## ATOMIC AND CRYSTALLOGRAPHIC

| | |
|---|---|
| Atomic Number | 22 |
| Atomic Weight | 47.90 |
| Atomic Volume | 10.64 cm $^{3}$ / mol |
| Lattice Type | Body Center Cubic |

| MASS | METRIC | ENGLISH |
|---|---|---|
| Density at 20˚C | 4.51 g/cm $^{3}$ | 0.163 lb/in $^{3}$ |

## THERMAL

| | | |
|---|---|---|
| Melting Point | 1660˚C | 3320˚F |
| Boiling Point | 3285˚C | 5945˚F |
| Specific Heat at 0˚C ñ 100 C | .540 J/g/˚C | .129 BTU/lb/˚F |
| Average Linear Coefficient of Expansion at 25˚C (68˚F–212˚F) | 8.64 × 10 $^{-6}$ cm/cm/˚C | 4.8 × 10 $^{-6}$ in/in/˚F |

## THERMAL CONDUCTIVITY

| | | |
|---|---|---|
| 20˚C (68˚F) | 219 W/cm K | 12.6 BTU/hr-ft˚F |

## MECHANICAL PROPERTIES OF TITANIUM GRADES 2, 7, 16, 26

| | | |
|---|---|---|
| Tensile Strength (Minimum) | 345 Mpa | 50,000 PSI |
| Yield Strength (Minimum) | 276 Mpa | 40,000 PSI |
| Modulus of Elasticity (Tension) | 103 Gpa | 15,000,000 PSI |
| Nominal Hardness | 82 Hrb | |

Ti

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PROPERTIES OF

# TITANIUM

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# APPLICATIONS OF TITANIUM

## TITANIUM AS A METAL

Many Titanium alloys have been developed for aerospace applications where mechanical properties are the primary consideration. The main issue with industrial applications is typically corrosion resistance.

Commercially pure industrial grades of titanium are listed by ASTM grade in Table 1. Titanium Grade 2 represents the vast majority of the titanium used for industrial applications where corrosion resistance is the main concern.

The corrosion resistance of titanium is due to a stable, protective, strongly adherent oxide film layer. This film forms instantly when a fresh surface is exposed to air or moisture. A 12–16 angstroms thick oxide film is immediately formed on clean titanium when it is exposed to air. It continues to grow slowly, reaching 50 angstroms after 70 days, and 80–90 angstroms after 545 days. The film growth is accelerated under strong oxidizing conditions. The oxide film is very stable and is only attacked by a few substances—most notably, hydrofluoric acid. The titanium oxide film is capable of healing itself instantly in the presence of moisture or oxygen.

Anhydrous conditions should be avoided since the protective film may not be regenerated in the absence of oxygen.

**TABLE 1**

| ASTM GRADE | UNS DESIGNATION | NOMINAL COMPOSITION | YIELD STRENGTH, PSI |
|---|---|---|---|
| 1 | R50250 | Commercially Pure | 25,000 |
| 2 | R50400 | Commercially Pure | 40,000 |
| 3 | R50550 | Commercially Pure | 55,000 |
| 4 | R50700 | Commercially Pure | 70,000 |

Several titanium alloys have been developed with small amounts of palladium or ruthenium which have significance in industrial applications. Even though titanium has excellent corrosion resistance to a wide variety of corrosive media, it is limited in very hot brine and under acidic or reducing conditions as occur in crevices. The addition of palladium or ruthenium improves the corrosion resistance of the alloy under these conditions and extends the service temperatures in sea water and brine service. The presence of a small amount of these noble metals does not change the mechanical properties of the titanium. Palladium- and ruthenium-stabilized industrial grades of titanium are represented by the following ASTM grades in Table 2.

**TABLE 2**

| ASTM GRADE | UNS DESIGNATION | NOMINAL COMPOSITION |
|---|---|---|
| 7 | R52400 | Grade 2 + .15% Pd |
| 11 | R52250 | Grade 1 + .15% Pd |
| 16 | R52402 | Grade 2 + .05% Pd |
| 17 | R52252 | Grade 1 + .05% Pd |
| 26 | R52404 | Grade 2 + .10% Ru |
| 27 | R52254 | Grade 1 + .10% Ru |

The availability of lean palladium and ruthenium grades of titanium is still low, but with ASME code approval and increasing potential applications, the supply will increase to meet demand.

## INDUSTRIAL APPLICATIONS

Titanium has found its niche in many industrial applications where corrosion resistance is required. Below we have listed some of the common applications of titanium in corrosion resistant service:

- Chlorine Chemicals
- Hydrochloric Acid
- Phosphoric Acid
- Sea Water
- Sulfuric Acid
- Nitric Acid

## CHLORINE CHEMICALS

The corrosion resistance of titanium in chlorine gas and chlorine containing solutions is the basis for a large amount of titanium installations.

Titanium is widely used in chloro-alkali cells as anodes, cathodes, bleaching equipment for pulp and paper, heat exchangers, piping, vessels, and pumps for the manufacture of other intermediate organic chemicals. See Table 3 for the corrosion resistance of unalloyed titanium in aerated chloride solutions.

**TABLE 3**

| MEDIA | CONCENTRATION (%) | TEMPERATURE (˚F) | CORROSION RATE (mpy) |
|---|---|---|---|
| Aluminum Chloride | 5 – 10 | 140 | .12 |
| | 10 | 212 | .09 |
| | 10 | 302 | 1.3 |
| | 20 | 300 | 630 |
| | 25 | 68 | .04 |
| | 25 | 212 | 258 |
| | 40 | 250 | 4300 |
| Ammonium Chloride | All | 68 – 212 | <0.5 |
| Barium Chloride | 5 – 25 | 212 | <0.01 |
| Calcium Chloride | 5 | 212 | .02 |
| | 10 | 212 | 0.3 |
| | 20 | 212 | 0.6 |
| | 55 | 220 | .02 |
| | 60 | 300 | <0.01 |
| | 62 | 310 | 2 – 16 |
| | 73 | 350 | 84 |
| Cupric Chloride | 1 – 20 | 212 | <0.5 |
| | 40 | Boiling | 0.2 |
| Cuprous Chloride | 1 – 20 | 212 | <0.5 |
| Ferric Chloride | 1 – 20 | 70 | Nil |
| | 1 – 40 | Boiling | <0.5 |
| | 50 | Boiling | .16 |
| | 50 | 302 | <0.7 |
| Lithium Chloride | 50 | 300 | Nil |
| Magnesium Chloride | 5 | 212 | .03 |
| | 20 | 212 | 0.4 |
| | 50 | 390 | 0.2 |
| Manganous Chloride | 5 – 20 | 212 | Nil |
| Mercuric Chloride | 1 | 212 | .01 |
| | 5 | 212 | .42 |
| | 10 | 212 | .04 |
| | 55 | 215 | Nil |
| Nickel Chloride | 5 – 20 | 212 | 0.14 |
| Potassium Chloride | Saturated | 70 | Nil |
| | Saturated | 140 | <0.01 |
| Stannous Chloride | Saturated | 70 | Nil |
| Sodium Chloride | 3 | Boiling | .01 |
| | 29 | 230 | .01 |
| | Saturated | 70 | Nil |
| | Saturated | Boiling | Nil |
| Zinc Chloride | 20 | 220 | Nil |
| | 50 | 302 | Nil |
| | 75 | 392 | 24 |
| | 80 | 392 | 8000 |

## FRESH AND SEA WATER

Titanium resists all forms of corrosive attack in fresh and sea water to temperatures of 500˚F (260˚C). Titanium tubing has been used in surface condensers successfully for more than 15 years in polluted sea water with no sign of corrosion. Titanium has provided over thirty years of trouble-free sea water service for the chemical, oil refining and desalination industries.

## NITRIC ACID

Titanium is resistant to highly oxidizing acids over a wide range of temperatures and concentrations. Titanium has been extensively used in the handling and production of nitric acid. Titanium offers excellent resistance over a full concentration range at temperatures below boiling. Table 4 shows titanium's resistance to nitric acid vapors produced by boiling 70% azeotrope.

**TABLE 4**

| ASTM DESIGNATION | CORROSION RATE (mpy) |
|---|---|
| Titanium Grade 2 | 2.0 |
| Titanium Grade 12 | 0.8 |
| Titanium Grade 7 | .08 |

## RED FUMING NITRIC ACID

Although titanium has an excellent corrosion resistance to nitric acid over a wide range of temperatures and concentrations, it should not be used in applications with red fuming nitric acid. A dangerous pyrophoric reaction product can be produced.

## PHOSPHORIC ACID

Unalloyed titanium is resistant to phosphoric acid up to 30% concentration at room temperature. The resistance extends to about 10% pure acid at 140˚F. Table 5 shows unalloyed titanium's resistance to phosphoric acid.

**TABLE 5**

| MEDIA | CONCENTRATION (%) | TEMPERATURE (˚C) | CORROSION RATE (mpy) |
|---|---|---|---|
| Phosphoric Acid | 2 | 100 | 5 |
| | 10 | 50 | 5 |
| | 20 | 30 | 5 |
| | 30 | 20 | 5 |

## HYDROCHLORIC ACID

Titanium has useful corrosion resistance in dilute hydrochloric acid applications. Small amounts of multivalent metal ions in solution can effectively inhibit corrosion.

**TABLE 6**

| HCL CONCENTRATION (%) | $FeCl_3$ ADDED | TEMP. (˚F) | TITANIUM GRADE 2 | TITANIUM GRADE 7 |
|---|---|---|---|---|
| 1 | | Room | Nil | 0.1 |
| 2 | | Room | Nil | 0.2 |
| 3 | | Room | 0.5 | 0.4 |
| 5 | | Room | 0.2 | 0.6 |
| 8 | | Room | 0.2 | 0.1 |
| 1 | | Boiling | 85 | 0.8 |
| 2 | | Boiling | 280 | 1.8 |
| 3 | | Boiling | 550 | 2.7 |
| 5 | | Boiling | 840 | 10 |
| 8 | | Boiling | >2000 | 24.0 |
| 3 | 2 g/l | 200 | 0.2 | 0.1 |
| 4 | 2 g/l | 200 | 0.4 | 0.3 |

## SULFURIC ACID

Titanium is corrosion resistant to sulfuric acid only at low temperatures and concentrations such as 20% acid at 32˚F and 5% acid at room temperature. Like hydrochloric acid, small amounts of multivalent metal ions in solution can effectively inhibit corrosion as illustrated in Table 7.

**TABLE 7**

| $H_2SO_4$ CONCENTRATION (%) | INHIBITOR ADDED | TEMP. (˚F) | TITANIUM GRADE 2 |
|---|---|---|---|
| 20 | None | 210 | >2400 |
| 20 | 2.5 g/l Copper Sulfate | 210 | <2 |
| 20 | 16 g/l Ferric Ion | Boiling | 5 |

## ORGANIC ACIDS

Unalloyed titanium generally has good resistance to many organic acids such as those shown in Table 8.

**TABLE 8**

| MEDIA | CONCENTRATION (%) | TEMPERATURE (˚C) | CORROSION RATE (mpy) |
|---|---|---|---|
| Acetic Acid | 5 / 25 / 75 / 99.5 | 100 | Nil |
| Citric Acid | 50 | 100 | <.01 |
| Citric (Aerated) | 50 | 100 | <5 |
| Citric (Nonaerated) | 50 | Boiling | 14 |
| Formic (Aerated) | 10 / 25 / 50 / 90 | 100 | <5 |
| Formic (Nonaerated) | 10 / 25 / 50 / 90 | Boiling | >50 |
| Lactic Acid | 10 | 60 | .12 |
| | 10 | 100 | 1.88 |
| | 85 | 100 | .33 |
| Lactic (Nonaerated) | 10 | Boiling | .55 |
| | 25 | Boiling | 1.09 |
| | 85 | Boiling | .40 |
| Oxalic Acid | 1 | 35 | 5.96 |
| | 1 | 60 | 177 |
| | 25 | 100 | 1945 |
| Stearic Acid | 100 | 182 | <5 |
| Tartaric Acid | 50 | 100 | 0.2 |
| Tannic Acid | 25 | 100 | Nil |

*Information courtesy of Titanium Metals Corp. & RTI International Metals, Inc.*