Titanium for Aircraft Uses, Technologies, and Future Trends

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Boeing Technology – Phantom Works
Titanium for Aircraft

- Background
- Usage Forecast
- Benefits
- Drawbacks
- Technologies to Increase Usage
- Summary
Background - Organization

*Phantom Works Is a Centrally Managed Research and Development Organization*

Boeing Commercial Airplanes

Integrated Defense Systems

Connexion By Boeing
Background

The World Fleet Will More Than Double Over the Next 20 Years

- Regional jets: 6%
- Single-aisle: 14%
- Twin-aisle: 58%
- 747 and larger: 17%

2003: 16,168 airplanes
2023: 34,764 airplanes

Boeing Current Market Outlook 2004,
Demand for Commercial Airplanes
Composites is also Driving Growth in Titanium
Ti Usage in Aircraft Has Been Increasing

- Military Aircraft 9% (F-4) to 35% on Current Aircraft
Titanium Usage:

- In 2005, Boeing Commercial will use ~15M lbs of Ti
- Expect to more than double that when 787 reaches full-rate production

787 Program Concerns:

- Does Sufficient Titanium Production Capacity Exist?
- Does Sufficient Titanium Machining Capability Exist?
- How Much More Costly is Ti 5553 to Machine Than Ti 6Al-4V?
Titanium for Aircraft – Benefits

- Strength-to-Weight Ratio
- Elevated Temperature Capability (350°F – 1000°F)
- Oxidation and Corrosion Resistance
- Fatigue and Fracture Resistance
- Carbon / Epoxy Compatibility
  - Corrosion
  - Coefficient of Thermal Expansion
  - Strain
Titanium in Aircraft – Drawbacks

• **Stiffness-to-Weight Ratio – Same as Other Metals**
  – Many designs driven by stiffness requirements – not strength

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

• **High Cost**
  – Raw Material
  – Machining and Cutting
  – Assembly
Technologies to Increase Usage

• Improve Performance

• Reduce Cost
  – Lower Cost of Metal
  – Buy Less – Utilize Net Shape Processing
  – Reduce Processing Costs
  – Improve Value Stream
Higher Strength

- Ti-5Al-5V-5Mo-3Cr
  - High Strength Heat Treatment – 787 Landing Gear
    ✓ 185ksi UTS
    ✓ 30ksi-in$^{\frac{1}{2}}$ Toughness
  - High Toughness Heat Treatment – 787 Structure
    ✓ 165ksi UTS
    ✓ 80ksi-in$^{\frac{1}{2}}$ Toughness

Improve Performance
Higher Strength & Stiffness

- **Ti-B Alloys**
  - Potential for 20% Stiffness Increase
  - Potential for > 200ksi Strengths
  - Advanced Processing Technologies Could Improve Damage Tolerance

- **Ti-MMCs**
  - 80% Stiffness Increase
  - > 200ksi Strengths
  - Very High Processing Costs will Limit Applications
  - Used Where Weight is a Premium
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
Lower Cost of Metal

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

- **Reduce Wrought Process Operations and Increase Yield** - Single-Melt Ingot – Approved for 40 Military Aircraft Components

- **Increase Market Size and Supplier Base**
  - Air-Transport Requirements for Ground Vehicles
  - Automotive Applications
  - Naval Applications
Buy Less – Net Shape Processing

- Welding of Sheet Metal and Plate
- Casting
- Superplastic Forming and Diffusion Bonding
- Nearer-Net Die Forgings
- Direct Metal Deposition
- Feature Adding to Extrusions and Rolled Shapes
- Powder Metallurgy
Welding of Sheet Metal and Plate

- Reverses Trend from Fastened Sheet Metal to Machined Plate, SPF, and Forgings
- Laser Welding for Reduced Heat Input and Distortion
- Improved Tooling Technology to Maintain High Tolerances

Reduce Costs – Buy Less
Casting

• 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

Reduce Costs – Buy Less
Superplastic Forming & Diffusion Bonding

• Efficient Material Utilization
• Elimination of Thousands of Fasteners
• Move from Superplastic Forming / Diffusion Bonding to Diffusion Bonding / Superplastic Forming

– Diffusion Bonding Under Isostatic Pressure with Stop-Off Provides Improved Bonding
– Superplastic Forming is Short Part of Cycle and May Be Performed on Low-Cost Ceramic Tooling Versus High-Cost Metal Tooling Needed for High Diffusion Bonding Pressures
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
Direct Metal Deposition

- 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 Are Key to Cost Savings
Feature Adding to Extrusions and Rolled Shapes

- Extrusions and Rolled Shapes Have Traditionally Had Best Buy-to-Fly Ratios

- Complexity of Aircraft Structure Has Generally Precluded Use of Constant Cross-Section Features

- Improved Welding Techniques and Direct Metal Deposition Will Enable Addition of Stiffeners, Gussets, Bosses, and Thicker Areas
Powder Metallurgy

• Small Aircraft Components are Highest Cost in Terms of $/lb.

• 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
Reduce Processing Costs

- Near-Net Processes
- Alloys with Improved Machinability
- Higher Speed Machining
- Improved Drilling and Assembly
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
Improved Drilling and Assembly

- Titanium is Difficult and Time Consuming to Drill
- Automated and Power-Assist Drilling Reduces Assembly Labor Hours, Improves Quality
- Advanced Drills and Drilling Techniques
- Advanced Tooling Concepts, Determinant Assembly/Analysis Allows Better Fit for Ti-to-Composite Stack-ups
Improve Value Stream – Today

• **Value Stream**
  – Mill Makes Raw Product
  – Product Ships to Forging/Extruding Site or to Machining Site
  – Product May be Held by Second Source Provider
  – Product Ships to Machining Site for Rough and Final Machining
  – Finished Part Ships to Assembly Site
  – Chips Ship Back to Mill

• **Inefficiencies**
  – Too Much Shipping
  – Too Much Time
  – Too Little Chip Recovery

• **Origin – Competition At All Levels of Value Stream**
Improve Value Stream – Future

• Value Stream Stays at the Mill
  – Forging/Extruding
  – Rough Machining
  – Final Machining
  – Finished Part Ships to Assembly Site

• Efficiencies
  – Best Chip Recovery
  – Reduced Time and Cost
  – Only Finished Parts Bear Shipping Cost

• Moving Rough Machining to Mill or Using Near-Net Process Provides Most of Benefit While Enabling Competition at Finish Machining Level

• Increases in Rough Machining Rates Reduce Capital Equipment Needed to Accomplish
Summary

• Advanced Aircraft Designs Using Composite Materials are also Driving Significant Increase in Volume of Ti for Production

• This Increase in Volume Should Drive Innovations in Improved Alloys and Lower Cost Materials and Processing

• Boeing Will Continue to Invest in R&D to Support both Improved Performance and Lower Costs

Is the Titanium Industry Ready for This Dramatic Growth in Demand from the Aircraft Industry?