Titanium Powder Metallurgy for Armor and Structural Applications

Jane W. Adams(1), Vlad A. Duz (2), V.S. Moxson (2)

(1) US Army Research Laboratory, Weapons & Materials Research Directorate, Aberdeen Proving Ground, Maryland 21005, USA
(2) ADMA Products, Inc, 1890 Georgetown Road, Hudson, Ohio 44236, USA.

Increased use of titanium will provide weight reduction, which is the goal for armor and structural applications for all military systems. Powder metallurgy approach has great potential for low cost manufacturing of these products and can be the preferred manufacturing process for production of armor plates and composite armor module components for DoD and civilian applications. P/M approach offers cost reduction in manufacturing titanium parts as well as substantial reduction in lead time. In this presentation, Titanium PM is reviewed as a possible substitution of IM processes when a price reduction and shorter delivery time make PM approach more favorable to compare with the traditional IM. The lowest cost Blended elemental approach (BE) to produce Ti alloy components by room temperature consolidation (die-pressing, cold iso-static pressing, direct powder rolling) followed by sintering will be discussed. This BE approach would also allows to produce the low cost large ingots and slabs for subsequent high temperature deformation by forging, rolling, extrusion, flow forming and other conventional processes. Although these processes are being used in ingot metallurgy, the P/M starting material offers the lower cost and improved microstructure and properties which will be demonstrated in this presentation.
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Jane W. Adams
US Army Research Laboratory

Vlad A. Duz and V.S. Moxson
ADMA Products, Inc.

21-24 September 2008
Las Vegas, NV
2006 U.S. Powder Metallurgy (P/M) Industry Sales

Conventional P/M vs. Titanium P/M

INGOT → ATOMIZATION → POWDER → FORGING → P/M PARTS

$5,000,000,000

Ti SPONGE → POWDER → P/M PARTS

$10,000,000
ADMA Processing Step Options for P/M Ti Alloy Part Production

Base TiH₂ powder (≈150 μm) or Base Ti powder

+ Alloying elements added as master alloy powders (MAP)

**Ti alloy compositions**
- C.P. Ti
- Ti-6Al-4V
- Ti-3Al-2.5V
- Ti-6-6-2
- Ti-6-2-4-2
- Alpha and Gamma TiAl
- Other Ti alloys

**Metal Matrix Composites**
**Multilayered Structures**

**Blending**

Room temperature consolidation
- Direct powder rolling
- Cold-isostatic pressing
- Die-pressing

**Vacuum sintering**

**Post processing**
- Rolling
- Forging
Current Development Efforts

• Powder Type and Composition Evaluation
  - Hydrogenated Ti Powder (ADMA)

• Direct Powder Rolling
  - 0.25”-0.50” thick titanium alloy armor plates
  - Ti alloy foils

• Cold Iso-Static Pressing
  - P/M Ti Alloy Bradley Hatch
  - Flat Encapsulated Armor
  - Curved Encapsulated Ceramic Armor
  - Preform billets for extruded, rotary forge of roll-formed bar stock

• Die-Pressing
  - Various P/M washers for Boeing 787 Dreamliner
CIP + Sinter P/M Approach

- P/M Ti Alloy Commander Hatch
- Flat Encapsulated Armor
- Encapsulated Ceramic Armor

Cold Isostatic Pressing

Vacuum Sintering

CIP Unit
24” Dia x 50” Long
58,000 psi
15 min cycle
CIP – Sinter - Hot Rolled Plate

Billet size and weight:
- 12" x 8" x 30" = 410 lbs
- 16" x 5" x 55" = 560 lbs
P/M Ti-6Al-4V CIP/Sinter/Forge
Commander’s Hatch Pre-form

ADMA
Wyman-Gordon
BAE
ARL
TiH$_2$ powder green Ti-6Al-4V pre-form billet for forging (250 lbs)
P/M Ti-6Al-4V Commander’s Hatch Pre-form from Hydrogenated Ti powder (ADMA) β-forged at WG

**% HYDROGEN - HYDROGEN AFTER ALL PROCESSING COMPLETE - 0.0101% LECO;**
P/M Ti-6Al-4V Commander’s Hutch
(ADMA/Wyman Gordon/BAE)

<table>
<thead>
<tr>
<th>Elements, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
</tr>
<tr>
<td>6.04</td>
</tr>
</tbody>
</table>

Cold Isostatic Pressing

Sintering

Forging

H07-002-01

<table>
<thead>
<tr>
<th>Sample 1</th>
<th>Sample 2</th>
<th>BAE SPEC MIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>UTS (PSI)</td>
<td>146,300</td>
<td>152,500</td>
</tr>
<tr>
<td>0.2% YS (PSI)</td>
<td>131,800</td>
<td>138,900</td>
</tr>
<tr>
<td>ELONGATION, %</td>
<td>13.0</td>
<td>13.0</td>
</tr>
<tr>
<td>R. A., %</td>
<td>26.4</td>
<td>25.2</td>
</tr>
</tbody>
</table>

* MICRO STRUCTURE SATISFACTORY-NO ALPHA CASE;
** % HYDROGEN - HYDROGEN AFTER ALL PROCESSING COMPLETE - 0.0101% LECO;
Recently Commissioned Rolling Mill for plate or laminated P/M composites

Powder hopper detail
The C.P. Ti direct powder rolled plates 26” wide with different green thicknesses up to 0.25” were successfully rolled.
Ultrasonic Consolidation of Titanium Alloys for High Performance Aircraft Damage Repair

Ultrasonic Bonding: 1000 Newtons force, 25 μm sonotrode transverse amplitude, 100 inches per minute feed rate, 450°F

Figure 2: VC Joining Test Results on ADMA Foil.
Influence of Oxygen on RT Tensile Properties of Ti-6Al-4V Sodium-Reduced Ti Powder
Low-oxygen P/M Ti-6Al-4V from Hydrogenated Ti Powder

<table>
<thead>
<tr>
<th>Material</th>
<th>TiH sponge</th>
<th>TiH powder</th>
<th>Ti-6Al-4V blend</th>
<th>Ti-6Al-4V sintered small sample</th>
<th>Ti-6Al-4V sintered large sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen, ppm</td>
<td>1090</td>
<td>790</td>
<td>650</td>
<td>1270</td>
<td>1320</td>
</tr>
</tbody>
</table>
Cold Isostatic Press + Sinter Components

Applications:
Fredserts
JLTV Undercarriage supports
Extrusion preforms for piping
Fasteners
Process Development for Blended Elemental
P/M Ti-6Al-4V FRED SERT® Threaded Attachment Insert

(extruded, rotary forge or roll-formed bar stock)

3 in. diam. x 26 in.
P/M Ti-6Al-4V Extrusion billets

<table>
<thead>
<tr>
<th>Ti-6Al-4V</th>
<th>Ultimate Strength, ksi</th>
<th>Yield Strength, ksi</th>
<th>Elongation, %</th>
<th>Reduction of Area, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADMA P/M</td>
<td>134 - 135</td>
<td>156 - 157</td>
<td>12.5 - 12.9</td>
<td>28.2 - 28.3</td>
</tr>
<tr>
<td>Ingot Based</td>
<td>125 - 127</td>
<td>140 - 142</td>
<td>12.4 - 12.6</td>
<td>26.9 - 27.6</td>
</tr>
</tbody>
</table>
ADMA has made P/M CP Ti Preforms Successfully Flowformed by DFC
CP Titanium Piping Applications

- **Low Cost Titanium Piping**
  - Rationale: Reduce Cost of Proven Titanium Application
  - Low Cost Powder Preform
    - Hollow, Cylindrical Preform
    - Navy Can Benefit from Government/Industry Low Cost Powder Initiatives
    - Consolidation Process
  - Flowform Conversion
    - Minimal Material Waste
    - Proven Technology

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**Issue Limiting Increased Use:**

- High material and fabrication costs
- Ti system estimated to saved $17M/ship if life cycle savings
FY09 Development Plans

Powder Type and Composition Evaluation
- Engineering-scale Hydrogenated Ti Powder Production System (ADMA)

Cold Iso-Static Pressing
- Qualification/Production of preforms for vehicle hatches
- Preform extrusion billets for Fredserts and aerospace components

Al-Ti Laminar Plates:
- Ultrasonic consolidation
- HIP
- Brazing

MMC Plates:
- Discontinuous particulate
- Continuous fiber reinforcement
Summary

• P/M reduces cost by alloying and pre-forming at RT

• P/M manufacturing reduces processing steps

• P/M manufacturing can reduce time to delivery

• Low oxygen powders are becoming commercially available

• Capability to make large Titanium P/M parts exists now:
  - Plate
  - Extrusion pre-forms
  - Encapsulated materials