Stan R. Seagle
RMI Company - U.S.A.
TITANIUM TECHNOLOGY FORECAST

1 - INTRODUCTION

Titanium usage continues to grow being spurred by an expanding commercial aerospace industry and increased requirements in non-aerospace applications. Currently, non-aerospace usage is approximately 20% of USA consumption. The rapid growth rate of this market segment suggests that the non-aerospace usage of titanium will be a larger portion of total market in the 1990s.

High specific strength (strength/density) to 1000 F is the key property utilized in applying titanium alloys in aerospace applications. In non-aerospace use, titanium's excellent corrosion resistance is often the critical, and most important characteristic. These two properties, specific strength and corrosion resistance, differentiate titanium from other materials and account for nearly all the titanium applications.

Titanium, a relatively new commercial metal, has demonstrated excellent performance in aerospace to moderately elevated temperatures and outstanding corrosion resistance in neutral and mildly acidic chloride environments. As we move into the 1990s, new titanium alloys are expected to be used at higher temperatures, at higher strength levels and in more aggressive environments. In addition, the gas turbine industry will require continually improved quality to enhance both performance and safety. Specific background on these expected advances in alloy and process technology are discussed below.

2 - HIGH TEMPERATURE ALLOYS

Figure 1 contains elevated temperature stress-rupture data on both current and developmental titanium base alloys. Ti-6242 is the most advanced commercial alloy and used extensively in the U.S.A for the high temperature compressor portions of gas turbines.
The maximum design temperature for this alloy is about 1000 F. More recently, the temperature capability of titanium has been increased to about 1150 F through the development of IMI834 by IMI in England and Ti-1100 by Timet in U.S.A.. The IMI834 is being used in modest quantities in new Rolls Royce engines while the Ti-1100 is being evaluated by U.S.A. engine producers for potential use. As the applications temperature exceeds about 1050 to 1100 F, surface oxidation of titanium alloys becomes to develop suitable coatings that could be used with

confidence to prevent oxidation. The marginal improvement in temperature capability over existing titanium alloys (150F) and the potential need for coatings to prevent oxidation, could present a significant barrier to obtain the necessary expensive verification and approval required for gas turbine applications in the U.S.A..

The intermetallic compounds (Ti_3Al ($\alpha 2$) and TiAl (δ) have appreciable appeal because of their very high elevated temperature strength and low density. The Ti_3Al alloy has attractive strength to 1350 F while the TiAl is expected to be used as high as 1700 F. The low ductility (2 to 5%) of Ti_3Al and even lower ductility of TiAl (<2%) has presented problems in design, in manufacturing components and in producing sizable quantities of mill products. Current programs in modifying the alloy composition and processing research indicate acceptable ductility can be achieved in Ti_3Al type alloy. Recently, titanium mill manufacturers have produced mill products including .020"x36"x96" sheet form production size ingots. Progress on TiAl has not been as encouraging and only small quantities of material are available from laboratory-type processing. Both intermetallic alloy systems are of significant interest in the National Aerospace Plane (NASP) Program. The rate of development and application of these titanium intermetallics will depend on NASP funding effort. Without the NASP support, however, some engine applications for Ti_3Al type alloy is still expected in the 1990s.

The high temperature strength potential of titanium alloys is greatly enhanced when combined with silicon carbide fibres to form a metal matrix composite. Many issues must be resolved before extensive use occurs. Some of the well-known issues are directional properties, low damage tolerance, non-destructive inspection problems and high cost. In addition, suitable methods of producing these metal matrix composites must be developed. The sandwich method of roll-fiber-foil is not attractive because of the difficulty of producing foil of the matrix alloys. A plasma spray process such as developed by G.E. Aircraft Engine Group appears a more likely method of fabrication. Because of the numerous problems in production, only small quantities of titanium metal matrix composites are expected to enter application in the next decade.

3 - HIGH SPECIFIC STRENGTH ALLOYS

Titanium alloys are generally creep limited above approximately 600 F. Below this temperature specific ultimate strength, fatigue and toughness are all major design considerations. Annealed Ti-6Al-4V (Ti64) has been the dominate alloy since the 1950s at temperature below 800 F. Although the strength of this annealed alloy (130 ksi UTS) is very competitive with other metals, there has been little enthusiasm to utilize the high strength capability (>150 ksi UTS) of heat treatable titanium alloys. As builders of airframe and engines attempt to design and produce more efficient structures, higher strength alloys will be used. Engine manufacturers already utilize heat treatable alloys such as Ti-6246 and Ti-17 at temperatures in the 500 F to 800 F range. However, use of high strength titanium alloys is not significant in airframe structures. Advanced military airframes of the 1990s may utilize new high strength high toughness alloys such as Ti62222 (Ti-6Al-2Sn-2Z-2Mo-2Cr-0.25Si) shown in Figure 2. This alloy allows the use of higher strengths without a significant change in fracture toughness.

Titanium alloy springs are one of the few high strength applications in airframes. Titanium alloys with a high specific strength and low modulus, is an ideal spring material (Figure 3). Beta-C™ is utilized as springs in airframes at 200 ksi ultimate strength. Modest quantities are now being used, but the amount is expected to grow because of the significant weight savings (50%) and design compactness.

The high strength capability of beta type titanium alloys also is expected to be exploited for use in high strength castings. Figure 4 shows typical properties of the beta alloys Ti-15-333 and Beta-C™.These properties are comparable to high strength steels such as 17-4PH. Currently Ti-64 castings are used extensively in non critical components of the gas turbine engine. Use of the lower strength Ti-64 castings in airframes is starting to occur and the use of the high strength beta type alloys is now a consideration for application in the 1990s.

4 - <u>CORROSION APPLICATION</u>

Engineers in the chemical process industries began applying titanium in the early 1960s. At the same time, titanium's unique electrochemical characteristics revolutionized the chlor/alkali industry through the use of precious metal-coated, dimensionally-stable titanium anodes.
From this start, titanium quickly expanded into many distinct market areas such as chemical, power, petrochemical, refinery and pulp and paper. Future non aerospace growth is expected to occur in 1990s in energy extraction, biomedical, concrete re-enforcement protection, electronic, automotive, marine and environmental applications.

Many, if not most, of the current applications are based on commercially pure titanium, a moderately low strength metal. Titanium ASTM Grade 7 (Ti-0.2Pd) and more recently ASTM Grade 12 (Ti-0.3Mo-0.8Ni) have expanded the use of titanium because of their improved corrosion performance in reducing acidic chloride environments. Unfortunately, both alloys have only moderate tensile strength, which limits their application in many industrial areas particularly at elevated temperatures. Recently a commercial, high strength beta titanium alloy, Beta-C™, was found to possess comparable corrosion resistance to Grade 12. This finding, unique because the alloy is heat-treatable to high strength with exceptional corrosion resistance, will fill a void in several markets, particularly in energy extraction where high temperature strength combined with corrosion resistance in slightly acidic brines containing H_2S is desired.

For pressure vessel application, only commercially pure titanium and a few low-strength titanium alloys are ASME Boiler Code approved. Currently, the industry is in the process of qualifying Ti-3Al-2.5V (ASTM Grade 9). Figure 5 illustrates the design strength advantage of this alloy when compared with other titanium and nickel-base alloys.
The alloys are compared on a design stress-to-density ratio, which reflect weight efficiency of a structure and therefore, is directly related to cost per pound. After code approval is received for Ti-3Al-2.5V in 1990, these property advantages, combined with excellent mill producibility, good fabricability and good corrosion resistance offer new opportunities in design of elevated temperature pressure vessel equipment.

The development of high-strength alloys for pressure vessels and for reducing chloride environments will broaden the applicability of titanium. Figure 6 summarizes the general corrosion and strength behaviour of titanium alloys. Higher elevated temperature strength, coupled with excellent corrosion resistance in oxidizing and moderately reducing environments results in a metal system with a broad range of applications.

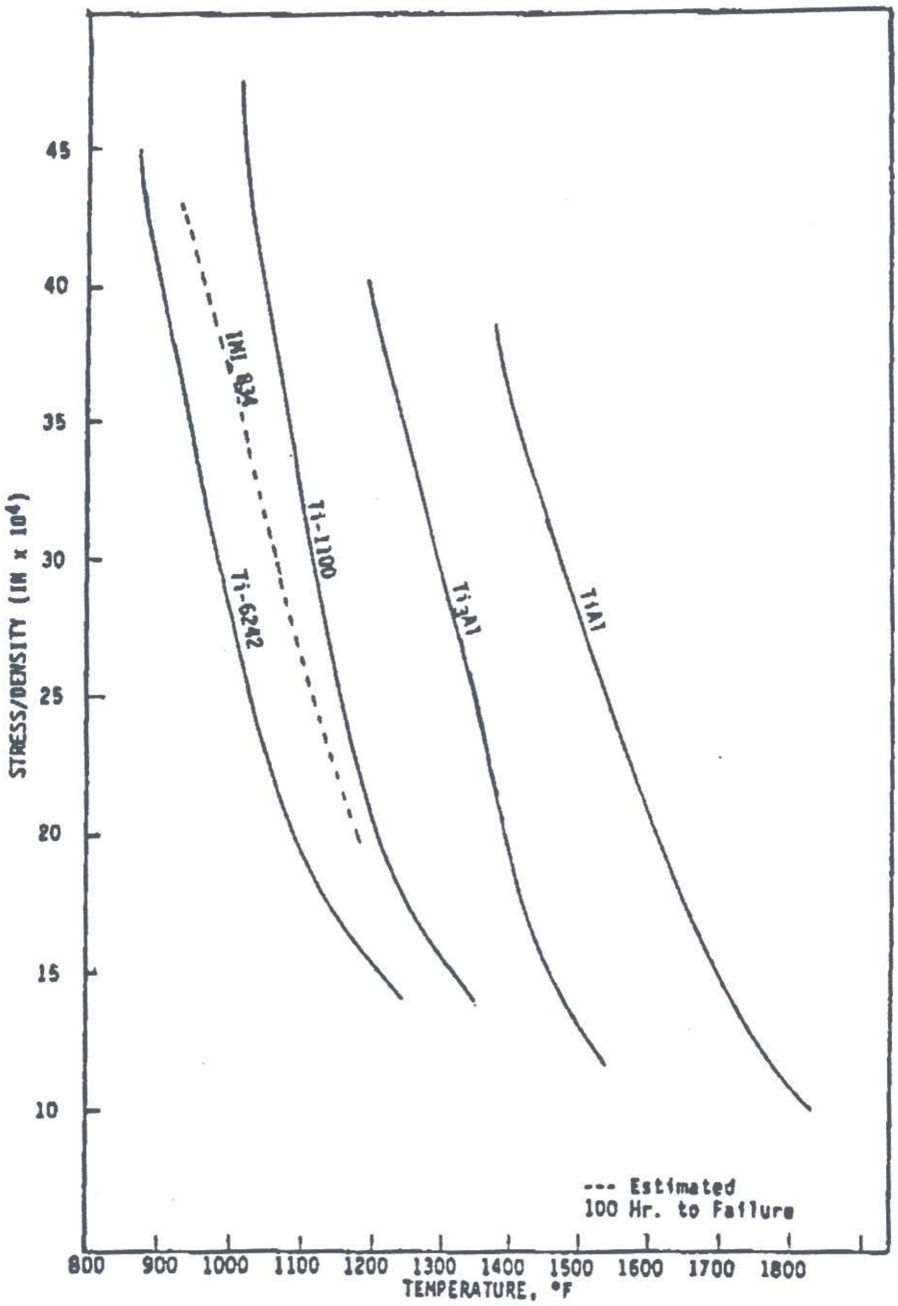
5 - PROCESS IMPROVEMENTS

Aerospace applications, particularly jet engines, require continually improved quality. The most bothersome and persistent defect associated with titanium products has been a high melting point interstitially rich area commonly called LDI or Type I. The defect, being extremely hard, can act as a nucleation site for premature failure. Although the incidence rate for such a defect has decreased significantly in the past decade, the defect can still occur. New technology scheduled for major implementation in the early 1990s, should solve this nagging issue. The process consists of replacing a vacuum arc melting operation with a hearth melting operation. This newer process will either dissolve the defect or allow the defect to settle innocuously in the hearth skull. Two electron beam hearth and one plasma hearth furnaces are now operating in the U.S.A.

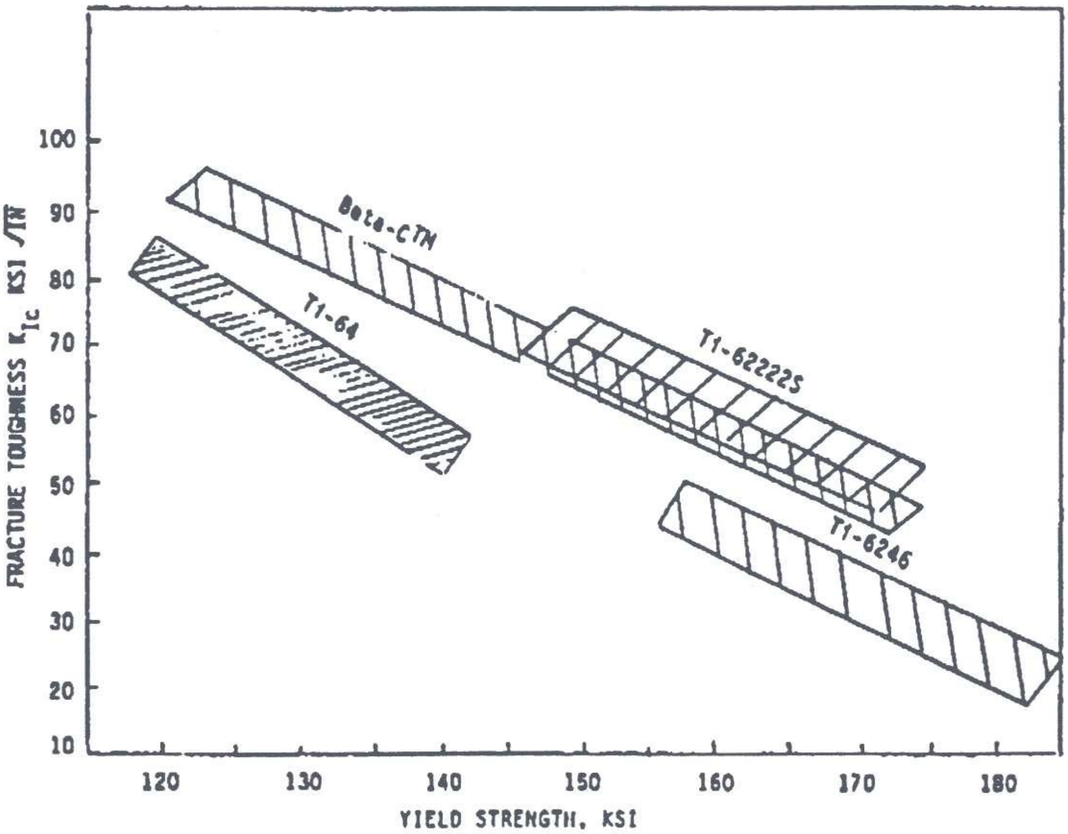
G.T.T., an engineering company in Turin, Italy has developed a new process for the electrolytic production of titanium sponge. The process produces a very high purity sponge containing both low oxygen and low residual metallics. In addition, the volatile residuals are about 50% of the best sponge now commercially available. This low volatile content will be desirable for the developing plasma and electron-beam melting processes. A large demonstration unit (300.000 lbs per year) has been started up this year and is scheduled for experimental operation at RMI Company in Ashtabula, Ohio in early 1990.

6 - SUMMARY

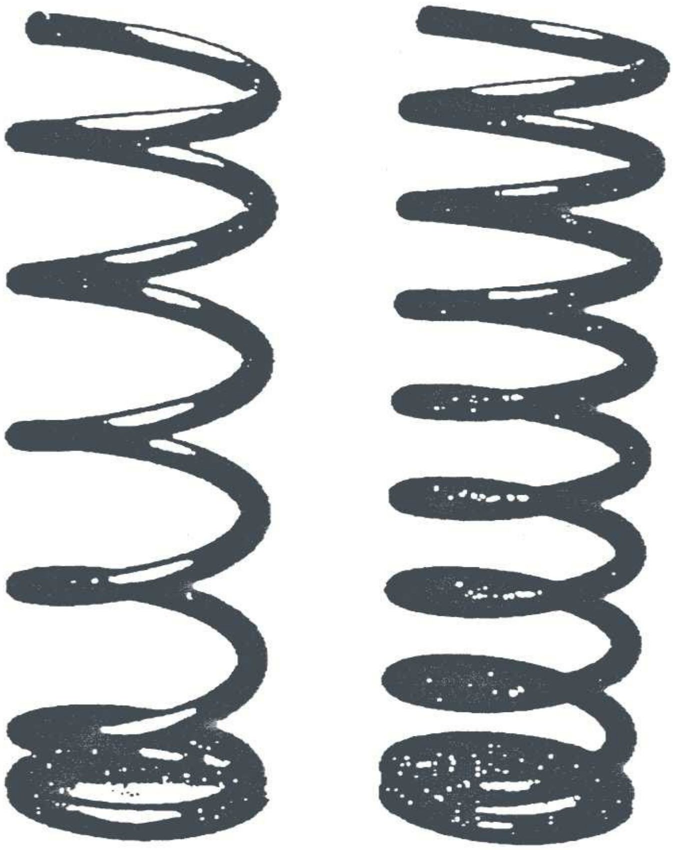
The 1990s will bring new challenges in the form of developing mew markets and improving quality. In aerospace, new applications will result from improved high temperature alloys for engine applications and new high strength alloys for airframe use. The industrial market growth will occur due to increased information on titanium's corrosion resistance and the availability of new and improved alloys.



Stress Rupture of Titanium Alloys



Fracture Toughness of Titanium Alloys

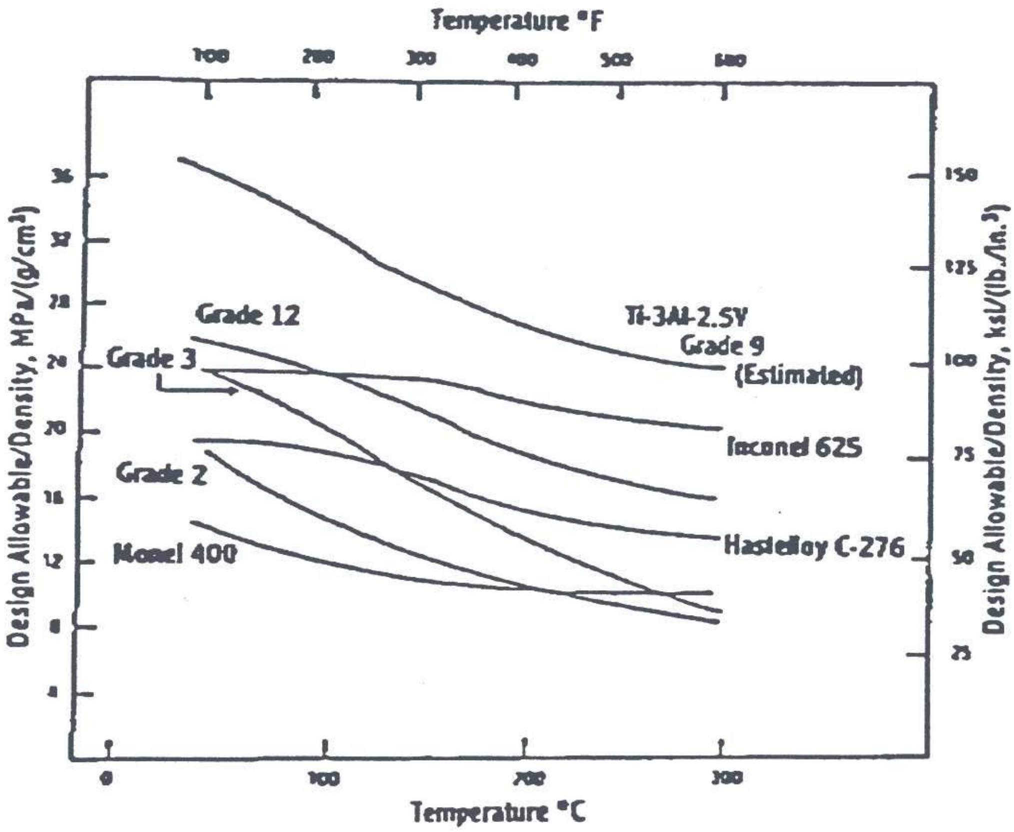


Equivalent Designs in Springs of Titanium and Steel. Titanium is 55% of Steel Weight

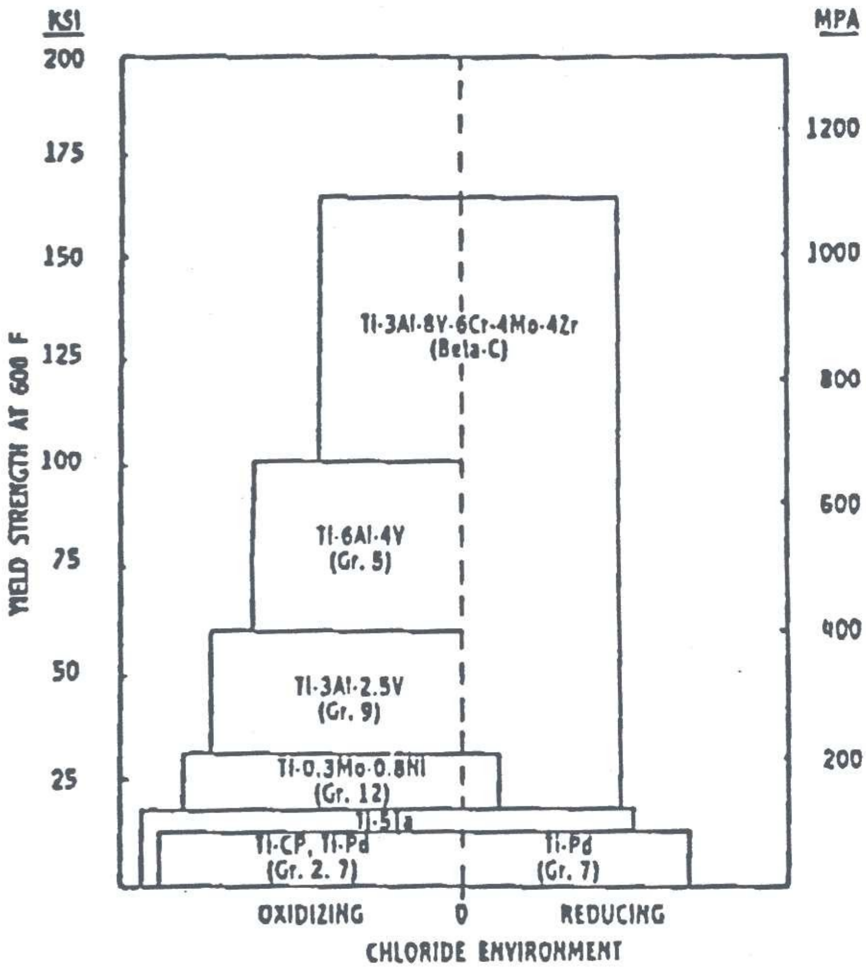
ROOM TEMPERATURE TENSILE
PROPERTIES OF TITANIUM ALLOY CASTINGS

ALLOY	UTS Ksi	YS Rsi	EL %	RA %
Ti-64	135	124	10	15
Ti-6246	195	184	2	3
Beta-C™	193	180	7	12
Ti-15-333	163	151	7	13

Source: Precision Castparts Corporation



Structural Efficiency
of Titanium and Nickel Alloys



Yield Strength vs. Corrosion Resistance For Titanium Alloys