STRUCTURAL APPLICATIONS FOR TITANIUM CASTINGS

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Introduction

Titanium castings are presently being utilized in critical structural applications. Both static and dynamic loading conditions are being encountered. Proven dynamic applications include impellers for desalination, compressors for natural gas liquification, waterjet impellers, and others. New dynamic applications currently under evaluation include compressor impellers for small jet engines, and helicopter rotor hubs. Critical static applications include space shuttle attachment fittings, jet engine support structures, helicopter weapons carriers, aircraft brake torque tubes, and numerous other aircraft structural components.

Titanium castings are unique, because the cast alloys are of the same composition as the wrought alloys. This is unusual, as in other metallic systems specific alloys have been developed as casting alloys. The titanium system is also unusual in that the cast material has tensile properties comparable in strength with the wrought material, and often direct substitution of parts is possible.

With the recent acceptance of Hot Isostatic Processing (HIP), as a predetermined manufacturing sequence, many problems associated with Non-Destructive Testing (NDT) of castings have been alleviated.

Critical cast titanium structures are now a reality because forward thinking engineers in some companies were willing to evaluate them, willing to endorse their use, and willing to share their results with others. Sometimes government agencies funded the work but in many cases private companies bore the cost of the effort.

The dominant driving force behind the growing interest in cast titanium shapes naturally is economics. The near net shape of a casting needs only 5 to 15% metal removal whereas the typical wrought shape requires metal removal of close to 70 to 90%. Coupled with this lower cost of metal removal for a cast shape is the reduced need for expensive machining equipment.

An important secondary reason for the current heightened interest in titanium castings has to do with lead times, particularly in this period of short supply. Foundry capacities and reduced metal needs favor lead times for castings compared with wrought materials.

Following is a series of case studies which will document the work of tests conducted both in the United States and Europe.

Casting Case Studies

Pitch Yaw Nozzle, Nose Nozzle, Hot Gas Deflector Plates, Manufactured for British Aerospace for AV-8B Aircraft.

The AV-8B aircraft utilizes directed gas discharges during its engine maneuvers for positioning and attitude control. The gas nozzles and their associated deflector mechanisms are designed as castings (both rammed graphite and lost wax) (Figure 1) to allow streamlined complex curves, a reasonable cost, and still remain within a weight restriction. Early units utilized cast steel components. Presently the steel parts have been replaced with cast titanium components, for a further weight reduction.

The qualification for these parts was considerably foreshortened by the extensive evaluation program previously conducted by British Aircraft on the Engine Hoist Tube and the Flap Track Castings (1).

A summary of mechanical property test data from British Aerospace is reported in Table II.

Figure 1.

Engine A-Frame Castings for Rolls-Royce RB 211-524 and RB 211-535.

The support structure in the two Rolls-Royce engines under consideration is a weldment made from several titanium components. A formed hollow air foil structure is welded to cast titanium end fittings (Figure 2).

The cast titanium was selected to reduce machining costs and allow complex designs, less practical as machined forgings. In the RB 211-524, the casting replaced a machined titanium forging; and the successful experience was further extended, with the A-Frame end fittings being initially designed as castings on the RB 211-535.

Figure 2.

Arrestor Hook for F-15 Fighter Aircraft.

The F-15 often carries arrestor gear for use in short landing situations or aborted take-offs. These hooks have been made as machined titanium forgings. Cast titanium (Ti6Al-4V) hooks have been qualified and are now in production. The qualification test rig is shown in Figure 3. The strength levels are comparable with the machined forging and the casting test strength exceeded 200,000 pounds. Included in the test program were welds in the critical areas and simulation of arrestor cable damage in the hook. The cast component passed these tests and weld restrictions were removed from the print/specifications.

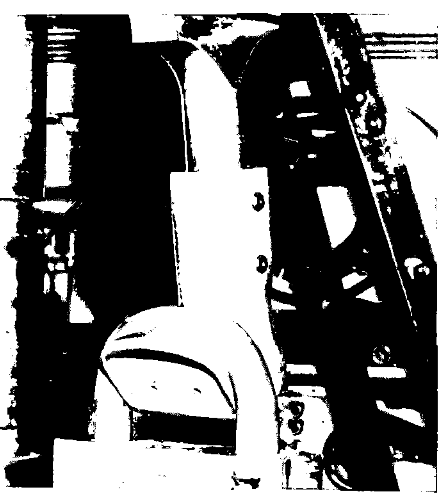

Figure 3.

Advanced Missile Combustion Duct

The transtage duct of the propulsion unit manufactured by the Marquardt Co. for the Advanced Strategic Air Launched Missile (ASALM) is a Ti6Al-2Sn-4Zr-2Mo casting (rammed graphite molding system)(Figure 4).

Prior to the successful demonstration of the propulsion vehicle, a casting was sectioned to study property uniformity and elevated temperature properties. Strength at elevated temperature was the predominant design consideration.

The castings were duplex heat treated at 1650°F (900°C) 1 hour Air Cool, plus 1450°F (790°C) 1 hour Air Cool.

Figure 4.

Uniformity of strength was remarkable within the triplicate tests at each of four different temperatures. Maximum strength variation for a set of data was typically less than 2 KSI (14 N/mm^2). (2)

The elevated temperature tensile data is plotted in Figure 5 along with published wrought data to show the similarity of the two.

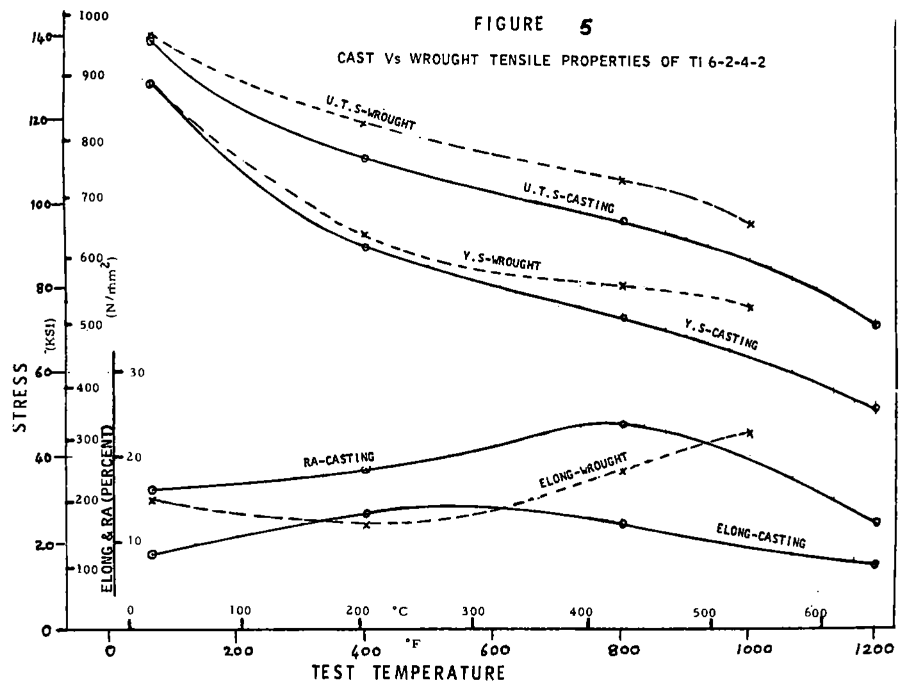

FIGURE 5

CAST Vs WROUGHT TENSILE PROPERTIES OF TI 6-2-4-2

Space Shuttle Attachment Fittings.

Figure 6.

The family of parts shown in Figure 6 are utilized by Martin Marietta in the Space Shuttle Program. These castings are fixed on the main propulsion tank and attach the Shuttle itself to the tank. The Ti-5Al-2.5Sn ELI alloy was selected because of its good cryogenic properties and its fracture toughness characteristics. During preproduction testing and qualification, the large size cast structures (up to 200 lbs. each) were sectioned into numerous test coupons for an extensive evaluation program. The strength levels of the cast materials are similar to the comparable wrought material. The crack propagation resistance of cast Ti-5Al-2.5Sn ELI is somewhat higher than both cast or wrought Ti6Al-4V but about the same as wrought Ti-5Al-2.5Sn over the range of -20° to -294°C tested. (3)

Other Active Cast Structure Programs

Table I lists a sampling of other actual structural titanium castings currently being produced by one United States casting supplier, TiTech International, Inc.

Table I

Part Name or Description	Approx. Weight (kg)	Alloy
Helicopter Rotor Hub	28	Ti6Al-4V
Helicopter Rotor Hub	100	Ti6Al-4V (HIP)
Weapon Beam - Helicopter	25	Ti6Al-4V (HIP)
Cargo Rail-Aircraft Cargo System	2	Ti6Al-4V
Torque Tubes-Brakes F-15, F-18	13	Ti6Al-4V
Optical Housings-Laser Systems	.2	CP Ti (HIP)
Engine Hoist Tubes	6	Ti6Al-4V (HIP)
Inducers-Waterjet Propulsion Units	110	CP Ti
Impellers-Small Jet Engines	1	Ti6Al-4V (HIP)

Those parts that have Hot Isostatic Processing incorporated in their production plan are indicated.

Compilation of Mechanical Property Testing

Static Tensile Properties.

Table II lists a small but representative sampling of static test results obtained from "cut up" titanium (Ti6Al-4V) castings. Average results compare very favorably with static properties obtained from titanium forgings.

Table II

No. of Spec.	0.2% Yield Stress	Ultimate Tensile Strength	% Elongation	% Red. in Area	Ref.
105	882	1004	10.0 (4D)	17.9	(4)
54	922	1004	6.9 (5.65 A)	14.1	(5)
11	949	987	N.D.	N.D.	(6)
Min.	830	930	6.0 (4D)	10	

Fatigue Properties

A great number of individual fatigue evaluations have been made. Figure 7 is a compilation of various data received from the sources referenced.

Compilation of Fatigue Strength Data for Cast Ti6Al-4V Alloy

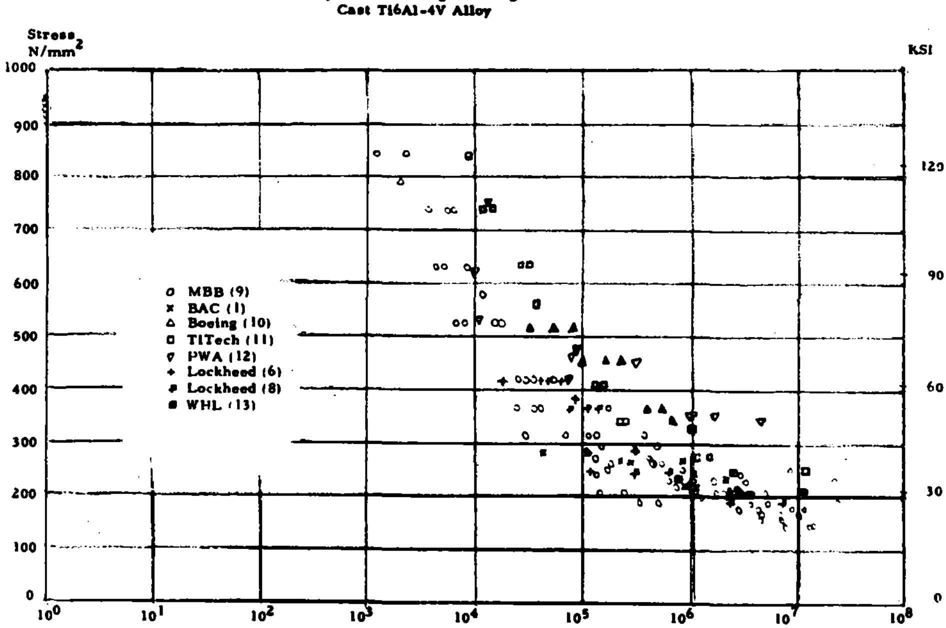

Figure 7

All results are from samples cut from castings and all, except for the Lockheed data, have notches or machined holes introduced to cause stress concentrations.

Two unexpected results have been demonstrated.

1. The fatigue properties of a cast surface are comparable to a machined surface.

   Recent studies by Lockheed Aircraft indicate that an as-cast surface has no deleterious effect on fatigue properties (7). Specially cast specimens were made utilizing a rammed graphite molding system. Specimen design was such that only the width was machined. Approximately 75% of the surface at the reduced section was therefore left in the as-cast condition.

   Results, included in Figure 7, show that the data are typical of 100% machined specimens.

   Naturally the alpha case was chemically removed to simulate typical aerospace surface preparation prior to testing.

2. The fatigue properties of HIP'ed material show little improvement over properly cast non HIP'ed material (9) (MBB).

Creep Properties.

The literature on creep properties of cast titanium is limited, however the creep properties of weld repaired cast Ti6Al-4V is comparable to unwelded material. Reference 7 contains creep data at 600 and 1200° F.

Other Mechanical Properties

Determination of other mechanical property characteristics on cast titanium has been accomplished by a large number of investigators. Mechanical properties related to strength compare favorably with wrought material; and those properties related to ductility are somewhat lower than wrought material.

Summary and Conclusions

The major reason for selection of titanium castings is one of economics. Whether it be for design flexibility, availability of material, or to reduce machining requirements, economics is the only real reason to select a casting in any common material. Once the decision has been made to evaluate a cast component, many metallurgical and technical factors are to be considered.

Numerous technical considerations have been briefly described.

The cast titanium system is unique. The strength levels in the castings compare with the wrought material, the fracture toughness and crack propagation resistance equal or exceed the wrought material. With the recent widespread acceptance of Hot Isostatic Processing, many of the problems associated with non-destructive test standards for castings have been greatly reduced. With more widespread acceptance, even more ambitious casting designs will be successfully made.

The group of cast titanium structural parts described are only a sample of the work from one titanium foundry. The several other foundries have made similar contributions to the State of the Art. Titanium castings have gone beyond simple valves and pumps. We are reaching the point where titanium castings have been tested, and accepted by major aerospace companies worldwide, and with each documented success, the designers develop confidence to more fully utilize the process to its full capability.

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