Cost Effective Developments for Fabrication of Titanium Components

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Outline of the presentation

- Why Ti is so expensive?
- Ways that the cost of Ti can be reduced:
  - Reduced extraction cost
  - Reduced processing costs
  - Emerging applications
- Conclusions
Boeing 787 Side-of-body chord, Manufacturing cost breakdown
(Courtesy: Jim Cotton, Boeing)
Potential Low Cost Approaches to Fabrication of Titanium Components

- New Extraction Techniques
  (including Electrochemical approaches)
- Innovative Melting Methods
  (Cold Hearth Single Melt Techniques)
- Near Net Shape Castings
- Extrusion Approaches
- Diffusion Bonding/Superplastic Forming
- Creative Joining/Processing
  (Including Friction Stir Welding and Microwave Sintering)
- New Alloys which can be cold processed
  (such as the Wah Chang 425 Alloy \(4Al-1.5Fe-2.5V-0.25O_2\) compared to Ti-6Al-4V)
- Powder Metallurgy Methods
  (Various methods will be Discussed in Subsequent Overheads)
Powder Metallurgy Approaches

- Blended Elemental Powders
- Microwave Sintering
- Cold Spray
- Pre-alloyed Powders
- Additive layer manufacturing
- Metal Injection Molding
Irregular shaped Hydride-Dehydride Ti-6Al-4V Powder (Courtesy of Ametek Corp.).

Spherical gas atomized Titanium Powder (Courtesy Osaka Ti technologies Co. Ltd.)
ADMA TiH$_2$ powder (-100 mesh)
Auto connecting rod fabricated via the blended elemental approach
(Courtesy: ADMA Products Inc.)
Schematic of Dynamet Technologies Inc. CHIP process

- BLEND
- SINTER
- CIP
- HIP
- EXTRUDE
- FORGE
## Ti-6Al-4V Alloy: ASTM E-8 Tensile Properties

<table>
<thead>
<tr>
<th></th>
<th>% of Theoretical Density</th>
<th>Ultimate Tensile Strength MPa (ksi)</th>
<th>Yield Strength MPa (ksi)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMS 4928 (Min)</td>
<td></td>
<td>896 (130)</td>
<td>827 (120)</td>
<td>10</td>
</tr>
<tr>
<td>Typical Wrought</td>
<td></td>
<td>965 (140)</td>
<td>896 (130)</td>
<td>14</td>
</tr>
<tr>
<td>Typical PM CIP-Sinter</td>
<td>98%</td>
<td>951 (138)</td>
<td>841 (122)</td>
<td>15</td>
</tr>
<tr>
<td>Typical PM CHIP</td>
<td>100%</td>
<td>965 (140)</td>
<td>854 (124)</td>
<td>16</td>
</tr>
</tbody>
</table>

(Courtesy Dynamet Technologies)
Density of Ti-6Al-4V compacts after sintering, conditions 5 & 7 used hydrided powder and show by far the highest and most uniform densities (US Patent 6,638,336 B1, October 28, 2003).
### Room Temperature Tensile Properties of a Hydrogenated Titanium Compact (after dehydrogenation)

<table>
<thead>
<tr>
<th>P/M Ti-6Al-4V</th>
<th>Ultimate Tensile Strength, MPa (ksi)</th>
<th>Yield Strength, MPA (ksi)</th>
<th>Elongation, %</th>
<th>Reduction of Area, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 cm (1.376&quot;) thick</td>
<td>994-1028 (144-149)</td>
<td>911-938 (132-136)</td>
<td>14.0 – 15.5</td>
<td>34 – 38</td>
</tr>
<tr>
<td>ASTM</td>
<td>897 (130)</td>
<td>828 (120)</td>
<td>10</td>
<td>25</td>
</tr>
</tbody>
</table>

Titanium Based Material processed using the Hydrogenated Sponge Method is designated ADMATAL™ by ADMA Products
ADMA P/M Ti-6Al-4V
CIP/Sinter/Forging

**Cold Isostatic Pressing**

**Sintering**

**Forging**

### Room Temperature Tensile Properties

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>V</th>
<th>Fe</th>
<th>C</th>
<th>N</th>
<th>O</th>
<th>H</th>
<th>Ti</th>
<th>Other, Each</th>
<th>Other, Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIP/Sinter</td>
<td>6.16</td>
<td>4.21</td>
<td>0.080</td>
<td>0.009</td>
<td>0.021</td>
<td>0.179</td>
<td>0.0018</td>
<td>Bal.</td>
<td>&lt;0.10</td>
<td>&lt;0.40</td>
</tr>
<tr>
<td>ASTM/AMS</td>
<td>5.5 – 6.75</td>
<td>3.5 – 4.5</td>
<td>0.30</td>
<td>0.080</td>
<td>0.050</td>
<td>0.20</td>
<td>0.0125</td>
<td>Bal.</td>
<td>&lt;0.10</td>
<td>&lt;0.40</td>
</tr>
</tbody>
</table>

### Room Temperature Tensile Properties

<table>
<thead>
<tr>
<th>P/M Ti-6Al-4V</th>
<th>Ultimate Tensile Strength, ksi</th>
<th>Yield Strength, ksi</th>
<th>Elongation, %</th>
<th>Reduction of Area, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.375” thick</td>
<td>144 – 149</td>
<td>132 – 136</td>
<td>14.0 – 15.5</td>
<td>34 – 38</td>
</tr>
<tr>
<td>ASTM</td>
<td>130</td>
<td>120</td>
<td>10</td>
<td>25</td>
</tr>
</tbody>
</table>
Ti-6Al-4V parts produced using a press-and-sinter approach and titanium hydride:
(1) connecting rod with big end cap, (2) Saddles of inlet and exhaust valves,
(3) Plate of valve spring, (4) driving pulley of distributing shaft,
(5) roller of strap tension gear, (6) Screw nut, (7) embedding filter, fuel pump, and
(8) embedding filter

(courtesy Ukrainian Academy of Sciences).
The Toyota Altezza, 1998 Japanese car of the year, the first family automobile in the world to feature titanium valves. Ti-6Al-4V intake valve (left) and TiB/Ti-Al-Zr-Sn-Nb-Mo-Si exhaust valve (right).
(courtesy Toyota Central R & D Labs, Inc.).
Near-net shape Ti-6Al-4V engine casing fabricated using the prealloyed approach (Courtesy: Synertech P/M)
Selectively net shape Ti-5Al-2.5Sn impeller for a rocket engine. Fabricated using the pre-alloyed method (Courtesy: Synertech P/M)
Comparison of powder HIP’d, wrought and cast tensile properties
Laser Forming of Titanium Alloys

Schematic of Laser Forming Process

Z-Axis Positioning of Focusing Lens and Nozzle
Beam and Powder Interaction Region
Formed Part
Preform
X-Y Positioning Table
High Power Laser Beam
Powder Delivery Nozzle

Schematic of laser forming process
(Courtesy of The Boeing Company)

Examples of titanium structural components made by laser forming
Lock barrel prototype fabricated by ALM

Automotive pulley prototype fabricated by ALM
Material waste in machining features on a forged preform in conventional manufacture

Roll Forged Case Profile – Forging Waste

Discrete features such as axial flanges and bosses produce a disproportionate increase in forging size and weight.
Additive Manufacturing of Aerospace Brackets

Courtesy: R. Dehoff, ORNL, Oak Ridge, Tenn.
JSF Ti-6AI-4V Bleed Air Leak Detector (Bald) Bracket Fabricated Using Additive Manufacturing

- From plate: 33:1 buy: fly ratio to produce 1 pound component.
- Slightly over-sized part produced using the Arcam AB electron beam melting requires machining of 0.05 inches on all surfaces.
- Average mechanical properties after Hip'ing: YS 127ksi-UTS 137ksi-elongation 14.4\%o
- Chemistry: Ti-6.06AI-4.08/4.1OV-0.17/0.1402
- Part fabrication cost decreased by greater than 50\%.
Schematic of the steps involved in powder injection molding, in which a polymer binder and metal powder are mixed to form the feedstock which is molded, debound and sintered.
Titanium MIM components (Courtesy of Praxis Technology).
### TYPICAL Ti-6Al-4V MIM CHARACTERISTICS

<table>
<thead>
<tr>
<th>Oxygen Contents (w/o)</th>
<th>Relative Density (%)</th>
<th>UTS (Ksi)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.14-0.32</td>
<td>96-98</td>
<td>120-135</td>
<td>9-14</td>
</tr>
</tbody>
</table>
Conclusions

- High Price has Restricted the use of Titanium
  - There are promising new extraction processes emerging.
  - Powder Metallurgy is a promising technique for the production of components that are in various stages of maturity.
  - The blended elemental approach appears ready to produce cost-effective components.
  - Cost-effectiveness for complex parts will be even more attractive if powder costs can be significantly reduced.
- There is an "emotional" barrier to overcome with the P/M approach.