



Practical Aspects Related to the Heat Treatment of Titanium and Titanium Alloys

Of the various nonferrous materials in use today, titanium and its alloys have experienced rapid growth for industrial (38%), commercial aerospace (29%) and military aerospace (23%) products. Titanium alloys are used extensively for heavily loaded aerospace components and most recently because of their excellent compatibility with composites. Interest in titanium will continue to grow as military consumption is expected to double in the next 10 years, and commercial aerospace reports that the world fleet will more than double over the next 20 years (Fig. 1). The heat treatment of these alloys is complex and demands an understanding of the end-use application, desired microstructure and process variables. Let's learn more.



Why Use Titanium?

Titanium alloys have excellent corrosion and erosion resistance as well as very high tensile strength and toughness, even at extreme temperatures. Titanium's benefits can be summarized as:

- Excellent strength-to-weight ratio
- Compatibility with carbon/epoxy materials
- Elevated temperature 350°F-1000°F service capability
- Superior oxidation and corrosion resistance
- Excellent fatigue and fracture resistance
- Biocompatibility

Applications for titanium alloys include:

- Manned and unmanned aircraft (commercial and military aircraft, rotorcraft)
- Artillery (howitzers)
- Military vehicles (tanks, hovercraft)
- Naval and marine applications (surface vessels, subs)
- Turbines (power generation)
- Medical devices (implants, instruments)
- Chemical processing plants (petrochemical, oil platforms)
- Architecture (sculptures)
- Automotive (motorcycles, performance automobiles)
- Pulp and paper industry (washing and bleaching systems)
- Consumer electronics (batteries, watches)
- Sports equipment (bicycle frames, golf clubs)

Types of Alloys

Titanium alloys are classified in four main groups based on the types and amounts of alloying elements they contain:

- Alpha (α) – cannot be strengthened by heat treatment; low to medium strength, good notch toughness, formable, weldable, good creep resistance (superior to beta alloys) at somewhat elevated temperatures.
- Near alpha – medium strength and good creep resistance.
- Alpha-beta (α - β) – strengthened by heat treatment; medium to high strength, high formability, good creep resistance (but less than most alpha alloys), alloys with beta content less than 20% are weldable. The most familiar alloy in this category is Ti-6Al-4V.
- Beta (β) – strengthened by heat treatment; high strength, fair creep resistance, prone to a ductile-to-brittle transition temperature.

Some alloying elements (Al, Ga, Ge, C, O, N) raise the alpha-to-beta transition temperature (alpha stabilizers) while others (Mo, V, Ta, Nb, Mn, Fe, Cr, Co, Ni, Cu, Si) lower the beta transition temperature (beta stabilizers).

Types of Heat Treatments

While pure titanium is soft and relatively weak, heat treating can significantly enhance its properties. Titanium and titanium alloys are heat treated in order to:

- Reduce residual stresses from fabrication (stress relieving)
- Produce an optimum combination of ductility, machinability, and dimensional and structural stability (annealing)
- Increase strength (solution treating and aging)
- Optimize specific properties such as fracture toughness,

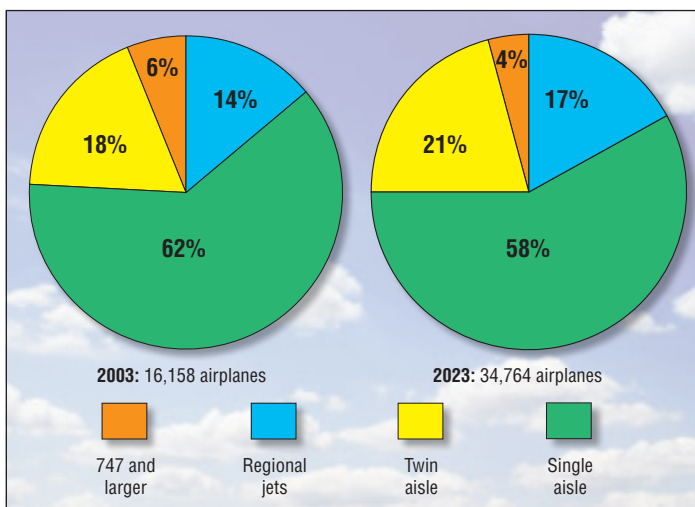


Fig. 1. Projected commercial aerospace growth^[1]



fatigue strength, and high-temperature creep strength

- Create specific material conditions

Standard heat treatments include:

- Annealing – increases fracture toughness and ductility (at room temperature) and improves dimensional stability and creep resistance. Annealing may be necessary following severe cold work and to enhance fabrication and machining.
- Homogenizing – improves chemical homogeneity in castings.
- Solution treating and age hardening (aging) – a process of heating into the beta or high in the alpha-beta phase region, quenching and then reheating again to the alpha-beta region. A wide range of strength levels is possible. Fatigue strength increases while ductility, fracture toughness and creep resistance are enhanced.
- Stress relief – used to reduce residual stresses during fabrication or following severe forming or welding to avoid cracking or distortion and to improve fatigue resistance. Strength and ductility will not be adversely affected and cooling rate is not critical.
- Tempering – When titanium is quenched from an elevated temperature, reheated to a temperature below the beta-transition, held for a length of time and again quenched, it is said to have been tempered. Three variables exist in tempering: the phases present, the time held and the tempering temperature.

Custom heat treatments include:

- Beta vacuum annealing and vacuum aging – improves fatigue and yield strength as well as elongation in alloys such as Ti-5553 (Ti-5Al-5V-5Mo-3Cr).
- Brazing – induction, resistance and furnace brazing in an argon atmosphere or in vacuum. Cleanliness is important to avoid contamination.
- Creep forming – takes advantage of the fact that titanium moves and takes a set well at temperature.
- Degassing – involves removing of en-



Fig. 2. Load of titanium ingots for vacuum degassing (Photograph Courtesy of Solar Atmospheres of Western Pennsylvania)

trapped gases such as hydrogen (to under 50 ppm) to avoid embrittlement.

- Diffusion bonding – powder metallurgy where individual particles fuse from intimate surface contact.
- Hydriding – the deliberate addition of hydrogen to embrittle the material.
- Isothermal transformation – involves quenching an alloy from the all-beta region into the alpha-beta field, holding and then continuing to quench to room temperature. This causes precipitation of the alpha phase from the beta.
- Sintering – typically involving hot isostatic pressing and laser sintering of powder particles to form near-net-shape components.

Practical Considerations – What's Important?

Heat-treat-furnace capacity is an important consideration since many titanium parts are volume-limited rather than weight-limited. Load support is a critical issue in many applications to prevent creep or other dimensional changes, especially for intricate or complex part geometry.

Temperature measurement and control must be exact – usually $\pm 10^\circ\text{F}$ (5.5°C) or better throughout the entire working zone of the furnace. Work thermocouples are required because part temperature must be known. Caution: when heating parts over 1730°F (943°C), titanium cannot be in contact with a nickel alloy or stainless steels since eutectic melting will occur.

Vacuum pumping systems must be capable of reaching high vacuum levels - $1 \times 10^{-}$



Fig. 3. Load of titanium sheet for vacuum age hardening (Photograph Courtesy of Solar Atmospheres of Western Pennsylvania)

5 torr or lower before starting to heat. This vacuum level must be maintained while heating (requiring very slow ramp rates) and at temperature. Diffusion pumping systems must be properly maintained for maximum efficiency and to avoid backstreaming.

Since titanium is a strong “getter” material, vacuum-furnace interiors must be pristine. Ideally, all-metal hot zones and dedicated furnaces are desired, but graphite-lined furnaces, also used for other processes, are typical throughout the industry as a practical necessity. Thus fixtures and furnaces must be “baked out” (cleaned) before use typically at 2400°F (1315°C).

Finally, the reason why vacuum is used to process titanium is:

- Superior buy-to-fly ratio (no wasted material)
- Minimization of alpha case – avoidance of an oxygen contamination layer that is very brittle and must be removed by mechanical or chemical means (allows closer near-net-shape parts) **IH**

References

1. Mr. Robert Hill, Solar Atmospheres of Western Pennsylvania, private correspondence.
2. 2004 Boeing Market Outlook, The Boeing Company (www.boeing.com)
3. Wood, J. R. and P. A. Russo, “Heat Treatment of Titanium Alloys,” *Industrial Heating*, December 2004.

Additional related information may be found by searching for these (and other) key words/terms via BNP Media SEARCH at www.industrialheating.com: alpha titanium, beta titanium, homogenization, solution treat, age hardening, brazing, isothermal transformation