Initiating Low Cost Titanium Parts

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Acknowledgements

- Craig Blue, Bill Peter and The Materials Processing Group at Oak Ridge National Laboratory
Introductions – ITP and Cristal Global

- Cristal US, Inc.
  - d/b/a International Titanium Powder
    - Wholly owned subsidiary of Cristal Global
  - Cristal Global
    - World's largest titanium chemicals producer; 2nd largest TiO2 producer
    - 8 manufacturing plants & 2 titanium mining operations; about 4,000 employees
- International Titanium Powder: Plant under construction; R&D and pilot plant
Build a production facility based on the Armstrong Process® to produce commercial levels of titanium and titanium alloy powder – Phase 1 Objectives

• Design, build and operate titanium powder production facility
• Capable of making both CP and Ti-Al-V alloys
• Annual production of 4.4 MM lbs when complete
• Initial production expected in late Q4 2010
The Armstrong Process® Technology

- Continuous
- Reaction efficiency 100%
- Low-temperature
- Direct alloy production
Morphology of ITP Powder

<table>
<thead>
<tr>
<th>Element</th>
<th>wt %</th>
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<tbody>
<tr>
<td>Aluminum</td>
<td>6.4</td>
</tr>
<tr>
<td>Vanadium</td>
<td>3.8</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.18</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.004</td>
</tr>
<tr>
<td>Carbon</td>
<td>0.016</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.004</td>
</tr>
<tr>
<td>Iron</td>
<td>0.027</td>
</tr>
<tr>
<td>Sodium</td>
<td>0.003</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0.001</td>
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Process Capability

**Process Capability for Hydrogen**

**Process Data**
- Sample Mean: 0.006
- Sample N: 96
- StDev (Within): 0.00140
- StDev (Overall): 0.00183

**Potential (Within) Capability**
- Cp: *
- CPL: *
- CPU: 1.53
- Cpk: 1.53

**Overall Capability**
- Pp: *
- PPL: *
- PPU: 1.17
- Ppk: 1.17

**Process Capability for Vanadium**

**Process Data**
- Sample Mean: 4.053
- Sample N: 69
- StDev (Within): 0.087
- StDev (Overall): 0.159

**Potential (Within) Capability**
- Cp: 1.90
- CPL: 2.11
- CPU: 1.70
- Cpk: 1.70

**Overall Capability**
- Pp: 1.04
- PPL: 1.15
- PPU: 0.93
- Ppk: 0.93
- Cpm: *
Potential Powder Processing Routes

Powder Modification
- Mill / Sift
- SPHEROIDIZE
- ROLL COMPACT

Powder Consolidation
- CIP
- Add Man
- Press
- Canless HIP
- Roll Comp
- Casting
- MIM
- Extrude

Final Parts
Interconnected Porosity Eliminated: Armstrong Process® Ti-6Al-4V

Powder

Press + Sinter (100 ksi + 1300°C/1h)

Interconnected Porosity Eliminated: Armstrong Process® Ti-6Al-4V

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Interconnected Porosity Eliminated: Armstrong Process® Ti-6Al-4V
CIP & Sinter Approach

Low Densities (~80%) ➔ Fully Dense Canless Hot Isostatic Pressing

<table>
<thead>
<tr>
<th></th>
<th>% of Th. Density</th>
<th>YS (MPa)</th>
<th>UTS (MPa)</th>
<th>EL (%)</th>
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</thead>
<tbody>
<tr>
<td>CPTi</td>
<td>82.4</td>
<td>400</td>
<td>455</td>
<td>6.6</td>
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<tr>
<td>Ti-6Al-4V</td>
<td>94.6</td>
<td>900</td>
<td>991</td>
<td>4.4</td>
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ASTM Minimum Requirements for Ti Tensile Properties (Fully Dense)

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<tbody>
<tr>
<td>CP-Ti, Grade 2</td>
<td>275</td>
<td>345</td>
<td>20</td>
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<tr>
<td>Ti-6Al-4V</td>
<td>828</td>
<td>895</td>
<td>10</td>
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Roll Compaction

Powder Feed

Roll Compaction

Sponsored by DOE – EERE Industrial Technologies Program

![Graph showing density comparison](attachment:graph.png)

- Armstrong Ti-6Al-4V
- HDH Ti-6Al-4V

- Green
- Cold-rolled
- CR+ 1300C/1h
Summary

- Key process component: control of chemical precursors
- ITP powder morphology is unique and challenging
- Process routes to mill products and sheet have been demonstrated
- Press & sinter, direct HIP, additive manufacturing approaches are in early development stages