Introduction

It was almost 200 years ago that titanium was first isolated and named after the powerful mythological first sons of the Earth—the Titans. The industry as we know it today is over 40 years old. Titanium is most commonly associated with jet engines and airframes, but the most recent media attention has been given to fittings for prosthetic devices and the artificial heart.

Once judged to be expensive, titanium, in life-cycle costing, is now more often seen to be economical. The key to its cost-effective use is to utilize its unique properties and characteristics in the design rather than to substitute titanium for another metal.

Titanium is the world's fourth most abundant structural metal. It is found in North America, South America, Europe, Africa, U.S.S.R, China and Australia in the forms of ilmenite, rutile and other ores. The most widely used means of winning the metal from the ore is the Kroll process which uses magnesium as a reducing agent. Sodium is also used as a reducing agent by some producers.

To produce titanium, the basic ore, usually rutile (TiO_2) is converted to sponge in two distinct steps. First, TiO_2 is mixed with coke or tar and charged in a chlorinator. Heat is applied and chlorine gas is passed through the charge. The titanium ore reacts with the chlorine to form $TiCl_4$, titanium tetrachloride, and the oxygen is removed as CO and CO_2. The resultant crude $TiCl_4$ produced is a colorless liquid and is purified by continuous fractional distillation. It is then reacted with either magnesium or sodium under an inert atmosphere. This results in metallic titanium sponge, and either magnesium or sodium chloride which is reprocessed and recycled.

Melting is the second step. Titanium is converted from sponge to ingot by first blending crushed sponge with the desired alloying elements to insure uniformity of composition, and then pressing into briquets which are welded together to form an electrode. The electrode is melted in a consumable electrode vacuum arc furnace where an arc is struck between the electrode and a layer of titanium in a water-cooled copper crucible. The molten titanium on the outer surface solidifies on contact with the cold wall, forming a shell or skull to contain the molten pool. The ingot is not poured, but solidifies under vacuum in the melting furnace. To insure homogeneity of the final ingot, a second or sometimes a third melting operation is applied.

The properties and characteristics which are important to design engineers are:

☐ **Excellent Corrosion Resistance**
Titanium is immune to corrosive attack by salt water or marine atmospheres. It also exhibits exceptional resistance to a broad range of acids, alkalis, natural waters and industrial chemicals.

☐ **Superior Erosion Resistance**
Titanium offers superior resistance to erosion, cavitation or impingement attack. Titanium is at least twenty times more erosion resistant than the copper-nickel alloys.

☐ **High Heat Transfer Efficiency**
Under "in service" conditions, the heat transfer properties of titanium approximate those of admiralty brass and copper-nickel. There are several reasons for this:
(1) Titanium's higher strength permits the use of thinner walled equipment.
(2) There appear to be unusual and beneficial characteristics in titanium's inherent oxide film.
(3) The relative absence of corrosion in media where titanium is generally used leaves the surface bright and smooth for improved lamellar flow.
(4) Titanium's excellent erosion-corrosion resistance permits significantly higher operating velocities.

☐ **Superior Strength-to-Weight Ratios**
The densities of titanium-based alloys range between .160 lb/in^3 (4.43 gm/cm^3) and .175 lb/in^3 (4.85 gm/cm^3). Yield strengths range from 25,000 psi (172 MPa) commercially pure (CP) Grade 1 to above 200,000 psi (1380 MPa) for heat treated beta alloys.

The combination of high strength and low density results in exceptionally favorable strength-to-weight ratios for titanium-based alloys. These ratios for titanium-based alloys are superior to almost all other metals and become important in such diverse applications as deepwell tubestrings in the petroleum industry and surgical implants in the medical field.

Physical Metallurgy Considerations

To understand the microstructure of any alloy system it is necessary to outline the phase relationships and constitution of the system being studied.

Titanium can exist in two crystal forms. The first is alpha which has a hexagonal close-packed crystal structure and the second is beta which has a body-centered cubic structure. In unalloyed titanium, the alpha phase is stable at all temperatures up to 1620°F. (880°C.) where it transforms to the beta phase. This temperature is known as the beta transus temperature. The beta phase is stable from 1620°F. (880°C.) to the melting point.

As alloying elements are added to pure titanium, the elements tend to change the temperature at which the phase transformation occurs and the amount of each phase present. Alloy additions to titanium, except tin and zirconium, tend to stabilize either the alpha or the beta phase. Elements called alpha stabilizers stabilize the alpha phase to higher temperatures and beta stabilizers stabilize the beta phase to lower temperatures.

Alloy Classifications

There are three structural types of titanium alloys:

☐ **Alpha** alloys are non-heat treatable and are generally very weldable. They have low to medium strength, good notch toughness, reasonably good ductility and possess excellent mechanical properties at cryogenic temperatures. The more highly alloyed alpha and near-alpha alloys offer optimum high temperature creep strength and oxidation resistance as well.

☐ **Alpha-Beta** alloys are heat treatable and most are weldable. Their strength