Attributes, Characteristics, and Applications of Titanium and Its Alloys

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Rationale for Titanium Usage

Weight Savings

The high strength and low density of titanium (~40% lower than that of steel) provide many opportunities for weight savings. The best example of this is its use on the landing gear of the Boeing 777 and 787 aircraft and the Airbus A380. Figure 1 shows the landing gear on the 777 aircraft. All of the labeled parts are fabricated from Ti-10V-2Fe-3Al. This alloy is used at a minimum tensile strength of 1,193 MPa; it is used in replacement of a high-strength low-alloy steel, 4340M, which is used at 1,930 MPa. This substitution resulted in a weight savings of over 580 kg. The Boeing 787 used the next-generation high-strength titanium alloy, Ti-5Al-5V-5Mo-3Cr, which has slightly higher strength and some processing advantages. The use of titanium in landing gear structure should also significantly reduce the landing gear maintenance costs due to its corrosion resistance. The low density and high strength make it very attractive for reciprocating parts, such as connecting rods for automotive applications. Again, the price is too high for family vehicles but the U.S. Department of Energy is investing in a substantial effort to make titanium components for automobiles and trucks affordable. (Titanium is successfully utilized for high-end racing cars, where cost is not that much of an issue.)

Space Limitations

This application does not come up often, but it is an important one. The best example for this is the landing gear beam used on the 737, 747, and 757. This component, running between the wing and fuselage, supports the landing gear. Other Boeing aircraft utilize an aluminum alloy for this application, but for the above aircraft the loading is higher and the aluminum structure will not fit within the envelope of the wing. An aluminum alloy would be the preferred option as it is much lower in cost. Steel would be another option, but that would be higher weight.

Operating Temperature

The structure in the engine and exhaust areas operates at elevated temperature, so the primary options are titanium- or nickel-base alloys; again, the nickel alloys would add significant weight. Titanium engine alloys are used up to about 600°C. There are applications, such as the plug and nozzle (Figure 2), which experience temperatures higher than this for short times during certain operating conditions. The temperature limitation for titanium alloys,
other than specialized engine alloys, is about 540°C. Above this temperature oxygen contamination becomes an issue, embrittling the surface. Titanium is also used at cryogenic temperatures for structures such as impellers for rocket engines.

**Corrosion Resistance**

Titanium has a very tenacious nascent oxide which forms instantly upon exposure to air. This oxide is the reason for the excellent corrosion resistance. Corrosion is not a factor for titanium in an aerospace environment. Titanium does not pit, which in the author’s opinion is the rationale for the excellent service experience. In service, aluminum and steel alloys will eventually form corrosion pits, which serve as stress risers which will then initiate stress corrosion or fatigue cracks. This does not happen with titanium. This corrosion resistance carries through to the chemical, petrochemical, pulp, paper, and architectural industries. Titanium and its alloys have excellent resistance under most oxidizing, neutral, and inhibited reducing conditions. It is also corrosion resistant within the human body. Biocompatibility is also excellent; it is used for prosthetic devices and bone will grow into properly designed titanium structures. Commercially pure titanium is also being used for exterior architectural applications, a practice started in Japan. It is used for exterior surfaces as it will never require any maintenance. The most famous of these is its use on the exterior of the Guggenheim Art Museum in Bilbao, Spain.

**Composites Compatibility**

Titanium is compatible with the graphite fibers in the polymeric composites. There is high galvanic potential between aluminum and graphite, and if the aluminum comes into contact with the graphite in the presence of moisture the aluminum would be corroded away. It can be isolated from the composite by methods such as a layer of fiberglass, but in areas that are difficult to inspect and difficult to replace, titanium is used as a conservative approach. In addition, the coefficient of thermal expansion (CTE) of titanium, while higher than that of graphite, is much lower than that of aluminum. Even in the operating temperature range of fuselage structure, about −60°C at cruise to +55°C on a hot day, the difference in CTE using aluminum structure attached to the composite would result in very high loading. This is not an issue with titanium structure. Obviously, the longer the component, the bigger the issue would be for utilizing aluminum.

**Low Modulus**

The primary area where this is important is in the replacement of steel springs. With the modulus being about half that of steel, only half the number of coils are required. That in conjunction with the high strength and density being about 60% of that of steel could ideally result in a weight savings of about 70% of that of a steel spring. In addition, the titanium offers much superior corrosion resistance, reducing maintenance costs.

**Armor**

Titanium has excellent ballistic resistance and provides a 15–35% weight savings when compared to steel or aluminum armor for the same ballistic protection at areal densities of interest, which has resulted in substantial weight savings on military ground combat vehicles. Lighter vehicles have better transportability and maneuverability. The excellent corrosion resistance, low ferromagnetism, and compatibility with composites also provide significant benefits. Two programs that use titanium in upgraded vehicles are the Bradley Infantry Fighting Vehicle.