Advice & Counsel

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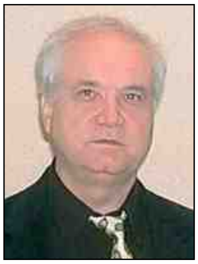

Titanium

Dear Advice & Counsel,
I am the new foreman at an airline plating shop and my experience in metal finishing is minimal. I was wondering if you could provide me with a quick primer on the kinds of metals used in the airline aerospace industry.

Signed, New Guy

Dear New Guy,

This month's metal is Titanium.

The basic physical/chemical properties of this metal are:

Symbol:	Ti
Atomic number:	22
Valence:	+3, +4
Crystal structure:	HCP or BCC
Density:	4.5 g/cm^3
Melting point:	3000ºF (1649ºC)
Soluble in:	Strong acids, HF
Insoluble in:	Most non-fluoride containing solutions
Color:	Silvery white
Discovered:	1791
Commercialized:	1948
Unusual property:	Powder is flammable
Magnetic:	Not magnetic
Corrosion resistance:	Better than stainless steel
Operational temperature:	Up to ~1050°F (~565°C) (alloys)
Joining methods:	Welding, brazing, adhesives

In the electrochemical series of the elements, titanium lies between beryllium and magnesium. Its single electrode potential is -1.75 V. Despite this potential, titanium is resistant to most chemical solutions due to the formation of a passive oxide upon exposure to air.

Solutions containing hydrofluoric acid or acids containing fluoride ions will attack titanium and can be used in conjunction with chromic acid to etch the alloy. The chromic acid acts as an inhibitor due to its strong oxidizing characteristic.

Titanium was discovered some 200 years ago in England. It is the 9th most abundant element in the earth's crust.

Practical use of titanium began in 1948, when its commercial production started in the United States using the magnesium reduction process, or the Kroll Process, named after its developer, the metallurgist Dr. W.J. Kroll, of Luxembourg. Since then, titanium has found a wealth of industrial applications primarily in the chemical processing and aerospace industries.

Titanium alloys are as strong as most steel alloys, at about half the weight. Titanium is non-magnetic and exceptionally corrosion resistant - better than stainless steel. Titanium alloys can be used at temperatures up to ~1050°F (~565°C). Titanium may be joined using standard techniques of fusion welding, brazing and adhesives.

Titanium is 60% more dense than aluminum, but more than twice as strong as 6061-T6 aluminum alloy. Certain titanium alloys (*e.g.*, Beta C) achieve tensile strengths of over 200,000 psi (1,400 MPa). However, titanium loses strength when heated above 806°F (430°C).

Titanium is a poor conductor of heat and electricity. Machining requires precautions, as the material will soften and gall if sharp tools and proper cooling methods are not used.

The most noted chemical property of titanium is its excellent resistance to corrosion. It is almost as corrosion-resistant as platinum, capable of withstanding attack by acids, moist chlorine in water, but is soluble in concentrated acids. The most frequently encountered valence is +4, but +3 is also a possibility.

As a powder or in the form of metal shavings, titanium metal poses a significant fire hazard and, when heated in air, an explosion hazard. Water and carbon dioxide-based extinguishers are ineffective on titanium fires. Class D dry powder extinguishers can be used.

Titanium is an allotropic element, which means that it can exist in more than one crystal structure, termed "alpha" and "beta." Pure titanium is present in the alpha phase, a close-packed hexagonal (HCP) crystal structure. It transforms to the beta phase, a body-centered cubic (BCC) crystal structure, when exposed to temperatures greater than 1620°F (882°C).

Due to the high tensile strength-to-density ratio, high corrosion resistance, fatigue resistance, high crack resistance and the ability to withstand moderately high temperatures without creep, titanium alloys are used in aircraft, military, naval and space satellites/rocket components.

In aerospace applications, titanium is alloyed with a variety of other elements, notably aluminum and vanadium. Examples of aircraft components produced with titanium alloys include critical structural parts, fire walls, landing gear components, helicopter exhaust ducts and hydraulic systems.

About 65% of all titanium metal produced is used in aircraft engines and frames. In engine applications, titanium is used for rotors, compressor blades, hydraulic system components and nacelles. The 6Al4V alloy accounts for almost 50% of all alloys used in aircraft applications.

Titanium alloys may display alpha, beta or combination structures. The structures can be manipulated to yield desirable properties such as weldability, high temperature stability, the ability to be heat-treated and for fracture toughness. In designing an aircraft part, we may wish to optimize density, strength, weldability, ease of fabrication and creep resistance. No one alloy, however, maximizes all of these properties.

Titanium alloys fall into three categories:

1. α alloys in which the α phase is predominant
2. $\alpha + \beta$ alloys with a proportion of both phases
3. β alloys in which the β phase predominates.

Alpha (α) alloys are characterized by good weldability, high toughness and stability at high temperatures.

Beta (β) alloys offer significantly higher ultimate tensile strengths, but are brittle below about -10°F (-23°C). By producing alloys containing both α and β, aerospace part manufacturers are able to take advantage of some of the features while reducing the undesirable features of each phase structure.

Due to different solubility levels of alloying elements in each phase, the distribution of the alloying elements can vary significantly. For example, the alloy Ti6Al4V in the α phase contains about 2% vanadium and 10% aluminum, whereas the β phase may contain as much as 18% vanadium with only 5% aluminum.

Because of the differences in the lattice and the different compositions of the α and β phases, it is to be expected that the reaction of different titanium alloys with chemical solutions will also be different. Some of the commonly used alloys, such as Ti_6Al_4V, $Ti_6Al_8Mo_5Zr$ (IMI 685) and $Ti_6Al_2Sn_4Zr_2Mo$ are alloys of the α - β type.

Because titanium alloys are used extensively in jet engine components, inspection for defects in the machined parts is critical. Defects in titanium parts, notably inclusions of alpha or beta phase titanium have at times have been direct causes of aircraft crashes.

Alpha-related defects

1. In one form of this defect, the alpha phase is formed by the pickup of interstitial elements such as nitrogen, oxygen and sometimes carbon. Areas containing alpha inclusions are extremely hard and brittle, and will crack when loaded. A Sioux City DC-10 crash in the late 1980s was determined to be due to the presence of a hard alpha defect in the fan disk of a CF6 engine.

2. Another form is an alpha-stabilized region containing an abnormally high amount of aluminum. Type 2 defects can be fairly large. Due to their size, these are the most likely alpha defects to be found by blue etch anodizing (chances for them breaking through the surface of a part are good). These defects are not significantly harder than the normal material around them, but they can serve as a weak spot.

3. Alpha case is a region which is oxygen and nitrogen enriched due to local exposure to high temperatures in air. Alpha case can be the result of abusive machining (grind burn), improperly shielded welding or improper thermal treatment (heat treat). Alpha case is brittle, and usually contains micro-cracks. Surfaces containing alpha case are prone to fatigue cracking.

Beta-related defects

Beta segregation involves regions within the microstructure of alpha-beta alloys which have low alpha phase content. It can be caused by localized regions of either abnormally high beta stabilizer content (vanadium, molybdenum) or abnormally low in alpha stabilizer content (aluminum).

Beta segregation sometimes shows up as "flecks" which form during heat treat at temperatures near the beta transus. Sometimes beta segregation can occur adjacent to an alpha defect.

Impurities in titanium alloys may segregate to form inclusions. These may be significantly harder than the titanium alloy matrix, acting as a crack initiation site.

Since titanium does not conduct heat very well, cooling during machining is vital to prevent the formation of areas that are significantly lower in strength due to tempering. After etching or blue anodize inspection, these overheated zones may show up as "spangled" bright surfaces.

Acknowledgement

I am grateful to the Honeywell Corporation which provided me with most of the above information. *P&SF*