Overview of Near Net Shape Manufacturing of Titanium Components at Quad City Manufacturing Laboratory

James W Sears
Director – Additive Manufacturing Laboratory – SDSM&T
Exec. Director – Quad City Manufacturing Laboratory (QCML)
Rapid City, South Dakota

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Outline

- Overview: Quad City Manufacturing Lab
  - QCML: What & Where
- QCML: Vision & Role
- QCML: Facilities (Current)
- QCML: Facilities (FY 10/11/12)
- Titanium Powder
- Summary
Quad City Manufacturing Laboratory (QCML)

The QCML is a Not-for-Profit (501c(3)) Research and Development Company imbedded within the Rock Island Arsenal Joint Manufacturing and Technology Center
Rock Island Arsenal & QCML
QCML - Vision

“The Technology and Talent Gateway”

Rock Island Arsenal

QCML
Primary Mission
Technology Development
Titanium PM
Advanced Composites
Process Control Integration
Information Delivery Technology
Advanced Manufacturing

QCML
Educator’s Forum
Technology & Process Training
Universities
Community Colleges
Small Business
Industry
RIA/JMTC

QCML
Partnering
Industry & Technology
Titanium, Advanced Composites,
Castings Forgings, Adv. Materials
(Nano, Mg, AlBe, etc.),
Process & Control Integration,
Renewable Energy Technologies,
Many more

Education
Talent
Knowhow
Jobs
Sustainable
Business Community

Efficiency
Forward Looking
Innovation
Responsive
Community

Technology

Alcoa
John Deere

Vision
QCML Role

- Provide leadership to establish and maintain a Center of Excellence, within the JMTC, in manufacturing of titanium, lightweight composites and other advanced materials, to meet current and future requirements of the Army and sister services,

- Conduct research and development on manufacturing technologies for titanium, lightweight composites, and other advanced materials,
QCML Role

- Provide facilities, equipment and technical support to industrial and academic participants, to facilitate their exploration and development for titanium, lightweight composites, and other advanced materials applications.

- Conduct pilot production parts made of titanium, lightweight composites and other advanced materials, to aid in application qualification.
QCML Capabilities (current)

- Hot Isostatic Pressing (HIP)
- Spark Plasma Sintering (SPS)
- Laser Additive Manufacturing (LAM)
- Direct Metal Laser Sintering (DMLS)
- Ultrasonic Additive Manufacturing
QCML Facilities

- Established Lab space on the RIA (July 2010)
  - Building 299 – 7500 sq ft
  - Capabilities: HIP, SPS, LAM, EOS, Solidica

- Near Net Shape Manufacturing (NNSM)
  - Casting (Syvier Steel, UNI, JMTC)
  - HIP (KittyHawk/Sinter Tec)
  - SPS (Cee6Cube'd)
  - Additive Manufacturing (SDSMT, HF Webster, Xalloy)

- Titanium Powder Production Processes
  - PREP – (Advanced Specialty Metals (ASM))
  - GA – (ISU/AMES - Iowa Powder Atomization Technologies)
  - HDH – Spheriodization (Ametek/Reading)
  - ITP – Powder conversion technologies
Laser Additive Manufacturing (LAM)

- **LENS™ 850**
  - 1 KW laser, 450 mm cubed workspace, inert gas operations
- Ti parts fabrication & repair
- WC MMC’s for wear
- Tooling Fabrication & repair

M119, M777, M240L Armor Covers
Hydraulic rams
Remanufactured Parts
Tooling Enhancement
Direct Metal Laser Manufacturing

- **EOSINT M270**
  - 200W Fiber Laser
  - 250 mm x 250 mm x 215 mm build area

- **Functional Parts**
  - First articles, Low volume
Hot Isostatic Pressing (HIP)

- AE-8-30H
  - 1200° C, 200 Mpa, 100mm dia x 212 mm long HZ
- Powder Consolidation
- Casting Densification
- MIM Densification

- Small Arms M240 Castings
- M119, M777 Castings
- Armor Covers Ti LAM
- DMLM & MIM Parts
Spark Plasma Sintering (SPS)

- **SPS-10-3**
  - 3000 amps. 10 tons, 2400° C
- **SiC & WC**
- **Ti to Fe joining**
- **Refractory Metals**
- **Nano – materials**
  - SiC & WC components
  - W & W-Re Nuclear Reactor parts
  - Ti to Fe and Ti-Ta interfaces
Ultrasonic Additive Manufacturing

- **Solidica Formation™**
  - Build area 16” x 16” x 10”
  - 3.3kw 2000b power supply
- **Embedded Sensors**
- **Heat Sinks**

Examples of AL parts that have been fabricated using the ultrasonic system with embedded passages and heat sinks.
QCML Capabilities (FY-10/11/12)

- Plasma-Arc Hearth Melting (PAHM)
- Plasma Additive Manufacturing (PAM)
- Plasma Rotating Electrode Process (PREP)
- Closed Coupled Gas Atomization (CCGA)
- Supersonic Laser Deposition (SLD)
- Friction Stir Welding (FSW)
- Internal Bore Laser Cladding (IBLC)
Supersonic Laser Deposition

W. O’Neill, A. Cockburn, M. Bray, M. Sparkes, R. Lupoi
Centre for Industrial Photonics, Institute for Manufacturing, Department of Engineering, University of Cambridge.
Plasma-Arc Cold Hearth Melting

- PAM 900
  - 4” to 10” billets 60” long
  - (2) 450 kW Torches
- Melt source for GA
- Casting Billet
- Powder Billet for GA & PREP
Plasma Rotating Electrode Process

- **ASM-PREP**
  - 4” PAM billets
  - 500 ton/yr
- **LAM**
- **HIP**
- **DMLM**

*Above: PREP® powder particles are uniformly spherical*
Closed Coupled Gas Atomization

Commercialization: Semi-Continuous Ti Powder Production System

- Semi-Continuous Plasma Arc Melting (0.5-1MW power) mature tech; Retech, Seco/Warwick
- 100 lb Induction Skull Melting System (0.7-1MW power) mature tech; Retech, Consarc, ALD
- Composite Pour Tube (30 kW, patented tech.)
- Close-Coupled Atomization Nozzle (patented tech.)

**Total Power 1-2MW System**
Ti Prototype Atomizer Project

- 4-5 kg ISM system
- Patented composite pour tube
- Superheat Coil
- Close-Coupled Atomization Nozzle

- Ability to generate high superheat immediately prior to gas atomization is critical
Internal Bore Laser Cladding
Induction Plasma

Titanium

**PHYSICAL PROPERTIES**

- Atomic Weight: 47.9
- Atomic Number: 22
- Melting point: 1667°C
- Boiling point: 3277°C
- Density: 4.5 g/cm³
- Heat Capacity: 0.528 J/g·°C
- Thermal conduct.: 17 W/m·K

**THE INDUCTION PLASMA TREATMENT**

Induction plasma treatment allows for superior treatment of metal and ceramic powders. Plasma processing provides several advantages such as creating spherical particles, improving flow, increasing density, allowing alloy synthesis and enhancing the purity of the material.
Friction Stir Welding (FSW)

- FSW
  - Solid State Joining
  - Green Technology
  - Ideal for Al & Mg
  - Developing for Ti
- Retrofit Existing Mills
Converting Powder into End Product – A unique capability on the Rock Island Arsenal

1. Plasma Melting Equipment
   - Make alloy pre-stock for PREP, Casting and GA
   - Molten metal source for Gas Atomization

2. Establish a powder production capability (e.g. PREP, GA, HDH, ITP and PAS)
   - Diversified sources will allow for immediate powder production to support manufacturing

3. Establish Powder Consolidation Capability (e.g. Hot Isostatic Pressing, Powder Injection Molding, Laser Additive Manufacturing, and Direct Manufacturing)
   - Diversified powder consolidation tools for manufacturing a wide variety of titanium components for military and commercial applications
Why Ti Powder?

- Trend towards ‘Green’ Technology.
- Powder provides more ‘Rapid Response’.
- Allows for complex parts.
- Mature Technology
- Shorten Supply Chain
- Less Capital Investment
- More Diverse Markets
- New Alloys Possible
Why not Ti Powder?

- Limited Supply
- Safety Issues
- Qualification
- High Cost of Production
- Limited Availability of Alloys
- Limited Process Knowledge
Titanium Powder Metallurgy

- Lack of Significant Quantities of Titanium Powder limits market potential.

- However, use of PM Techniques in the fabrication of Titanium have a positive effect on application developments, even with the current sources of Ti powder.
Solid State Consolidation

- Titanium Metal Powder Consolidation Techniques
  - Vacuum Hot Pressing (VHP)
  - Roll Compaction
  - Extrusion
  - Cold Isostatic Pressing & Sinter (CIP+S) or (CIP/HIP)
  - Hot Isostatic Pressing (HIP) or (HIP + Forge)
  - Press & Sinter (P&S)
  - Powder Forging
  - Metal Injection Molding (MIM)
  - Additive & Direct Manufacturing (LAM, LENS®, DMLM)
  - High Velocity Compaction
  - Others
Solid State Consolidation

ASM Metals Handbook, Vol. 7
Ti Metal Injection Molding (MIM)

Gr. 4 Titanium MIM Parts. 7cm long, weighing 8g. Photo courtesy Titanium Products Inc.
Ti Hot Isostatic Pressing (HIP)

Figure 18. Ti-6Al-4V components produced from prealloyed Ti-6Al-4V powder, using HIP'ing and the ceramic mold process; (a) a nacelle frame for F14A Ti-6Al-6V-2Sn, (b) radial impeller for F107 cruise missile engine Ti-6Al-4V. (Courtesy Crucible Materials Corporation).
Figure 16. 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 Ukraine Academy of Science).
Titanium Powder Issues

- No integrated titanium powder processing facility exists in US. (i.e., sponge to alloy to powder)
- Most titanium powder is produced from wrought processed titanium (products such as titanium plate, bar and forgings) or scrap
  - Need semi-continuous processes that convert sponge-alloy compacts and/or direct reduced titanium alloy to powder
- Limited Domestic Production ~ 10 ton/yr
  - Limits in Supply Chain prevents Market Developments
Emerging Titanium Powder Production

- Kraft Report 2004
  - 14 Emerging technologies - 12 produce powder
- ITP – Armstrong Process (Na Vapor Reduction)
- Metalysis – ‘Fray’ Oxide Reduction
- CSIRO – (Molten Mg reduction)
- MER – (Composite Anode) Oxide Reduction
- ADMA – A Modified Hydride Process
PM Consolidation Technologies are well established for Titanium applications.

The path for development of new Ti PM applications will be driven by the availability of powder.

QCML – RIA/JMTC developing a national resource for Titanium Near Net Shape Manufacturing (NNSM).
Thank You