Chemical and Mechanical Properties of Titanium and Its Alloys

Abstract:
Titanium, like other elements, is a composite of several isotopes, which range in atomic weight from 46 to 50. The proportions of these isotopes have been computed from spectrographic analysis. Mathematical calculations employing the proportions and mass numbers have assigned titanium a mean atomic weight of 47.88.
Unalloyed titanium may have tensile strengths ranging from 250 MPa for high purity metal produced by the iodide reduction process to 700 MPa for metal produced with sponge titanium of high hardness. The arc-melted unalloyed titanium products are reasonably ductile.

Chemical Properties

Titanium, like other elements, is a composite of several isotopes, which range in atomic weight from 46 to 50. The proportions of these isotopes have been computed from spectrographic analysis. Mathematical calculations employing the proportions and mass numbers have assigned titanium a mean atomic weight of 47.88.

Titanium has a large capture cross-section, and five other isotopes of titanium have been identified. Titanium 43 has a half-life of 0.58 second and is a beta positive emitter. Titanium 45 has two forms, one a beta positive and gamma emitter with a half-life of 3.08 hours and a second form with a half-life of 21 days. Titanium 51 has a half-life of 72 days and is a beta negative and gamma emitter. There is also a meta stable form of titanium 51, which has a half-life of 6 minutes and is also a gamma and beta negative emitter.

Valence. As is characteristic of transition elements, titanium has a variable valence and occurs commonly in the bi-, tri-, and tetra-valent states. Literature has reported valences of five and higher, but no substantiation of these has ever been shown.

Gases. The chemical reactivity of titanium is dependent upon temperature. The metal’s action with other substances proceeds more readily at elevated temperatures. This property is especially exemplified by the metal’s extreme reactivity to the gases of the atmosphere at high temperatures.

This necessitates the use of inert atmospheres for hot working and surface protection for high temperature applications. The rapid combination of titanium with the reactive gases of the atmosphere above 950°F produces surface scale. With larger intervals of time and increase in temperature, the gases diffuse into the lattice.

The metal combines with oxygen to form a long series of oxides from TiO to Ti_7O_{12}, each of which exhibits a different hue and, at short time exposures, a rainbow-colored surface film is produced. Although this surface oxidation proceeds at 950°F, no appreciable diffusion into the lattice occurs below 1300°F. Ignition of the metal occurs in air at 2200°F, and a pure oxygen atmosphere reduces this temperature to 1130°F.

The reactivity of titanium with nitrogen is similar to its action with oxygen where a yellow-brown scale is formed on the surface as the nitride. Nitrogen will diffuse into the lattice with a restricted depth of penetration. This property has been employed in the nitride casing of the metal.

Most unique of the gas-titanium reactions is that between hydrogen and the metal. The reaction proceeds at temperatures slightly above room temperature, and as much as 400 cc of the gas can be absorbed by one gram of titanium. In small amounts the gas adds as an interstitial, but at higher concentrations the hydride TiH is formed. The addition of hydrogen to titanium is only stable, however, below 680°F; above this temperature the gas is evolved and burns.

All of these gas-titanium reactions are accelerated by decreasing vapor pressures and complete protection from the atmosphere is required.

Water vapor and carbon dioxide are decomposed by hot titanium metal. Above 1500°F water vapor and the metal combine to form the oxide and evolve hydrogen. At higher temperatures the hot metal will absorb CO_2 and may form the oxide and the carbide.

Acids. The chemical reactivity of titanium to the halides is similarly exhibited by its combination with their acids. The most rapid reaction is again with the fluoride. This reaction has various applications; it is one of the basic agents for dissolution of the metal and its alloys for chemical analysis; it is used as a general etchant on both a macro and micro scale, in metallographic work; and it is also employed as a descaling agent.

The action of hydrochloric acid and, in a similar manner, that of sulfuric acid proceed slowly at room temperatures. However, a small input of heat accelerates the attack, which results in the formation of the lower chlorides and the mono-sulfate. These reactions are utilized in a similar manner to that of hydrofluoric acid and, because they are less toxic and corrosive, they are gradually replacing the acid fluoride.

Organics. The chemical reactivity of titanium with organic material has been exploited by the metal industry only to a slight extent. Organic acid-titanium reactions produce colored films on the metal’s surface and are being used by the metallographer to stain-etch microspecimens.

Solids. In the molten state titanium combines with many metals, metalloids, and carbonaceous matter to form systems of much importance. In the oxide state it reacts with the alkali, alkaline earth, and heavy base metals to form titanates, a few of which are being studied in conjunction with cheaper methods of production.

The reactivity to the metalloids, especially the metal oxides, has been extremely disturbing to the foundryman since molten titanium severely attacks most of the known refractories to form metal-metalloid systems. Such refractory materials as silicon dioxide and aluminum oxide are so severely attacked that their use is hazardous. Of all the metalloids only beryllium oxide and thorium oxide have shown any appreciable resistance to the liquid metal.

Another reaction with great import is that of carbon and titanium. The metal in the molten state has a great affinity for carbon, and because of its detrimental effect on the properties of titanium, extreme care must be taken to minimize its presence in fabricated items.

Electrochemistry. The metal may be electrodeposited by various complex methods, none of which gives industrially applicable films. Electrolytic means have been used to reduce the metal from its tetravalent state to both the bi- and trivalent forms by employing acid electrolytes and electrodes of cither lead, copper, platinum, or mercury jet.

Safety. The chemical reactivity of titanium is generally nonhazardous. With the exception of finely divided particles, and metal exposed to fuming nitric acid for a prolonged time, it has not been found to be either explosive or flammable.

Mechanical properties

Tensile Properties. Unalloyed titanium may have tensile strengths ranging from 35,000 psi (250 MPa) for high purity metal produced by the iodide reduction process to 100,000 psi (690 MPa) for metal produced with sponge titanium of high hardness. The arc-melted unalloyed titanium products are reasonably ductile.

Ductility. The arc-melted commercially pure titanium products range in ductility from 20% to 40% elongation and from 45% to 65% reduction in area, depending upon the interstitial content. The iodide process titanium yields a product possessing 55% elongation with 80% reduction in area.

As is the case with steel, titanium is alloyed with other metals to increase its strength. Such metallic additions as **Al**, **V**, **Cr**, **Fe**, **Mn**, **Sn** are employed either as binary additions or as complex systems. The resulting increase in strength is accomplished, however, with a lowering of ductility.

Modulus of Elasticity. Unalloyed titanium has a modulus of about $15x10^6$ psi and can be increased to about $18x10^6$ psi by alloying. Titanium’s modulus compares favorably with those of aluminum ($10.4x10^6$) and magnesium ($6.4x10^6$) but poorly with that of steel ($29x10^6$).

Like the modulus of elasticity the modulus in shear, modulus of rigidity, of titanium falls between that of aluminum and that of steel.

Hardness. Titanium is a much harder metal than aluminum and approaches the high hardness possessed by some of the heat-treated alloy steels. Iodide purity titanium has a hardness of 90 VHN (Vickers), unalloyed commercial titanium has a hardness of about 160 VHN and when alloyed and heat-treated, titanium can attain hardnesses in the range of 250 to 500 VHN. A typical commercial alloy of 130,000 psi yield strength might be expected to have a hardness of about 320 VHN or 34 Rockwell C.

Impact Resistance. Knowledge of tensile strength and ductility of a metal is insufficient for many engineering applications without the knowledge of toughness. Titanium falls among the few metals capable of possessing good toughness along with high strength and ductility.

Titanium may have impact strengths ranging from more than 100 foot pounds Charpy for the higher purity iodide product and 30 foot pounds for the commercial unalloyed product to 1 or 2 foot pounds for some of the high strength but brittle alloys.