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**PRODUCT
DATA
SHEET****Corrosion of Titanium
& Titanium Alloys****Titanium
Alloys****Introduction**

Titanium and titanium alloys owe their excellent corrosion resistance to a stable, protective surface layer of titanium oxide. Titanium metal is highly reactive with oxygen, and the surface oxide forms spontaneously and instantaneously in contact with air and most media. Damage to the oxide film usually heals rapidly if the environment contains oxygen or moisture at the parts per million level. Hence titanium alloys are highly resistant to corrosion, usually corrode at negligible rates and require no corrosion allowance. However, anhydrous or highly reducing conditions may prevent the formation or healing of the oxide film, and corrosion may then become rapid.

This form of corrosion resistance is similar to that of aluminium and magnesium alloys, and of stainless steels, which also rely on a protective oxide film on the surface of a reactive metal.

Alloy Composition Effects

All the commercial purity grades corrode at very low rates while the metal remains in the passive condition. Small contents (< 2 – 3%) of the elements normally present have little effect on the oxide film, and hence on corrosion resistance. However, where the corrosion resistance is marginal (i.e. corrosion rates above about 0.13 mm/year), small amounts of elements such as sulphur and iron accelerate the corrosion rate of the alloy. Minor additions of other elements, such as palladium and nickel, can greatly reduce corrosion under these conditions, and made to highly corrosion resistant alloys such as grade 7.

Weldments of the lean alloys generally show the same corrosion resistance as the unwelded parent metal, without surface treatment. In marginal or active conditions attack may be accelerated at the weld, due to a higher content of impurity elements such as sulphur, iron, oxygen and nitrogen.

Corrosion

When titanium is fully passive, corrosion rates are typically lower than 0.04 mm/year, due to the highly stable surface protective film. In many environments the film may thicken, which gives interference colours and a slight weight gain. General corrosion may be encountered in reducing acid conditions, particularly at elevated temperatures. In strong and hot reducing acids the titanium oxide film can dissolve, and the unprotected titanium metal be taken rapidly into solution.

Crevice Corrosion

Titanium alloys may suffer crevice corrosion attack by a similar mechanism to that encountered in stainless steels: oxygen depleted reducing acid conditions develop within tight crevices isolated from the bulk corrosion media. Crevice corrosion may be encountered in hot (>70°C) solutions containing chlorides, bromides, fluorides, iodides or sulphates. It can stem from metal to metal joints such as tube to tubesheet joints or badly designed welds, at gaskets, or at surface deposits.

Pitting Corrosion

Titanium alloys are highly resistant to pitting corrosion, and it is rarely encountered.

Hydrogen Damage

Titanium alloys are widely used in environments containing hydrogen, and where impressed currents or galvanic couples generate hydrogen. Hydrogen embrittlement of the titanium may result due to the formation of titanium hydride precipitates, usually without significant reduction of the performance of the alloy. Embrittlement is loss of ductility and toughness of the alloy.

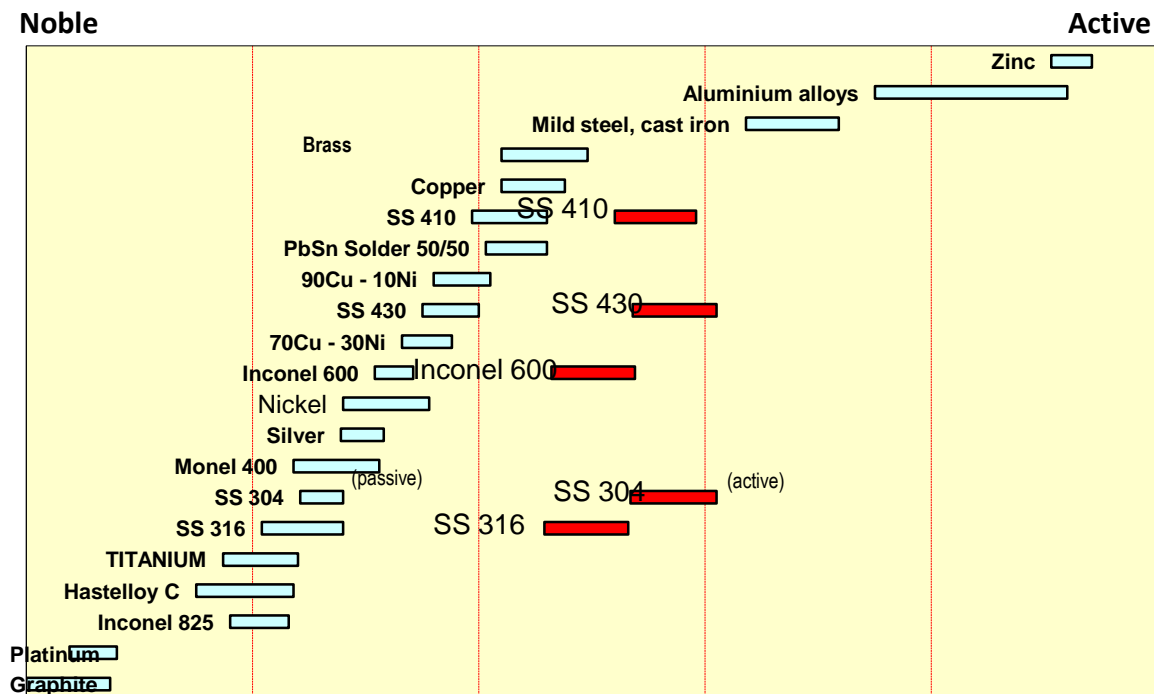
The surface oxide film is a highly effective barrier to the passage of hydrogen, and only traces of moisture or oxygen are effective in maintaining the oxide film. Hence hydrogen embrittlement can usually be avoided. It is unlikely to be encountered at temperatures below about 80°C, or at solution pH between 3 and 12.

The usual cause of hydrogen damage is excessive hydrogen charging from an impressed current corrosion protection system, or a galvanic couple (see below) with a more active metal, such as aluminium, zinc or magnesium. Metals which remain passive, such as other titanium alloys, stainless steels, copper alloys and nickel alloys, are unlikely to cause this problem.

Galvanic Couples

Titanium rarely suffers accelerated corrosion on coupling with other metals, but it may accelerate the corrosion of a more active metal coupled to it. The rate of attack depends on many factors, including solution chemistry and temperature, and the cathode to anode surface area ratio.

Galvanic series in flowing sea water (2.5 - 4 m/sec, 10 - 27°C)



Stress Corrosion Cracking

The commercially pure titanium alloys (grades 1, 2, 7, 11, 12) are immune to SCC except in a few environments, such as anhydrous methanol solutions containing halides, nitrogen tetroxide and red fuming nitric acid. The higher strength alloys have been found susceptible to SCC in aqueous chloride solutions at high stress levels in laboratory tests, but the problem is rarely encountered in practice.

Erosion Corrosion

The hardness of the surface oxide film gives excellent resistance to erosion corrosion, which is outstanding compared to most other candidates for heat exchanger service. High flow rates (30m/sec) can be used without problems due to inlet turbulence or pump cavitation effects.

Corrosion Fatigue

The highly protective surface oxide film results in insignificant reductions in fatigue strength in water, sea water and most chloride solutions where corrosion is not active.

Water & Sea Water

Titanium alloys corrode negligibly in sea water at temperatures up to 260°C. Even under biofouling and deposits, pitting and crevice corrosion are not encountered. Marine atmospheres, splash and tidal zones, and soils also have no effect. Corrosion at tight design crevices may be seen in waters with higher than about 1000 ppm of chlorides at temperatures above about 75°C.

Oxidising Media

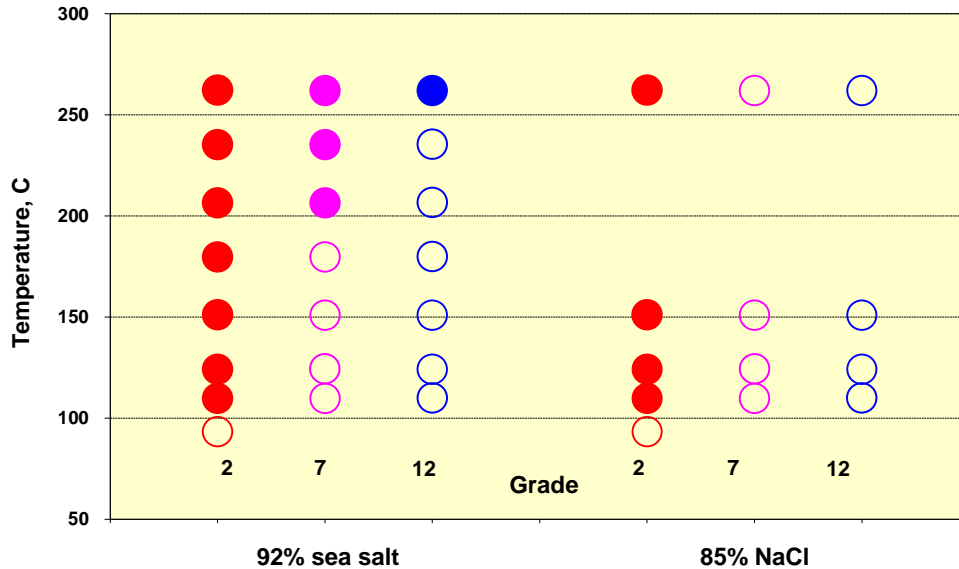
Titanium alloys are highly resistant to oxidising acids, with corrosion rates typically less than 0.03 mm/year.

Reducing Acids

Corrosion of titanium alloys may be encountered when the temperature & concentration of reducing acid solutions exceed critical values, which breaks down the surface oxide layer. Reducing acids include sulphuric, sulphamic, oxalic, trichloroacetic, phosphoric and halogen acids such as hydrochloric and hydrofluoric.

Austral Wright Metals can supply detailed corrosion data for these environments.

Guidelines for avoiding localised attack in pressure-bleed tests in the absence of crevices



Open circle: Not susceptible
 Filled circle: Susceptible
 Source: ASM Handbook, vol 13

Designations and typical tensile properties of common titanium alloys

Alloy	UNS	ASTM	Composition	Yield Stress MPa	Tensile Strength MPa	Elongation %
Grade 2	R50400	2	CP	350	485	28
Grade 7	R52400	7	Ti-0.15Pd	350	440	28
Grade 12	R53400	12	Ti-0.3Mo-0.8Ni	460	610	22
Grade 5	R56400	5	Ti-6Al-4V	910	1,000	18