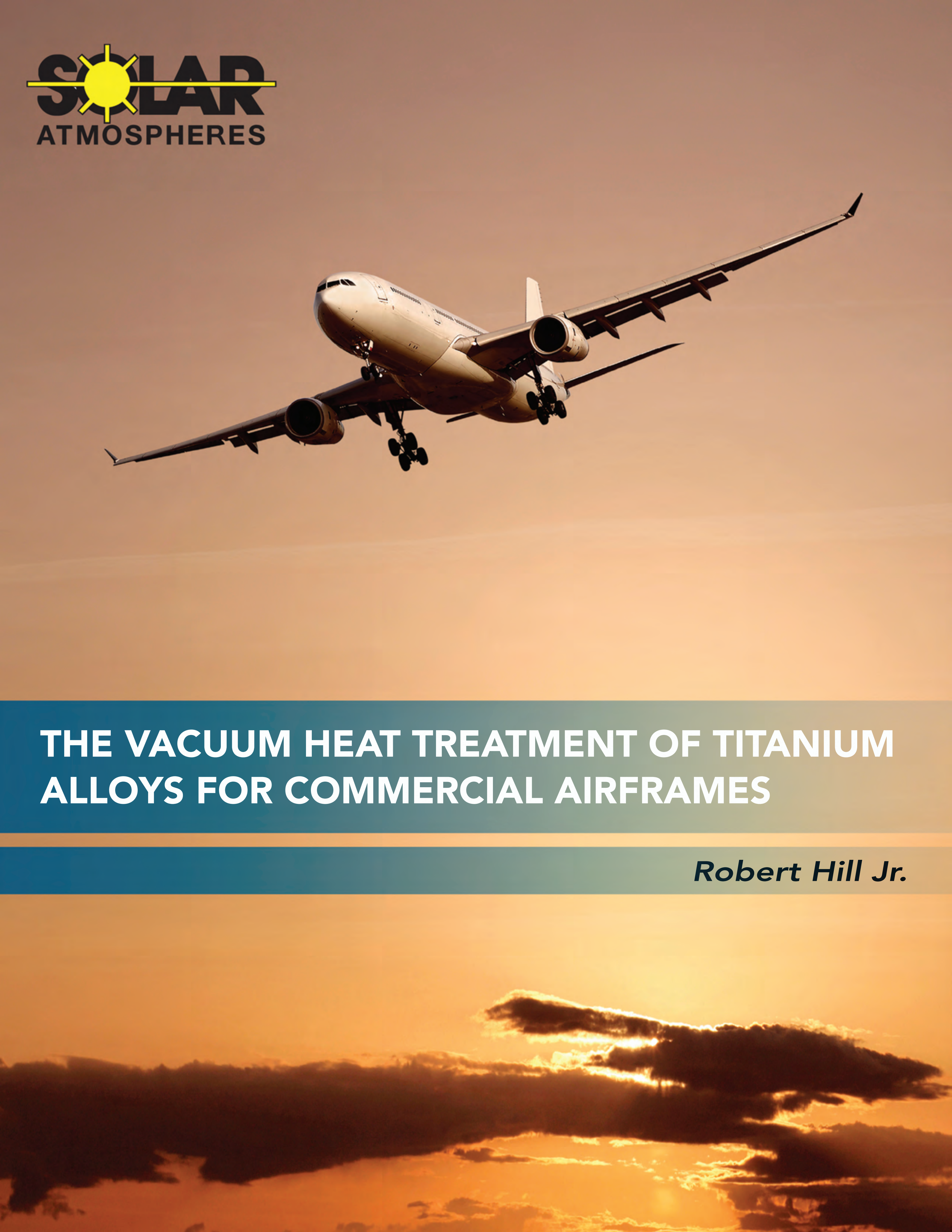

THE VACUUM HEAT TREATMENT OF TITANIUM ALLOYS FOR COMMERCIAL AIRFRAMES

Robert Hill Jr.

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Why Titanium?

Aeronautical engineers are consistently searching for new and optimal materials to achieve specific applications throughout an airframe. There are a multitude of considerations affecting the structural design of an aircraft such as the complexity of the load distribution through a redundant structure, the large number of intricate systems required in an airplane and the operating environment of that airframe. All of the above criteria is governed primarily by weight savings. Thus, the optimal materials selected today and for the future of airframes are composite material and titanium.

Today’s airframe is comprised of nearly half carbon fiber reinforced plastic and other composites. Composites, which are excellent in handling tension, greatly reduce maintenance due to fatigue when compared to an aluminum structure. When loading and environmental factors were analyzed, it was determined aluminum was a poor choice; whereas, titanium was an excellent low maintenance high strength material. In the new Boeing 787 Dreamliner, titanium has been expanded to approximately 15% of the total airframe.

Within the structure of the Boeing 787, the majority of the heat treatable titanium is in the following:

1. Landing gear and structural fittings (Ti5553)
2. Floor structure (Ti-6Al-4V)
3. Extrusions (Ti6Al-4V)
4. Nacelles (Ti-6Al-4V)

   (Picture from #4 from presentation)

While Ti-6Al-4V has been the workhorse alloy for the industry, Ti5553 (Ti5Al-5V-5Mo-3Cr) is being used in a number of key flight-critical parts in the 787 aircraft. Ti5553 is a new near beta alloy that exhibits excellent hardening ability characteristics with superior strength combined with high fracture toughness and excellent high cycle fatigue behavior properties when compared to Ti-6Al-4V. As a result of these superior properties, Ti5553 forgings are being used in highly loaded locations such as flap tracks, pylon, side of body chords or landing gear applications.

Heat Treatment of Titanium

Without the proper heat treatment of this exotic material, specific critical metallurgical properties could not be attained. The heat treatment of Titanium 6Al-4V typically involves a solution treatment above the beta transus temperature followed by fast cooling (water quenching). The part is then age hardened at a prescribed temperature for a period of time. This treatment works well for most wrought products. However, the aeronautical engineer today must design for improved "buy to fly" ratios. (The "buy to fly" ratio is the mass of material that is required to machine a part compared to the mass of the original part.) Due to the excessive distortion from heat treating 6Al-4V during the water quenching, today's engineers need to develop a newer alloy that could be "controlled cooled" to control distortion. The alloy developed to control this distortion to enable the engineer to design to near net shapes is Ti5553. The BASCA (beta anneal slow cool age) heat treatment of 5553 not only allows for better ultimate properties but also better "buy to fly" ratios over its competitor Ti-6Al-4V.

Shortfalls with Current Titanium Heat Treating Specifications

Currently, there are a multitude of heat treat specifications that engineers design to. These may include their own "in-house" specifications (e.g. BAC5613). There is a heat treating specification for titanium parts only (e.g. AMS2801B). There are specifications that exist for wrought mill products (e.g. AMS4928Q or AMS-H-81200). Since there is not one universal heat treating specification it is understandable why contradiction and nebulous statements exist within all of these documents. I will summarize the top five problems as I see them from a heat treating point of view.

1. Heat treating specifications need to describe critical cooling rates for quenching per units of measure (F or C). What is the exact cooling rate of "water", "oil" or "air"? Cooling rates of liquid quenchants vary when considering immersion temperature of the media, agitation of the media and the heat exchange rate of the media. This problem is not inherent for titanium only. This problem exists for all materials and, therefore, we are continually distorting parts at times more than necessary.

2. All titanium heat treating specifications assume subsequent thermal process will produce an oxygen rich layer of alpha case. With today's vacuum technology this is not necessarily true. There are many methods available to metallurgists today to help minimize alpha case in vacuum. Specifications could define pre-cleaning methods, bake out frequencies of furnace and fixturing, use of pre-holds for vacuum levels, specify slower treating rates, multiple argon sweeps during pump down and prior to heating, and more accurate minimal vacuum levels which must be attained during the entire thermal cycle.

3. Severe problems can arise when titanium alloys come in contact with hydrogen rich environments. Typically, this hydrogen pickup occurs during the manufacturing and processing of the metal; especially at non-inert elevated

temperatures. Deep vacuum processing along with elevated temperature depletes this hydrogen down to single digit part per million levels. Specifications need to state a maximum ppm level of hydrogen allowed to help eliminate hydrogen embrittlement and risk of failure in the material.

4. Specifications need to acknowledge the use of graphite for fixturing in vacuum. Graphite fixturing enables the engineer to design to nearer net shaped components. Graphite's attributes include excellent heat transfer characteristics, coefficient of thermal expansion (CTE) which mimics titanium, remains dimensionally stable and strong at temperature, and graphite can be easily machined to hold tight tolerances during thermal cycling.

5. Specifications currently do not clearly define and differentiate between work and control thermocouples and their individual intricacies. All values in the future must be recorded and reported on the work piece thermocouples only.

Looking to the longer term, Boeing and Airbus project the world fleet will double by the year 2029. This fleet will have airframes comprised of ever increasing composites and titanium. Currently, the Boeing/Airbus titanium usage is at 60 million pounds per year. Projections indicate that production will exceed 100 million pounds of metal by the year 2012 and maintain at that level through 2015! In order to properly thermally process this material downstream, metallurgists need to interact with Boeing, AMEC and SAE committees to discover and remedy these specification shortfalls. These actions will not only enhance the materials world, but also provide more safety to the military and commercial aerospace industries.