Temperature	C	A
			Bolling		C
		95	Room Temperature	C	A
			Bolling		C
	Sulfuric Acid + Hydrochloric Acid	10::90	Room Temperature	A	
		30::70	Room Temperature	A	
		50::50	Room Temperature	A	
		60::40	Room Temperature	A	
	80% H2SO4 + 0.5% HNO3		Room Temperature	A	
	10%HSO4+0.5%CuSO4		Room Temperature	A	
	15%H2SO4+2%Na2S +0.5%Na2S2O3		Room Temperature	A	
	10%H2SO4+24%HNO3 +1%ZnSO4+H2S injection		Room Temperature	A	
	Nitric Acid	37	Room Temperature	A	A
			Bolling	A	C
		64	Room Temperature	A	A
			Bolling	A	C
	Aqua Regia	1HNO3 + 3HCl	Room Temperature	A	A
			Bolling	A	C
	Chromic Acid	20	Room Temperature	A	A
			Bolling	A	A
	Phosphoric Acid	10	Room Temperature	A	A
			Bolling	C	A
		30	Room Temperature	A	A
			Bolling	C	B
		50	Room Temperature	B	A
			Bolling	C	B
	Acetic Acid	100	Room Temperature	A	A
			Bolling	A	A
	Formic Acid	50	Room Temperature	A	A
			Bolling	C	A
	Oxalic Acid	5	Room Temperature	A	B
			Bolling	C	B
		10	Room Temperature	B	A
			Bolling	C	B

A: Perfectly resistant, B: Reasonably resistant, C: Not applicable.

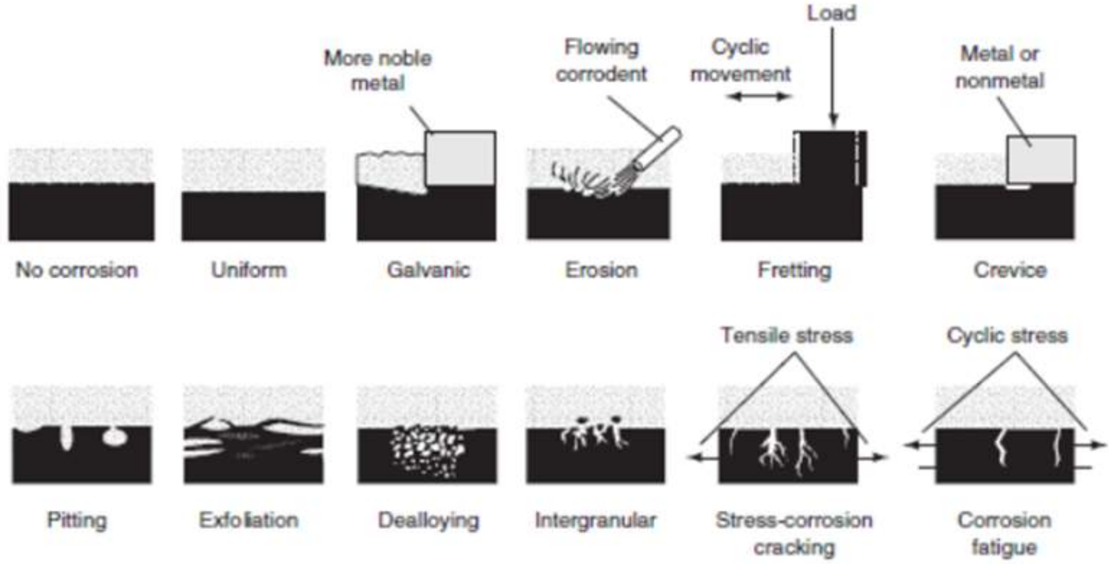
Table 06 - Comparison for different environment.

Comparison of Corrosion Resistance of Hastelloy C 276 and Titanium grade 2					
Name of Chemical		Concentration (%)	Temperature (°C)	Titanium Grade 2	Hastelloy C 276
Organic Substances	Lactic Acid	10	Room Temperature	A	A
			Bolling	A	
	Tannic Acid	20	Room Temperature	A	A
			Bolling	A	
	Citric Acid	50	Room Temperature	A	A
			Bolling	B	
	Stearic Acid		Room Temperature	A	A
			Bolling	A	
Chlorides	Ferric Chloride	30	Room Temperature	A	C
			Bolling	A	C
	Sodium Chloride	20°C Saturated	Room Temperature	A	A
			Bolling	A	B
	Ammonium Chloride	10	Room Temperature	A	B
			Bolling	A	
	Calcium Chloride	10	Room Temperature	A	A
			Bolling	B	
	Aluminum Chloride	25	Room Temperature	A	
			Bolling	B	
	Zinc Chloride	10	Room Temperature	A	A
			Bolling	A	A
	Magnesium Chloride	10	Room Temperature	A	B
			Bolling	A	
	Copper Chloride	50	Room Temperature	A	A
			Bolling	A	
	Carbon Tetrachloride		Room Temperature	A	A
			Bolling	A	
	Nickel Chloride	5	Room Temperature	A	A
		10	Bolling	A	
	Barium Chloride	20	Room Temperature	A	A
			Bolling	A	
Sulfated compounds and sulfides	Copper Sulfate	20	Room Temperature	A	A
			Bolling	A	A
	Ammonium Sulfate	20°C Saturated	Room Temperature	A	A
			Bolling	A	B
	Zinc Sulfate	20°C Saturated	Room Temperature	A	
			Bolling	A	B
	Sodium Thiosulfate	20°C Saturated	Room Temperature	A	A
			Bolling	A	A
	Sodium Sulfide	10	Room Temperature	A	
			Bolling	A	
	Sodium Sulfate	50	Room Temperature	A	B
			Bolling	A	
Nitric Acid Compounds	Ammonium Nitrate	10	Room Temperature	A	A
			Bolling	A	A
	Copper Nitrate	10	Room Temperature	A	B
		30	Bolling	A	
	Potassium Nitrate	All	Room Temperature	A	B
			Bolling	A	
Alkalis	Caustid Soda	20	Room Temperature	A	A
			Bolling	A	A
	Sodium Carbonate	20	Room Temperature	A	A
			Bolling	A	A
Corrosive gas and contained water	Chlorine Gas	100 wet	Room Temperature	A	B
	Chlorine Gas	Dry	Room Temperature	C	
	Ammonia Water	10	Room Temperature	A	A
			Bolling	A	A
	Chlorine Water	(100 gas saturated)	Room Temperature	A	A
			80	A	B
	Sufer Dioxide Solution	20	Room Temperature	A	
Others	Hydrogen Peroxide Solution	5	Room Temperature	A	A
			Bolling	A	A
		10	Room Temperature	A	A
			Bolling	A	A
	Potassium Bichromate	10	Room Temperature	A	A
			Bolling	A	A

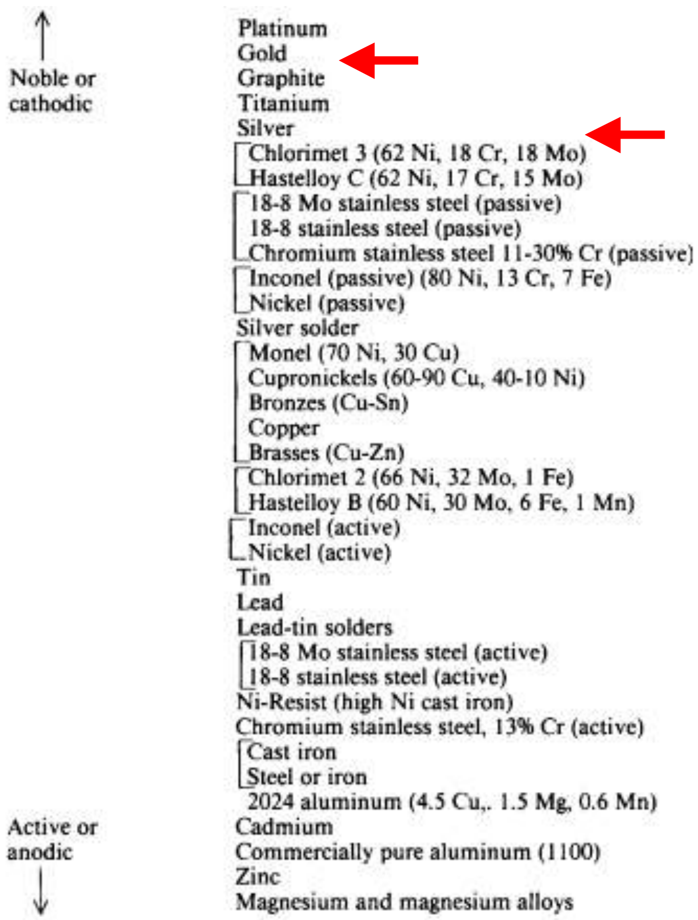
A: Perfectly resistant, B: Reasonably resistant, C: Not applicable.

The alloy of titanium grade 2 has a greater range of applications among different environment, but the choice of an alloy is a function of its working parameters in the field.

Schematic summary of the various forms of corrosion (ASM 2000)



Galvanic Series of Some Commercial Metals and Alloys in Seawater.



Source: Fontana,C.M. and Greene.N.D.(1983) Corrosion Engineering,2nd Edition, McGraw Hill International book company.