Low Cost Titanium by Advanced Powder Manufacturing Technology – Distinguishing the Current Opportunities from the ‘Wishful Thinking’

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Overview

- CHIP Process (NNS) Current
- PM Mill Product
- Rapid Turnaround
- Custom Alloys for Unique Applications
- Summary
PM Near Net Shape
Dynamet’s Near-Net Shape (NNS) CHIP Process

Dynamet’s powder metal CHIP process is used to produce near net shape titanium alloys and MMCs. The PM preforms can be hot worked to produce titanium MMC forgings and extrusions.
Ti-6Al-4V Microstructure

100% theoretical density
Ti-6Al-4V Alloy: ASTM E-8 Tensile Properties

<table>
<thead>
<tr>
<th></th>
<th>UTS (ksi)</th>
<th>YS (ksi)</th>
<th>EI (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spec. Minimum</td>
<td>130</td>
<td>120</td>
<td>10</td>
</tr>
<tr>
<td>Typical Wrought</td>
<td>140</td>
<td>130</td>
<td>14</td>
</tr>
<tr>
<td>Typical PM*</td>
<td>140</td>
<td>130</td>
<td>14</td>
</tr>
</tbody>
</table>

*Dynamet Technology, Inc. CHIP Process*
Titanium Powder

- Ti Powder produced from Kroll Sponge, currently commercially available with increased worldwide capacity underway
  - Without Na & low Cl content
- Could also use other powders in future years, if and when they become available, useable, and prove to be of lower cost.
Examples of Cost Saving
Production Missile Components

**Stinger**
- Warhead Casing
- Ti-6Al-6V-2Sn
- CHI P
- 50,000 parts

**Sidewinder Dome Housing**
- Ti-6Al-4V
- CHI P+Sinter
- 45,000 parts

**Seeker Housing**
- Ti-6Al-4V
- CHI P Process
- 2,000 parts

50-70% Cost Savings
Larger NNS Missile Parts

<table>
<thead>
<tr>
<th>Mat’l</th>
<th>Part Wt</th>
<th>Buy-to-Fly</th>
</tr>
</thead>
<tbody>
<tr>
<td>130</td>
<td>&lt; 1 lb</td>
<td>~130</td>
</tr>
<tr>
<td>30</td>
<td>&lt; 1 lb</td>
<td>~ 30</td>
</tr>
</tbody>
</table>

- Billet (130 lbs)
- Part (<1lb)
- Preform (30 lbs)
Future Aircraft NNS Parts:
P/M Ti-6Al-4V Fittings

- CHIP Process Replacing Forging from Barstock, or
- Forged from a PM Preform
Future Automotive Parts
P/M Titanium Automotive Con Rod and Exhaust Valve

CHIP FORGED

99% 100%

CermeTi Cladding

Ti-6Al-4V Core
PM Mill Product
Low Cost PM Billet Feedstock for Production of Casting Billet, Extrusion Billet, Forging Billet, and Plate
Mill Product Manufacture by PM vs Conventional Ingot Metallurgy

VAR Double Melt Process

Titanium Sponge
First Melt
Second Melt
Densified, Homogeneous, Alloyed Billet
Forging to Billet

Dynamet PM Process

Titanium Powder Blend
Densified, Homogeneous, Alloyed Billet
Forging
Extruding
Casting

Raw Material Yield 98%

Casting
Extruding
Forging
Raw Material Yield 66%
Rapid Turnaround
Production Leadtimes

- **Sidewinder Ti-6Al-4V Housings (including finish machining)**
  - Raytheon PO 5/9/06; shipped 6/1/06 (4 weeks)
  - Raytheon PO 9/21/06; shipped 11/29/06 (9 weeks)
  - Raytheon PO 4/12/07; shipped 5/11/07 (4 weeks)
  - Raytheon PO 7/19/07; shipped 9/12/07 (8 weeks)

- **Stinger Ti-6Al-6V-2Sn Preforms (CHIP Process)**
  - Army Subcontractor PO- 6/30/07  Shipped 9/12/07 (~10 weeks)

- **Ti-6Al-4V Forging Billet**
  - Boeing PO 5/17/07; shipped 7/18/07 (8 weeks)
Custom Alloys for Unique Applications
## Improved Titanium Alloys

<table>
<thead>
<tr>
<th>Material</th>
<th>UTS (ksi)</th>
<th>YS (ksi)</th>
<th>El (%)</th>
<th>RA (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP Ti</td>
<td>75</td>
<td>60</td>
<td>24</td>
<td>46</td>
</tr>
<tr>
<td>Ti-6Al-4V</td>
<td>138</td>
<td>125</td>
<td>14</td>
<td>28</td>
</tr>
<tr>
<td>Abkolloy®-15</td>
<td>132</td>
<td>124</td>
<td>27</td>
<td>58</td>
</tr>
<tr>
<td>Abkolloy®-HS</td>
<td>212</td>
<td>196</td>
<td>5</td>
<td>24</td>
</tr>
</tbody>
</table>

Abkolloy® is a registered trademark of Dynamet Technology, Inc. referring to titanium-tungsten alloys that are the subject of US and international patents pending.
Additional Ti Alloys & MMCs

- Titanium alloys with excellent high temperature strength
  - Ti-W alloys and MMCs with 80-140 ksi at 1000 F (vs. Ti-64 ~ 60ksi)

- Titanium alloy with low modulus
  - Ti-Ta alloys with 11-13 msi modulus (vs 16-17)

- Wear resistant titanium MMCs
  - TiC and TiB reinforced
Summary

- Economic Near Net Shapes
- Low Cost Mill Products
- Rapid Turnaround
- Custom Alloys for Unique Applications