Titanium: Its Attributes, Characteristics and Applications

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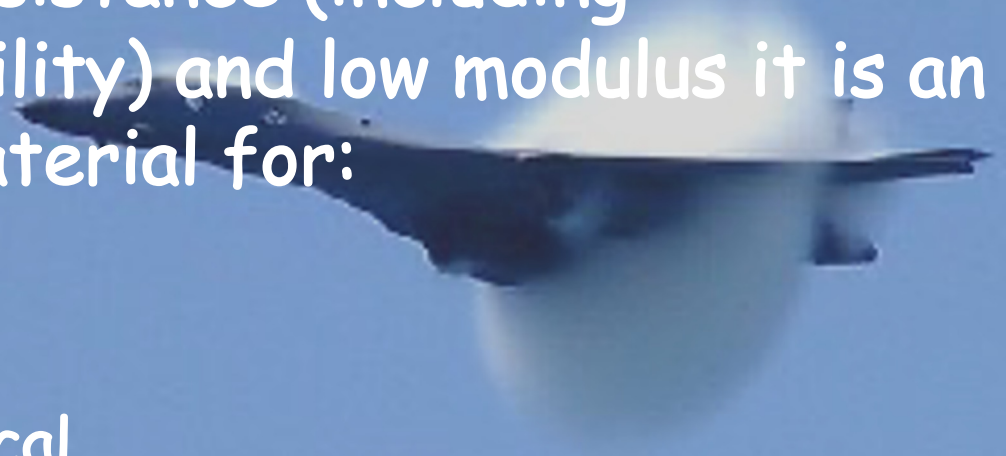
Titanium Attributes

- Due to titanium's high strength: weight ratio, corrosion resistance (including biocompatibility) and low modulus it is an excellent material for:
  - Aerospace
  - Chemical
  - Petrochemical
  - Biomedical
  - Architectural
  - Special Niche



Rationale for Titanium Use

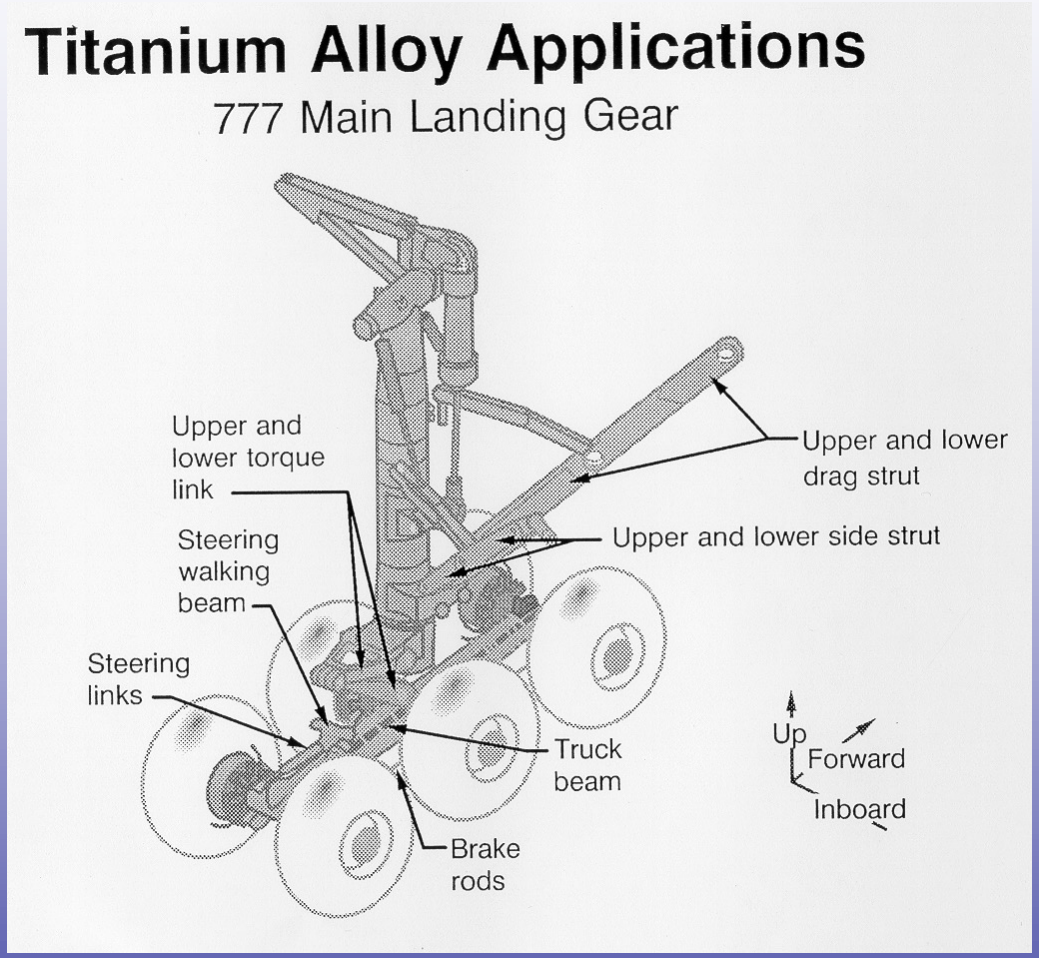
- Weight Savings
- Operating Temperature
- Space Limitations
- Corrosion Resistance
- Composites Compatibility
- Low Modulus

SR-71 All Titanium Aircraft Fastest and Highest Flying

- First Built in 1966
- Airframe titanium and titanium alloys
- Mach 3.5 flight at 85,000 ft altitude
- Painted with RADAR absorbing black paint

Source: NASA Dryden Flight Research Center Photo Collection, www.dfrc.nasa.gov, 1995.

Weight Savings



Boeing 777 Landing Gear

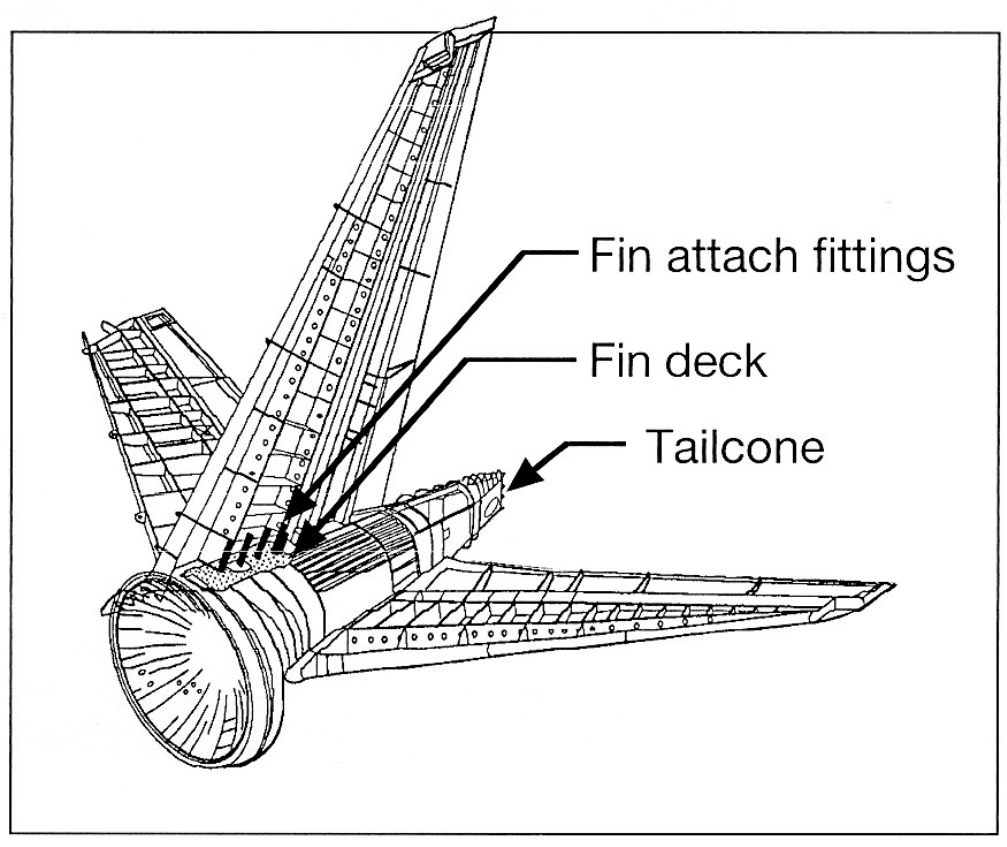
Operating Temperature

Boeing 777 Plug and Nozzle and Heat Shields

Space Limitations

Boeing 757 Mockup – Landing Gear Support Structure

Composites Compatibility



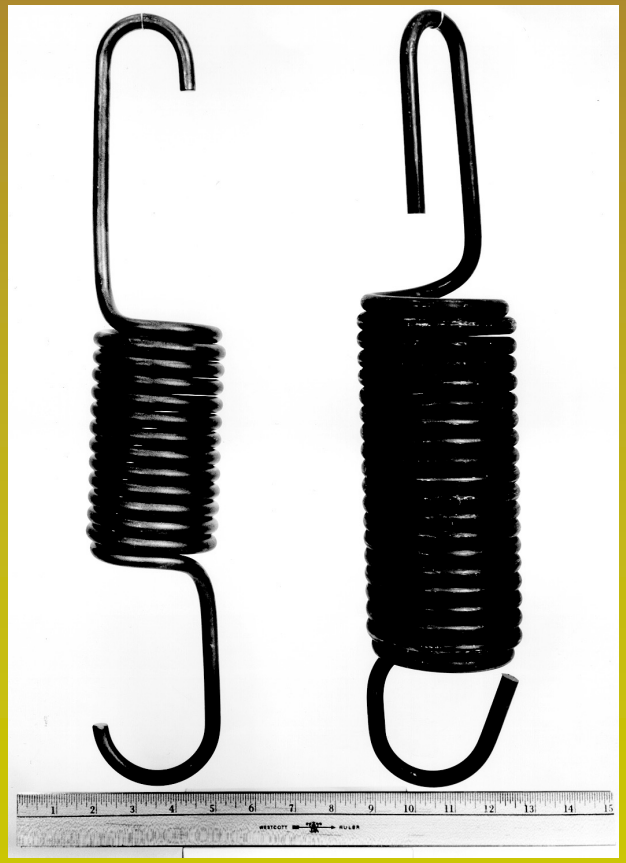
Boeing 777 Empennage (and APU Tail Cone)

Low Modulus

- **Lower Density and Modulus**
  - **–Up to 70% lighter than steel**
  - **–Up to 50% volume reduction compared to steel**
- **Eliminate corrosion problems associated with steel**

Steel Spring = 9.6#

Titanium Spring = 3.2#



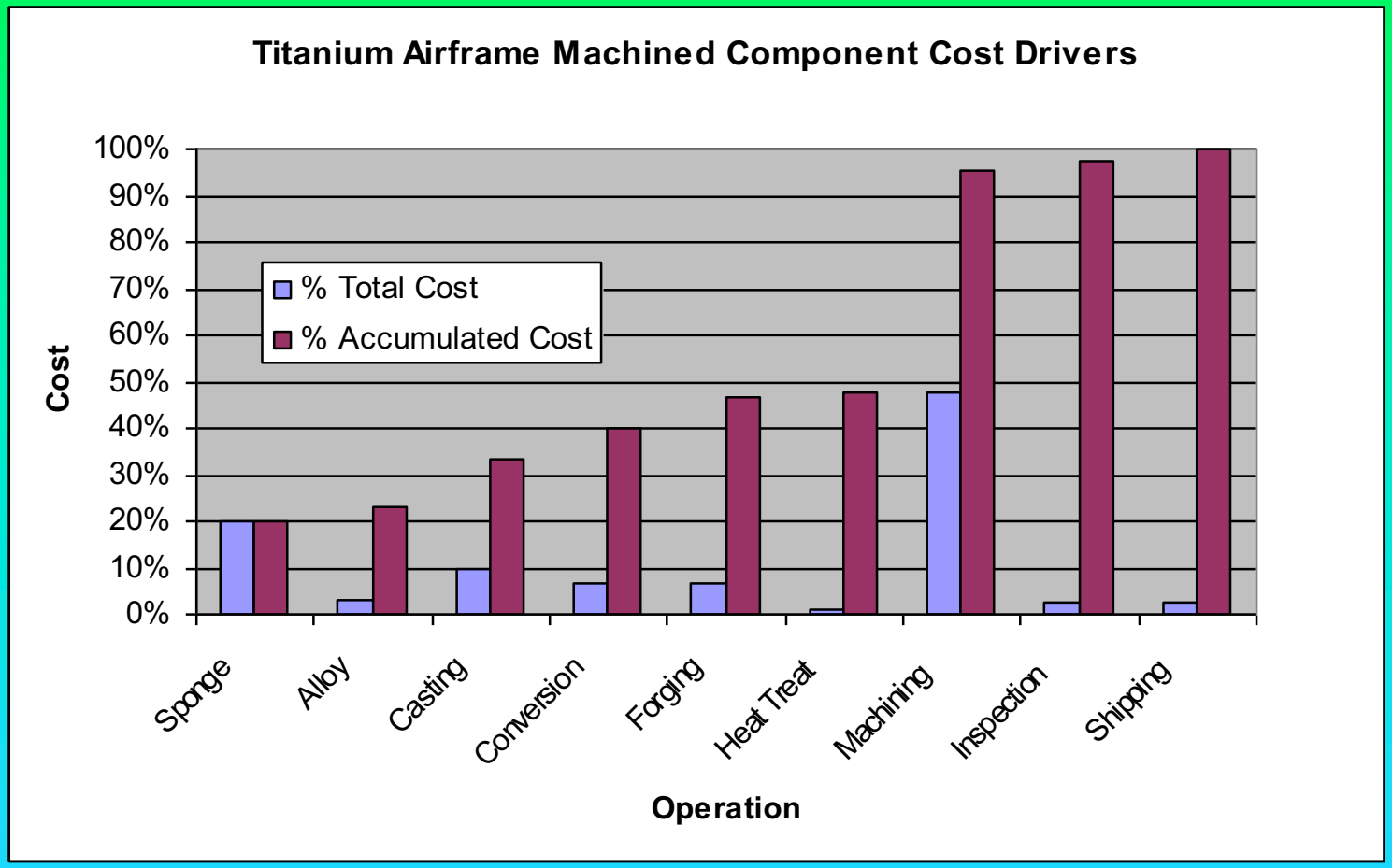
Unique Attributes

- Excellent corrosion resistance
  - In aqueous saline solution, titanium immune to corrosion
  - Requires fresh crack under load to initiate stress corrosion cracking
- Can manipulate the modulus
  - In β-alloys can manipulate from ≤12Msi to ~15Msi
- Can develop high crystallographic texture
- Bauschinger Effect
- Cd solid metal embrittlement

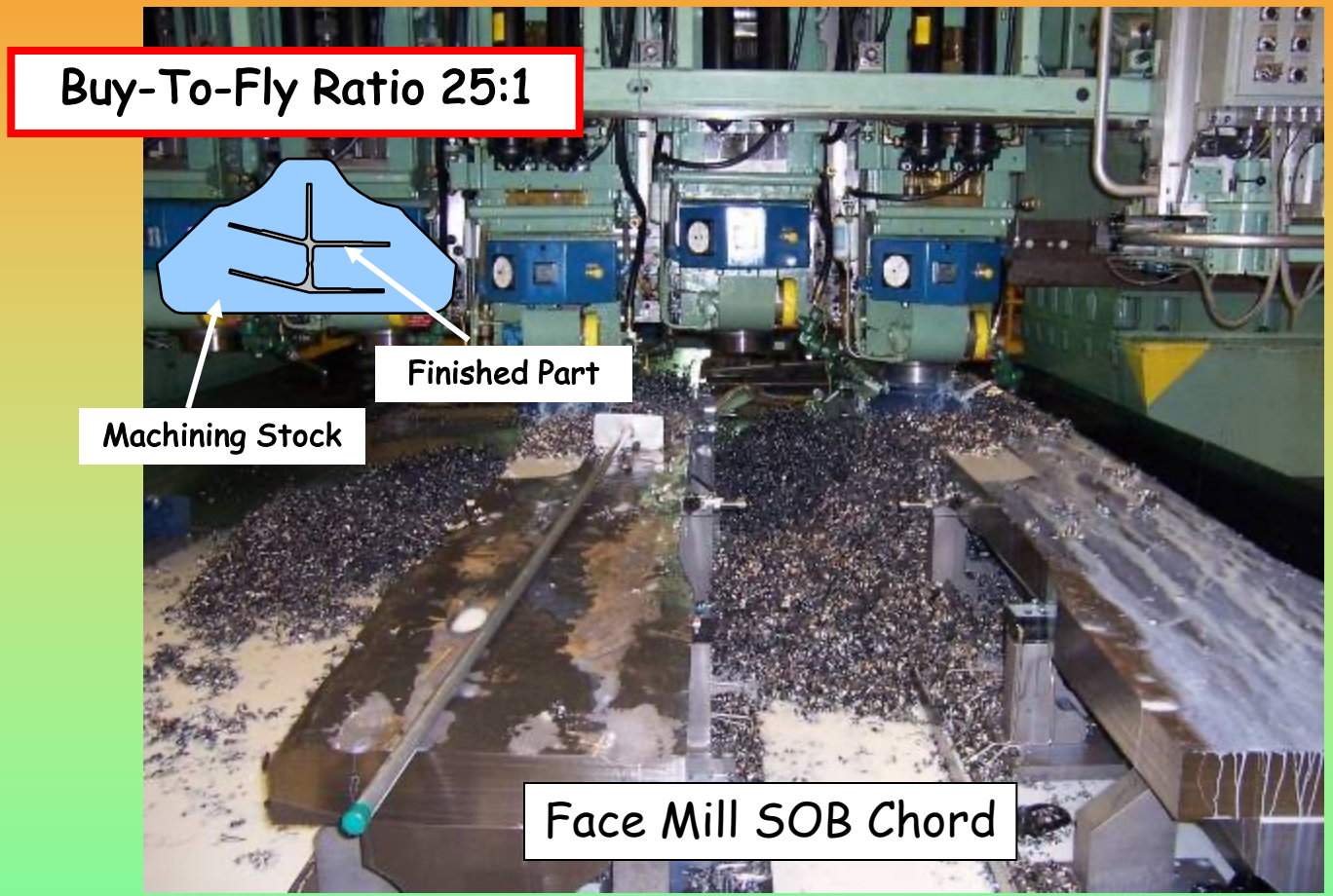
Titanium's Problem – High Cost

- High energy cost conversion of ore to metal
  - Aluminum sheet can often be procured for less than the cost of Ti sponge
- High energy cost associated with melting – must be done in vacuum or inert atmosphere
- High energy cost for conversion to mill products
- High cost for machining – on the order of 100 times the cost to machine aluminum

Titanium Value Chain - Forgings



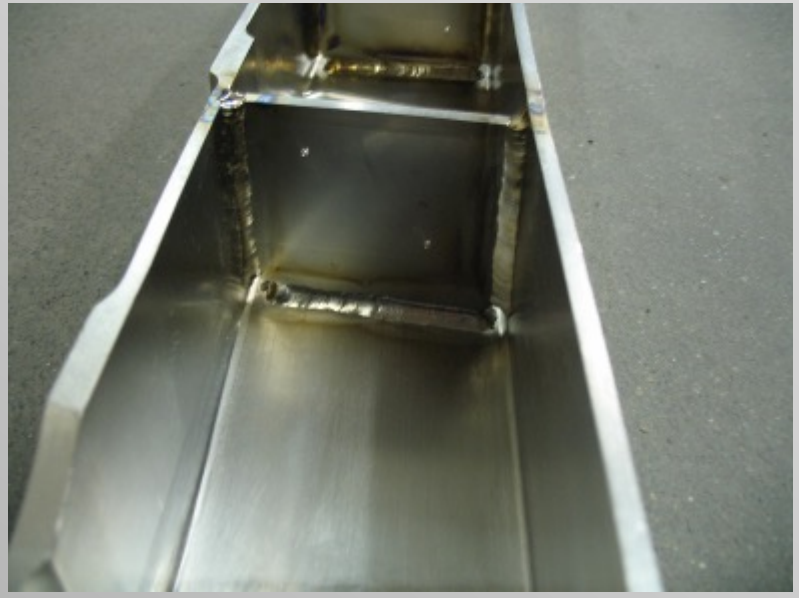
High Buy:Fly Ratio



Approaches to Cost Reduction

- Reduce Buy:Fly Ratio
  - Welding
  - Super Plastic Forming and Super Plastic Forming Diffusion Bonding
  - Higher extrusion utilization (787)
    - Hot stretch forming of extrusions
  - Lower flow stress alloys
    - Reduced forging weight, enhanced machining
- Powder Metallurgy
  - Lower cost mill products
  - Powder metallurgy near-net shapes
    (both of these dependent on low cost, but high quality powder)

Laser Welding (Prototype Part)



Buy:Fly

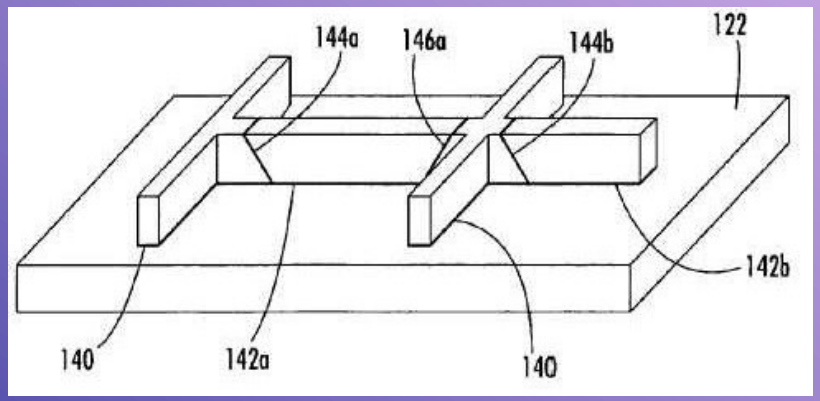
Machined from Plate/Block – 30:1

Laser Welded – 3:1

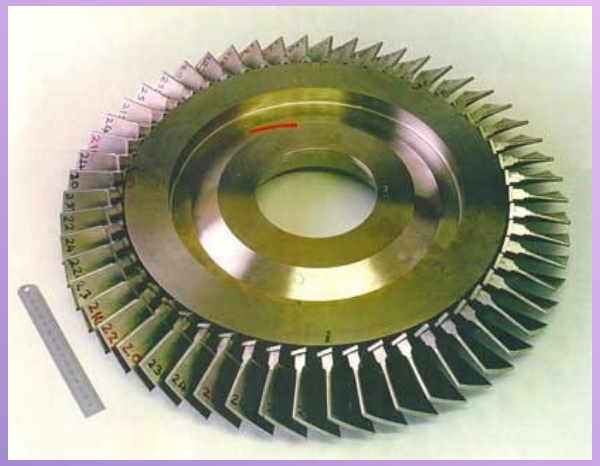
Linear Friction Welding

- Advantages
  - Reduced Buy:Fly
  - Wrought microstructure at interface
  - Base Metal Properties

Boeing Concept for Preforms by LFW

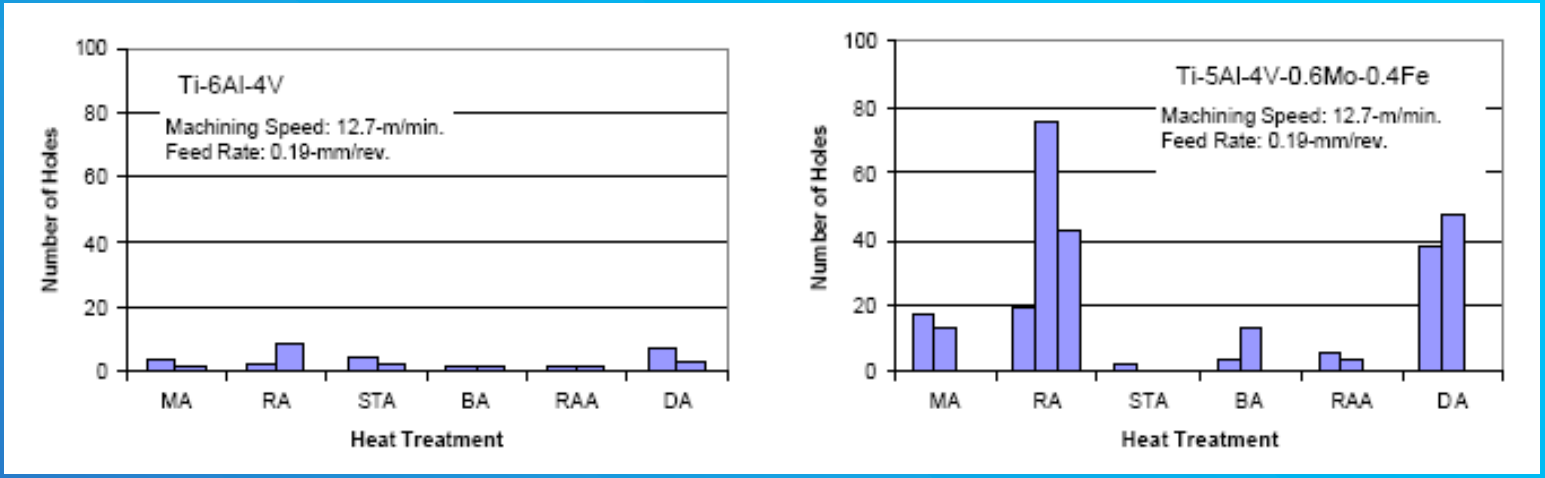


Pat. No. 2005127140 (The Boeing Co.)



Blisk

Improved Machinability – Ti54M Ti-5Al-4V-0.6Mo-0.4Fe



Properties appear similar to Ti-6Al-4V

TIMET's initial work was studying hole drilling

Boeing and MAI machining (milling) studies have indicated a 30% improvement in machining speed in comparison to Ti-6Al-4V with comparable tool wear.

In addition to having a flow stress reduction.

Powder Metallurgy

- Studying both Blended Elemental and Pre-alloyed powders
- Near-net shapes
- Mill products (ITP?) – primarily BE PM
  - Billets for extrusions and forgings
  - Bar
  - Plate
- Die pressing

Initial studies will be for static designed parts

BE PM

- Die pressing – low cost near-net shape parts with wrought mechanical properties.

- Extensive work can result in excellent properties not achievable by wrought means
  - Ti-1-8-5 - 240 ksi TYS with 14-16% El

Blended Elemental Extrusion Data

S. el-Soudani (high oxygen material)

- Mechanical properties higher than wrought – attributed to high oxygen
- Fatigue properties comparable to wrought
- Crack growth rate similar to wrought
- Debit in fracture toughness

(Preliminary data, but very encouraging)

Summary

- Titanium exhibits outstanding properties for aerospace and other industry applications
- Cost must be reduced to gain significant foothold in other markets
- There is a lot of current activity underway to reduce the cost of titanium components
- Significant cost savings are anticipated in the near future