Additive Manufacturing – A Revolution in the Making
ITA Annual Meeting, Scottsdale, AZ
September, 2016
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Luke Haylock
Alcoa Fastening Systems & Rings

Ed Colvin & Brandon Bodily
Alcoa Forgings & Extrusions
Launching Two Strong Companies: Driving Value

Separating into Value-Add Co. and Upstream Co.

**Arconic**
*Lightweight Multi-Material Innovation Powerhouse*

- **Premier supplier** of high-performance advanced **multi-material products and solutions**
- **Positioned** to strengthen in **growth markets** with significant **customer synergies**
  - e.g., aerospace, automotive, commercial transportation, building and construction
- **Expanded multi-material**, technology and process **expertise**
- **Innovation leader** with full pipeline of products & solutions
- **Successfully shifting** product mix to **higher value-add**
- **Robust margins** and **investment opportunities above cost of capital**

**Alcoa**
*Globally Competitive Upstream Business*

- **Robust projected aluminum demand growth** of 6.5% in 2015 and **double between 2010 and 2020**
- **Attractive Portfolio:**
  - World’s **largest, low cost bauxite miner** at the 1st quartile on the cost curve (46M BDMT)
  - World’s **largest, most attractive alumina** business in the 1st quartile of the cost curve (17.3M MT)
  - **Substantial energy** assets with operational flexibility
  - Optimized smelting capacity (3.4M MT) continuing to improve its 2nd quartile cost curve position
  - **17*** casthouses providing **value-add** products
- **Diverse sites – close proximity** to major markets
- **Committed to disciplined capital allocation** and **prudent return of capital** to shareholders

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1) CRU analysis 2) Mined in 2014, including equity interests 3) CRU and Alcoa analysis 4) Includes Saudi Arabia Joint Venture

BDMT = Bone Dry Metric Ton
Alcoa and 3D Printing

Our Revolution is in the Making
The World of Additive Manufacturing

Today

Design
Like to like
Very little of design for AM

Materials
Titanium, Nickel, Cobalt Chrome
Metals which are difficult to machine
Industry understanding powders

Adoption
Aerospace
Medical

Industry
Islands

Tomorrow

Design
Designed for AM
Lighter, more functional
On “demand”

Materials
Exotic metals and plastics - Designed for AM
Industry using 30 MT of metal powders

Adoption
Process will get faster, more productive
Larger
Hybrid – combining multiple processes seeking cost efficiencies

Industry
Integrated & automated

Titanium Metal Powder Usage

Metal Powder Consumption Projected Growth

You Are Here

1. BBC, Morgan, “Amaze Project aims to take 3D printing ‘into metalage’, 15Oct2013
2. CSIRO, Barnes & Kingsbury, 2014 Wohlers Conference, Euromold, Frankfurt, Germany
Alcoa’s Additive Advantage – *from ingot to install*

Manufacturing

- 770 ft³
- 22 m³

- 0.7 ft³
- 20 cm³

Multi-Material

- Ti
- Ni
- Al
- Fe
- Plastic

Legacy Know How

Design & Design Tools

Powder Feedstock & Atomization

Laser & E Beam Processing

HT & HIP Operations

Machining & Inspection
**Alcoa & 3D Printing: Our Revolution Is in the Making**

**Alcoa** is an expert in advanced alloys—the raw material for 3D printing.

Advanced alloys are made into wire or powder—the "ink" in our 3D printing processes.

Alcoa's cutting-edge 3D printers build three-dimensional products tailored to the aerospace industry.

In-house machining finishes 3D-printed parts to exact specifications.

We fortify 3D-printed parts for the highest performance through various methods including heat-treating, Hot Isostatic Pressing or our proprietary Ampliforge™ process.

**Material Science**

**Qualification Expertise**

**Design Optimization**

**Manufacturing Techniques**

Finishing parts are ready for takeoff on the world's most advanced aerospace platforms.

www.alcoa.com

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The Three I’s of Successful Additive Manufacturing

Alcoa is an established innovation leader in aerospace and 3D printing

- Innovate
- Integrate
- Industrialize

Ampliforge™ process advantages:
- Reduced input stock and improved buy-to-fly
- Fewer forging operations
- Reduce tooling NRCs
- Extend tooling life
- Nearer-net forgings

Current focus on titanium alloys

1 shape + 1 material x 2,000
Innovating through Investing

Norsk Titanium Receives Investment From RTI International Metals, Inc. To Expand Market Reach Of Its Advanced 3D Printing Technology

Investment to Increase Capacity to Meet Growing Demand for Complex Titanium Components

We just enabled the plane of the future.

Norsk Titanium
norsk titanium.com
Where are we today?

- **Direct**
  - Alcoa is working with multiple aerospace customers for direct part fabrication from AM

- **Indirect**
  - Alcoa has used AM for indirect methods for over 20 years

- **Hybrid**
  - Alcoa is working to use AM for
    - Repair
    - Details
    - In combination with conventional
Integrating by Utilizing Hybrid Additive process for engine cases

Disruptive utilization of hybrid (AM+ machining) technologies to produce near finish cases

Current flow path:
1. Ingot/ Billet
2. Semi Finished Ring
3. Subtractive Machining
4. Finish Processes

Low cost path:
1. Ingot/ Billet
2. Thinner Semi Finished Ring
3. Boss/Flanges added by AM
4. Finish Processes

Experiment High Pressure compressor case with a complex pattern of bosses and flanges

Benefits:
- Reduced cost
- Reduced lead time
- Increased flexibility
- Reduced buy-to-fly ratio 15:1 > 3:1
**Ampliforge™ Process – Plant Demonstration**

*Full-scale commercial aircraft part produced using the Ampliforge™ process, currently in test.*

**Ti-6Al-4V Ampliforge™ Preform**
- Optimized design for single forging operation.
- Produced using EBAM
- 1500mm x 400mm x 100mm (60”x16”x4”)

**Final Forging**
- Forged on 45MN press in Cleveland, Ohio.
- Eliminated three forging operations and flash
The Ampliforge™ process shows potential to improve the ability use conventional ultrasonic inspection techniques

Comparison of UT backwall return

Sciaky EBAM:
Looking “down” into the “Z”, build direction. Overlap of the individual beads leads to loss of backwall signal return (orange and red are not desirable).

EBAM + Ampliforge™:
Similar sized sister specimens that have been forged in the “Z” direction. Forging modifies the internal structure resulting in greater signal return and reduced risk that indications will be masked.
Industrializing - Ampliforge™ Performance Meets Forging Performance

Demonstrated in lab scale and plant trials for both powder bed and large format AM equipment

Microstructure before and after Ampliforge™ Process

Ampliforge™ process improves s/N fatigue versus as-deposited EBAM and meets standard Ti-6Al-4V requirements.
People are central to the adoption

Technology Adoption is a Full Contact Sport

AM Infographic (right) from Alcoa R&D Expansion press release, September 3, 2015
Benefits of Topological Design Optimization

Topological Optimization using Finite Element Software Tosca

- 43% weight reduction (hook example)
- Reduced material cost
- Reduced build time
- Geometric complexity is free
- Opportunity for unique design

1-2 Week Turnaround Time

Optimized Hook 43% lighter
C-17 latch test build
Collaborating with ATEP to generate concept for novel fitting

Design concepts for Boeing 777x blade fitting with integral fasteners

Cross training core team members at ATC and ATEP

**Alcoa Technical Center**

**ATEP Austin**

**Focus: Design Optimization**
Cluster computing

**Focus: Process development build simulation, integrated processing**

*Gregory Rizza PhD, Design Engineer*

*Wudhidham Prachumr, NPD Engineer*

*Huy Yang, R&D Technician*
Alcoa's Global Additive Manufacture Capabilities

**ALCOA BUSINESS UNITS**
- Alcoa Power & Propulsion Research Center
  Whitehall, MI
- Alcoa Fastening Systems & Rings
  Fullerton, CA
- Alcoa Titanium & Engineered Products
  Austin, TX
- Alcoa Forgings & Extrusions
  Cleveland, OH
- Alcoa Titanium & Engineered Products
  Niles, OH
- Alcoa Technical Center
  Pittsburgh, PA
- Alcoa Titanium & Engineered Products
  Montreal, Canada
- Alcoa Power & Propulsion Tital
  Bietigheim, Germany
- Alcoa Titanium & Engineered Products
  Tamworth, UK

**COLLABORATORS**
- AMRC
  Sheffield, UK
- America Makes
  Youngstown, OH
- CCAM
  Clapton, Virginia
- ORNL
  Oak Ridge, TN
- Norsk Titanium
  Hønefoss, Norway
- LAB22, CSIRO
  Melbourne, AU
Alcoa is an established innovation leader in aerospace and 3D printing
The Alcoa AM Advantage goes from *Ingot to Install*