Locations

- Eighty-four, PA (Powders & Clad)
- Reading Alloys, PA (Titanium Powder Alloys)
- Wallingford, CT (Strip, Wire, Engineered Shaped Components)
- Hamilton Precision Metals, Lancaster, PA (Precision Re-roller)
- Coining, Montvale, NJ (Microstampings, Solders, Cladding)

Paper Presented by Ametek-Reading Alloys: Ryan Smith, Muktesh Paliwal, Joe Capone
In Collaboration with: Customer Partnerships, ORNL, BAE, Lockheed Martin
SMP Division- Key Processing Technologies

- Water-atomization
- Cladding
- Thermite Melting
- HDH & DOSS
- Roll Compaction**
- Pneumatic Isostatic Forging (PIF)**
- Precision Re-Rolling**
METAL STRIP- AMETEK is a world class producer of metal strip using powder metallurgy technology.

Strip – Roll Compaction Process

Roll Compaction

Prealloyed or Elemental Powder

Sinter

Coil-up
Roll Compaction Process
Overview

• Preparation of pre-alloyed or elemental blends of powder
• Roll compaction of powder into strip:
  – Thickness 0.050”- 0.150”
  – Production widths 15”, 18”, 24”
  – Coil Weights up to 8,000 lbs.
• Sintering, hydrogen or vacuum
• Further densification, homogenization, and purification of the strip using a series of cold roll and thermal treatment steps
Advantages of P/M Roll Compaction

• Consistency – Compositional control lot-to-lot
• Homogeneity – Segregation, typical of cast products, is eliminated in favor of homogeneous microstructure
• High Purity – Exceptional mechanical, electrical, surface, and thermal performance characteristics
• Flexibility – Very low level alloy additions can be used to formulate alloy systems with special properties
P/M Processing: Roll Compaction
SCHEMATIC OF PIF PROCESS

CONTAINER

FURNACE

PRESSURE VESSEL
Advantages of PIF

• Higher Material Yields
• Improved Product Density
• Controlled Microstructure
• Shorter Processing Times
• Small batches
• Net Shape Fabrication
• In-line Water Quench Capability
Cu - 15%Ni - 8%Sn BEFORE AND AFTER PIF

(a) CIP + ANNEAL
(b) PIF at 885°C / “X” psi

Full density achieved in <60 seconds
Alloys Available via Roll Compaction and PIF’ing

- High Purity Ni
- Nickel-Tungsten
- Nickel-Iron (36-80%)
- Sealvar ASTM F-15 (Kovar)
- High Purity & Ductile Cobalt (90-99%)
- Cu-Ni-Sn, Spinodal Alloys (BeCu Substitute)
- Iron-Aluminide
- Tungsten-Copper, Moly-Copper
- CP Ti & Ti 6/4
Products & Applications
Precision Re-rolling

• Hamilton Precision Metals is the leading producer of CP Ti for Pacemaker shells
• Foils can be rolled to 1.5 micron (0.00006”)

![Image of precision rolling process]
Alloys for Medical Implant applications....

**CP Titanium**

*for outer shields and internal battery case*

Heart pacemaker and drug infusion pump made with titanium outer shell
Titanium Processing & Development Programs

1. Roll Compaction of CP Ti and Ti 6/4 Powders (Reading Alloys, ITP, et al)
2. Pneumatic Isostatic (PIF) Forging of CP Ti, Grade 5 & Grade 23 Powders into Bars, Billets & Tubes
3. Processing of light gauge (<=0.010”) Grade 23 strip

• Samples are in Reading Alloys Booth #227
Titanium Processing & Development Programs

1. Roll Compaction of CP Ti and Ti 6/4 Powders (Reading Alloys, ITP, et al)
   • First 4” wide program launched with DARPA in 2005.
   • Subsequent programs with ORNL which included Industrial partners and 15” wide development.
   • Ongoing efforts to commercialize CP opportunities & optimize 15” wide Ti 6/4 processing.
Powders Used For Roll Compaction and CIP/PIF Processes:

- **Armstrong Powders**
  - CP Ti
  - Ti-6Al-4V

- **Reading Alloys HDH Powders**
  - CP Ti
  - Ti-6Al-4V
### Production of Roll Compacted Strip: CP Ti HDH Powder

<table>
<thead>
<tr>
<th></th>
<th>YS MPa, (ksi)</th>
<th>UTS MPa (ksi)</th>
<th>Ductility (%)</th>
<th>Density (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strip - 0.02” Thick</td>
<td>511 (74)</td>
<td>592 (86)</td>
<td>16.3</td>
<td>99.7</td>
</tr>
<tr>
<td>Strip - 0.04” Thick</td>
<td>334 (48)</td>
<td>451 (65)</td>
<td>25.3</td>
<td>99.7</td>
</tr>
</tbody>
</table>

- Note: Heat Treatment used for the two strips are different.
CP & Ti 6/4 Processing

Coilable 5” CP Ti at 0.050”

15” Production Line
Titanium Processing & Development Programs

2. Pneumatic Isostatic (PIF) Forging of CP Ti, Grade 5/23 Powders into Bars, Billets & Tubes
   - Several programs have been completed including production of plates for Armored vehicles with BAE & ORNL.
   - Our current focus is in following areas:
     - Customer driven partnerships
     - Down-hole applications
     - Niche property requirements
     - Difficult to cast alloys
     - Near shape applications
Titanium Processing & Development

- Pneumatic Isostatic Forging of CP Ti & Grade 5/23 Reading Alloys Powders into Billets & Tubes

<table>
<thead>
<tr>
<th></th>
<th>Ti 6/4</th>
<th>Actual</th>
<th>ASTM/Hdbk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield-ksi</td>
<td>126</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Tensile-ksi</td>
<td>141</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>Elong.-%</td>
<td>15</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Red. Area</td>
<td>36%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CVN ft-lbs</td>
<td>13-14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$K_{ic}$ ksi.inch$^{1/2}$</td>
<td>75.4</td>
<td>57-60</td>
<td></td>
</tr>
<tr>
<td>Oxy. Wt %</td>
<td>0.12</td>
<td>&lt;0.20</td>
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Plate Production

Reading HDH Powders CIP&PIF Consolidation
ITP non-milled powders require additional processing to consolidate

RA (Ti-6Al-4V)
ITP (CP Ti)
3. Processing of light gauge (<=0.010”) Grade 23 strip

- Wrought Processed
- P/M approach
**Grade 23 Light Gauge Strip**

(≤0.010”)

- Non-ground solution to produce light gauge materials for Medical Implant Applications

![Surface @ 200X 90° Bent Test](image1)

![Microstructure 500X](image2)

<table>
<thead>
<tr>
<th>Side “A”</th>
<th>Side “B”</th>
<th>Internal</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRC 30.5</td>
<td>HRC 31.0</td>
<td>HRC 28.0</td>
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<table>
<thead>
<tr>
<th>Cup Height</th>
<th>90° Good Way</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.4mm</td>
<td>4.1T</td>
<td>Pass</td>
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Conclusion

• Ametek Specialty Metals has a unique combination of metal production capabilities.
• Powder production and consolidation technologies are focused on Titanium development.
• Current programs are underway with Customers, Industrial Partners and Research Organizations.