Titanium Manufacturing Processes and Alloy Selection for Aerospace Applications

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Titanium Material Use by Percent Weight on Commercial Programs

Year of Roll Out

Percent Ti by Total Weight

Target

787 (Notional)

707
727
737
747
747SP
757
777
...and now comes the 787 Dreamliner
Titanium Use for Aircraft

- Benefits
- Drawbacks
- Usage
- Technologies to Improve Usage
Titanium in Aircraft - Drawbacks

- **Stiffness to Weight Ratio**
  - Same as Other Metals
  - Worse than Al & Mg in Buckling When Accounting for Geometry

- **Minimum Gage and Density Can Add Weight**

- **High Cost**
  - Material
  - Machining and Cutting
  - Assembly
Titanium Value Chain—Forgings

Titanium Airframe Machined Component Cost Drivers

- Sponge
- Alloy
- Casting
- Conversion
- Forging
- Heat Treat
- Machining
- Inspection
- Shipping

1. F. Tregubenko and A. Morozov, Global Equity Research Report, VSMPO, by Brunswick UBS, April 2004
2. I. Molyneux, Rolls Royce, ITA Conference, Phoenix, AZ, 2005
Needs and Trends in Airframe Titanium

- Improving Performance
- Reducing Cost
  - Lower Cost of Metal
  - Buy Less – Net Shape Processing
  - Reduce Processing Costs
  - Improve Value Stream
- Reducing Lead Times
- Two Aerospace Markets are Emerging
  - Commercial Aircraft
    - > 20 Year Production Runs
    - > 100 Ships/Year
    - Predictable Orders
    - Weight and Cost are Drivers
  - Military Aircraft
    - 5 Year Production
    - 4 – 10 Aircraft/Year
    - Unpredictable Ordering
    - Weight and Non-Recurring Costs are Drivers
Improving Performance - Reduce Minimum Gage

- Reduced Cutting Forces Are Necessary to Reduce Deflection and Minimum Gage
- Carbide Cutters and Higher Cutting Speeds Enable Lower Cutting Forces and Faster Machining Times
- Improved Machining Strategies and Geometries Reduce Minimum Gages and Corner Radii
- Minimum Gage and Radii Reduction
  - 1980s – 0.1” gage, 4:1 depth:diameter
  - 1990s – 0.05”, 6:1 depth:diameter
  - 2000s – 0.03”, 8:1 depth:diameter
Reduced Costs – Lower Cost of Metal

- **Low Cost Extraction**
  - Armstrong and Other Processes for Alloy Reduction
  - Solid-State Consolidation to Mill Products

- **Reduce Wrought Process Operations and Increase Yield - Single-Melt Ingot**
  - In Use Since 2006

- **Increase Market Size and Supplier Base**
  - Air-Transport Requirements for Ground Vehicles
  - Automotive Applications
  - Naval Applications

- **Lower-Cost Alloys**
Reduce Costs – Buy Less – Net Shape Processing

- Welding of Sheet Metal and Plate
- Casting
- Superplastic Forming and Diffusion Bonding
- Nearer-Net Die Forgings
- Metal Additive Manufacturing
- Powder Metallurgy
Welding of Sheet Metal and Plate

- Reverses Trend from Fastened Sheet Metal to Machined Plate and Forgings
- Standardized Features for Reduced Tooling
- Can Also Add Features to Extrusions
Casting & Superplastic Forming/Diffusion Bonding

- Castings Extensively Used for Turbine Engines
- Airframe Castings Have Traditionally Been Net Forging Geometries, Descended From Sheet Metal Geometries
- Redefine Structure Geometries to Optimize 3-D Capabilities of Castings
- Superplastic Forming is Used to Make Unique Complex Contoured Structures
Titanium Sheet has to be Formed Hot

- Hot Size or Stress Relief 1350 deg. F
- Superplastic Forming 1650 deg. F
Nearer-Net Die Forgings

- Forging Above Beta Transus Allows for Lower Flow Stresses and Ability to Form Nearer-Net Part with Equivalent Press Capacity
- Use of Larger Forging Presses and Additional Blocker Dies Improves Definition
- Advanced Forging Modeling Allows to Optimize Forging Sequence
- Use of Powder Preforms
Metal Additive Manufacturing

- Direct Fabrication of Parts Without Part-Specific Dies
- Parts Are Qualified for Flight and are in Production
- Ability to Reduce Cost is Very Geometry Dependent
- Increased Deposition Rates and Dimensional Control are Key to Cost Savings
Powder Metallurgy

- Small Components are Highest Cost per Weight

- Variety of Processes Have Different Geometry / Quantity Windows
  - Press & Sinter – Simple Shape, High Quantity
  - CIP & HIP – Complex Shape, Medium Quantity
  - Direct HIP – Complex Shape, Low Quantity
  - Metal Injection Molding – Complex Shape, High Quantity

- Long-Term Cost Savings Dependent on Low-Cost Titanium Alloy Powders

- Direct Consolidation to Mill Products Key to Fully Realizing Cost Potential of Direct Reduction to Powder Technologies – Weldability for Synergies
Higher Speed Machining

- **Balance Between Metal Removal Rate, Cutter Wear, and Surface Finish**

- **Rough Machining Improvements**
  - 1980s - 1in³/min
  - 1990s - 2in³/min
  - 2000s - 6in³/min

- **Finish Machining Improvements**
  - 1980s – 0.01in³/min
  - 1990s – 0.1in³/min
  - 2000s - 1in³/min
Rough Machining

Maximize Metal Removal Rates Using Correct Tools & Strategies

KrestCut
- High-Speed Steel 50sfm 3-5in³/min
- Powdered metal 60sfm (4-6in³/min)
- Poor performance in shallow or narrow pockets

Center Cutting Plungers
- Carbide 125sfm 4-6in³/min
- Equal Performance to KrestCut
- Equal performance in shallow and narrow pockets
Finish Machining

Use Multi-Flute Carbide Cutters

Plunge Corners - 125SFM

Finish Ribs - 400SFM
Laser Welding (fusion welding)

CNC YAG Laser welding test part.

Laser light through a fiber optic cable.
## Reducing the “Buy to Fly” Ratio for Titanium

<table>
<thead>
<tr>
<th>Process</th>
<th>Weight/frame</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut from Plate</td>
<td>1347 lbs</td>
<td>27:1</td>
</tr>
<tr>
<td>Nested Plate</td>
<td>575 lbs</td>
<td>11.5:1</td>
</tr>
<tr>
<td>Die Forging</td>
<td>425 lbs</td>
<td>8.5:1</td>
</tr>
<tr>
<td>Weldment</td>
<td>100 lbs</td>
<td>2:1</td>
</tr>
</tbody>
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Robotic Laser Welding for Titanium is Easily Adaptable Using Fiber Lasers
Linear Friction Welding Titanium
Another new alternative for Ti buy-to-fly reduction: Linear Friction Welding
Development of Friction Stir Welding Titanium for Superplastic Forming

- FSW was invented in 1991, used extensively in aluminum alloys
- Solid state weld, no melting
- Retains, or produces, fine grained microstructure
- Low occurrence of defects (cracking, porosity, etc.)
- Exceptional properties (static and fatigue)
Friction Stir Welding Combined With SPF
Moving Towards Larger Titanium SPF Parts

This part has six friction stir welds that cannot be seen after SPF forming.
Summary

• Emerging mill techniques will lower the cost of raw material in many different forms.

• Machining of titanium is being minimized by using alternatives to plate and bar.

• Several emerging joining technologies are revolutionizing the use of titanium.

• New alloys are being developed to fit niche applications and to reduce the cost.
Thank You