Fundamentals of Additive Manufacturing for Aerospace

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Intent of This Talk

- Introduce the general methods for forming metal parts using additive manufacturing
- Give multiple examples of each type of method
- Compare and contrast the methods given

Disclaimer:
- This talk serves as an introduction to the various additive manufacturing technologies which work with metals. There are so many methods available we will not have time to discuss them all.
- Once you determine the right approach for you, please investigate different machine manufacturers and service providers to determine the optimal solution for your needs.
- I have tried to be objective in the presentation. Where I can I have given the affiliations for the materials used. If I’ve missed any I apologize in advance.

About me and EWI

- I am a Technology Leader at EWI specializing in additive manufacturing (AM) with a focus on Metals AM. I have over 17 years of AM experience, collaborating with research scientists, engineers, and medical doctors to develop new equipment and devices.
- Non-profit applied manufacturing R&D company
  - Develops, commercializes, and implements leading-edge manufacturing technologies for innovative businesses
- Thought-leader in many cross-cutting technologies
  - >160,000 sq-ft in 3 facilities with full-scale test labs (expanding)
  - >$40 million in state of the art capital equipment (expanding)
  - >170 engineers, technicians, industry experts (expanding)
Structural Gap between Research and Application

![Graph showing the gap in manufacturing innovation between government & universities and private sector, with Technology Maturity Scale indicated.]

Source: NIST AMNPO presentation Oct 2012

EWI Applied R&D Bridges the Gap Between Research and Application

![Graph showing the gap in manufacturing innovation bridged by EWI Applied R&D, with Technology Maturity Scale indicated.]

Source: NIST AMNPO presentation Oct 2012

Deep Technical Capabilities

- **Leading edge**: unique national resource in our manufacturing technology areas
- **Cross cutting**: impact a wide range manufacturing sectors and client applications
- **Applied**: full-scale equipment and manufacturing technology application expertise
Connecting Colorado to EWI's Capabilities Nationally

- EWI Colorado opening in 2016
- Customers have access to EWI capabilities nationally
- Among the broadest range of metal AM capabilities

1984 Columbus OH: Joining, forming, metal additive mfg, materials characterization, testing

2016 Loveland CO: Quality assessment: NDE, process monitoring, health monitoring

2015 Buffalo NY: Agile automation, machining, metal additive mfg, metrology

Growing Range of Cross-Cutting Manufacturing Technologies

- Materials Joining
- Forming
- Machining & Finishing
- Additive Manufacturing
- Agile Automation
- Applied Materials Science
- Testing & Characterization
- Quality Measurement

EWI AM Capabilities Overview

- Laser PBF
- Electron Beam PBF
- Laser PBF: Open Architecture EWI Designed and Built
- Electron Beam DED: Siacky EBAM 110
- Laser DED: RPM 557
- Sheet Lamination LAM

EWI (Electronic Workforce Innovation)
Metal Parts Using Additive Technologies

Metals Today


Now it is estimated ~$20 billion by 2020.

Many companies are going into production with metals AM.

GE Today

GE Installs First Additive-Made Engine Part in GE90

The U.S. Federal Aviation Administration granted certification of the sensor, which provides pressure and temperature measurements for the engine's control system. In February, Engineers have begun retrofitting the upgraded T2S sensor, located in the inlet to the high-pressure compressor, into more than 400 GE90-94B engines in service. The new shape of the housing, made from a cobalt-chrome alloy, better protects the sensor's electronics from icing and airflow that might damage it, according to GE.
Pratt & Whitney Today

Pratt & Whitney has announced that when it delivers its first production PurePower® PW1500G engines to Bombardier this year, the engines will be the first ever to feature entry-into-service jet engine parts produced using Additive Manufacturing.

Rolls-Royce Today

Biggest engine part made with Additive Manufacturing
1.5 meter diameter bearing housing inside a Rolls-Royce Trent XWB-97

Avio Aero Today

Material: γ-TiAl Shape: 8 x 12 x 325 mm
Weight: 0.5 kg Build time: 7 hours / blade
Exploding Markets

- Not Just Aviation
- Medical
  - Over 8,000 interbody fusion devices have been implanted since 2013
  - Over 50,000 acetabular cups have been implanted since 2007

Adler Ortho, IT 2007
Lima, IT 2007
Exactech, US 2010

Exploding Markets

- Space
  - Satellites and Space Vehicles
- Defense
  - Armed Forces
  - UAVs
  - New Material Development

Space Examples

Hot-fire tests of key additively manufactured components for its AR1 booster engine

Evolution of existing multi-part bracket to ALM concept for Eunstar

Airbus Defence & Space
In order to help standardize additive manufacturing in the United States the ASTM F42 Committee on Additive Manufacturing Technologies was formed in 2009 and categorized AM technologies into seven categories including Vat Photopolymerization, Material Extrusion, Powder Bed Fusion, Material Jetting, Binder Jetting, Sheet Lamination, Directed Energy Deposition (F42 Committee. 2012).

Types of Additive Manufacturing

ASTM International:
Technical Committee F42 on Additive Manufacturing

Vat Photopolymerization
- Liquid photopolymer in a vat is selectively cured by light-activated polymerization

Processes:
- Stereolithography (SL)
- Digital Light Projection (DLP)
- Spin, Spin, Selectively Photocure (3SP)

Materials:
- UV Curable Photopolymers (acrylate, epoxy & vinylether)

Powder Bed Fusion
- Directed Energy Deposition

Sheet Lamination
- Material Extrusion

Material Jetting
- Binder Jetting
Stereolithography

For each layer, the laser beam traces a cross-section of the part pattern on the surface of the liquid resin. Exposure to the ultraviolet laser light cures and solidifies the pattern traced on the resin and joins it to the layer below. After the pattern has been traced, the SLA's elevator platform descends by a distance equal to the thickness of a single layer, typically 0.05 mm to 0.15 mm (0.002" to 0.006"). Then, a resin-filled blade sweeps across the cross-section of the part, re-coating it with fresh material. On this new liquid surface, the subsequent layer pattern is traced, joining the previous layer.

Digital Light Projection

The Perfactory® system builds 3D objects from liquid resin using a projector. This projector is almost identical to those found in high quality presentation and commercial theater systems, known as Digital Light Processing or DLP® projectors. It builds solid 3D objects by using the DLP® projector to project voxel data into liquid resin, which then causes the resin to cure from liquid to solid. Each voxel data set made up of tiny voxels (volumetric pixels), with dimensions as small as 16μm x 16 μm x 15 μm in X, Y and Z direction.
Digital Light Projection

https://www.youtube.com/watch?v=FLFmkzAvq8G_p=4-rD0ViA2oILFDLzC7k&list=PLFHnUwIG6_pf-q7cCK45g2ooP1hCTjyE&v=83mRO4_dBbY

Material Jetting
Droplets of build material are selectively deposited

Processes:
• Drop On Demand
• Smooth Curvature Printing
• Multi-Jet Printing
• PolyJet Printing

Materials:
• UV Curable Photopolymers
• Wax

Wax Drop On Demand
Solidscape® 3D printers are primarily used to produce "wax-like" patterns for lost-wax casting/investment casting and mold making applications. The 3D printers create solid, three-dimensional parts through an additive, layer-by-layer process with a layer thickness (mm) from .00625 to .0762 and a resolution of [dpi] 5,000 x 5,000 x 8,000 XYZ. The patterns produced are extremely high resolution with vibrant details and outstanding surface finish. The printers combine drop-on-demand ("DoD") thermoplastic ink-jetting technology and high-precision milling of each layer.
Wax Drop On Demand

Solidscape® MAX²
the High Precision 3D printer for Jewelry Manufacturing

https://www.youtube.com/watch?v=gjM86qW7vP8

Multi-Jet Printing

The ProJet uses Multi-Jet Printing technologies from 3D Systems to print durable, precision plastic parts ideal for functional testing, design communication, rapid manufacturing, rapid tooling and more. It works with VisiJet materials in UV curable plastic, in a range of colors, translucency, and tensile strengths. Support material is a melt-away white wax.

https://www.youtube.com/watch?v=dE6wsdPcLZk
Poly Jet Printing
Polyjet 3D printing is similar to inkjet printing, but instead of jetting drops of ink onto paper, the Polyjet 3D Printers jet layers of curable liquid photopolymer onto a build tray. Fine layers accumulate on the build tray to create a precise 3D model or prototype. Where overhangs or complex shapes require support, the 3D printer jets a removable gel-like support material.

https://www.youtube.com/watch?v=pbjdpk6ig

Binder Jetting
Liquid bonding agent is selectively deposited to join powder material

Processes:
- Digital Part Materialization
- ColorJet Printing
- V-Jet (3D Printing)

Materials:
- Metals
- Polymers
- Foundry Sand
ColorJet Printing

ColorJet Printing (CJP) is an additive manufacturing technology which involves two major components – core and binder. The Core™ material is spread in thin layers over the build platform with a roller. After each layer is spread, color binder is selectively jetted from inkjet print heads over the core layer, which causes the core to solidify.


https://www.youtube.com/watch?v=sJKJruSAT_Q

Material Extrusion

Material is selectively dispensed through a nozzle or orifice

Processes:
• Fused Deposition Modeling™ (FDM)
• Fused Filament Fabrication (FFF)

Materials:
• Thermoplastics
• Wax

http://www.custompartnet.com/wu/fused-deposition-modeling
Fused Deposition Modeling

A plastic or wax material is extruded through a nozzle that traces the part's cross sectional geometry layer by layer. The build material is usually supplied in filament form. The nozzle contains resistive heaters that keep the plastic at a temperature just above its melting point so that it flows easily through the nozzle and forms the layer. The plastic hardens immediately after flowing from the nozzle and bonds to the layer below. Once a layer is built, the platform lowers, and the extrusion nozzle deposits another layer.

https://www.youtube.com/watch?v=WHO6G67GJbM
https://www.youtube.com/watch?v=WoZ2BgPVtA0
Fused Filament Fabrication

Fused Filament Fabrication is equivalent to Fused Deposition Modeling. A fused filament fabrication tool deposits a filament of a material (such as plastic, wax, or metal) on top or alongside the same material, making a joint (by heat or adhesion). FDM is trademarked by Stratasys, so the term fused filament fabrication (FFF), was coined by the RepRap project to provide a phrase that would be legally unconstrained in its use.

Powder Bed Fusion

Thermal energy selectively fuses regions of a powder bed

Processes:
- Selective Laser Sintering (SLS)
- Direct Metal Laser Sintering (DMLS)
- Electron Beam Melting (EBM)

Materials:
- Polymers
- Metals
- Ceramics
Selective Laser Sintering (SLS) is an additive manufacturing technology developed under sponsorship by the Defense Advanced Research Projects Agency (DARPA) and acquired in 2001 by 3D Systems. SLS uses high power CO2 lasers to fuse plastic, metal or ceramic powder particles together, layer-by-layer, to form a solid model. The system consists of a laser, part chamber, and control system.

Selective Laser Sintering

- Engineering Design:
  - Direct from 3-D Model Base Definition
  - Design and Build Flexibility
- Production:
  - Eliminate non-recurring tooling costs
  - Lower recurring unit part costs
  - Faster part delivery times
  - Supplier flexibility
  - Direct Fabrication:
    - 50% Cost Reduction
    - 67% Cycle Time Reduction at Minimum
- Product:
  - Reduced part count and weight
  - Lower inventory and transportation costs
  - Improved Life Cycle Product Costs

https://www.youtube.com/watch?v=srg6fRtc-oc
Directed Energy Deposition

Focused thermal energy is used to fuse materials by melting as the material is deposited

Processes:
- Laser Engineered Net Shaping (LENS)
- Direct Metal Deposition (DM3D)
- Laser Deposition Technology (LDT)
- Electron Beam Additive Manufacturing (EBAM)

Materials:
- Metals

Laser Engineered Net Shaping

Sciaky launched its groundbreaking Electron Beam Additive Manufacturing (EBAM) process in 2009, as the only large-scale, fully-programmable means of achieving near-net shape parts made of Titanium, Tantalum, Inconel and other high-value metals. Sciaky’s EBAM process can produce parts up to 19’ x 4’ x 4’ (L x W x H), allowing manufacturers to produce very large parts and structures, with virtually no waste.

Electron Beam Additive Mfg

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Sheet Lamination
Sheets of material are bonded to form an object

- Processes:
  - Layered Object Manufacturing (LOM)
  - Paper Lamination Technology (PLT)
  - Ultrasonic Additive Manufacturing (UAM)

- Materials:
  - Paper
  - Metals

Three Approaches to Metal AM

- Pattern-Based
  - AM-produced part is used as a pattern for a casting process. The part is destroyed or consumed during secondary processing.

- Indirect
  - The AM Process creates a powdered metal green part. Secondary furnace processing is necessary to create the final part

- Direct
  - The AM Process directly joins or deposits metal material to form the final part

The manufacturers of each piece of equipment is typically identified at the bottom of the slide

First General Approach: Pattern-Based Processes

- AM-Produced Patterns are used as:
  - Investment Casting Patterns
  - Sand Casting Molds
  - Rubber Mold Patterns
  - Spray Metal Patterns

- Pattern methods are often the least expensive, easiest methods for obtaining a metal part from the desired alloy

- Other traditional and non-traditional replication processes can and are used with patterns as well
AM Process Considerations for Pattern Fabrication

- Accuracy & Surface Finish of the Pattern Will Directly Influence the Part for all Pattern-Based Processes
- Ash Content of Material is Critical for Investment Casting
- Out-gassing of Material is Critical for Sand Casting
- Release Characteristics are Important for Rubber & Metal Spray Processes

Investment Casting Patterns

- Stereolithography – QuickCast Technology
  - Remains one of the most popular techniques
  - Accurate with a good surface finish (internal truss structure)
  - Drawback is that it often needs a special burn-out procedure and the ash content must be controlled
- Wax-based AM processes make excellent patterns
  - Often can be implemented with no change within the investment casting operation
- Starch and polymers with low ash content are also available

Investment Casting StereoLithography-Quick Cast

- Wax Gating
- Apply Slurry and Stucco
- Flash Fire De-Wax
- Metal Pour
- Quick Cast
- Final Part
Using several different processes, you can directly make a sand casting mold in an AM process:

- 3D Printing (e.g., ExOne, Soligen & 3D Systems/ZCorp) and SLS (e.g., EOS) are the primary commercialized methods.

ExOne Sand Casting Patterns

- **Rapid Casting Technology (RCT)**
  - Contrast Traditional Foundry Practices to ExOne Digital Part Materialization
**Binder Jetting Technology**

**M-Flex (Fast & Versatile)**
- Most complete system available @ 10x speed
- Materials: stainless steel, bronze, tungsten
- Resolution: 63 μm (xy), 100μm (z)
- Speed: 1 layer / 36 seconds (100 μm minimum)
- Build Volume = 400 x 250 x 250 mm (15.7 x 9.8 x 9.8 in)

**Innovent (Materials Research)**
- Small scale system for material & process development
- Materials: metal (steel, bronze, tungsten) & glass
- Resolution: 63 μm (xy), 100μm (z)
- Speed: 1 layer / min (50 μm minimum)
- Build Volume = 160 x 65 x 65 mm (6.3 x 2.5 x 2.5 in)

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**Binder Jetting Technology**

**S-Max**

**Furan**

**Technical Specifications**

- Build Volume
  - 400 x 250 x 250 mm
- Build Speed
  - 1 layer / 30 seconds
- Resolution
  - 63 μm (xy), 100μm (z)
- Speed
  - 1 layer / min (100 μm minimum)
- Build Volume
  - 400 x 250 x 250 mm (15.7 x 9.8 x 9.8 in)

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**VoxelJet 3D Printing**

The VX880 is a **continuous 3D printer**. This innovation allows the building and unpacking process steps to run simultaneously, without having to interrupt system operations. This leap in technology has become possible thanks to a novel pending patent design featuring a **horizontal belt conveyor** that controls the layer building process. The layers are built at the entrance of the belt conveyor, while the unpacking takes place at the exit.

Pattern Review

- AM Patterns are consistently used to produce metal parts for investment casting applications. QuickCast SLA parts, and photopolymer / wax parts made using ink-jet printing (binder droplet techniques) are the most common.
- Sand casting molds can be made directly from 3D Printing and Laser Sintering
- Any AM part can be used in conjunction with silicone rubber molding to form metal parts
Second General Approach: Indirect Metal AM Processes

- Create Powder Metal Green Part
- Debinding (Vaporize the polymer binder)
- Sinter (Long-term sintering can cause densification to high densities)
- Infiltrate (Porosity is filled with a secondary material)

ExOne Metal Method

- Spreading new layer of metal powder
- Powder Printing
- Print-Bonded Particles
- Particles agglomerated in one droplet (Paste)
- Parts Sintered for Infiltration
- Sintered Particles
ExOne Materials

Current Commerially Available Materials

- 400 Series Stainless Steel / Bronze
- 300 Series Stainless Steel / Bronze
- M4 Tool Steel
- Solid Bronze
- Tungsten / Copper
- Glass

ExOne Materials

Stainless Steel / Bronze Composite

ExOne Materials

Available Surface Finishes

$R_a \ 600$

$R_a \ 50$

$R_a \ 350$
ExOne Metal Examples

- 27 individual components reduced to a single piece
- Reduction of documentation and time
- Delivered in 3 days

Third General Approach: Direct Metal Processes

- 3 Types of Commercialized Equipment
  - Powder-bed fusion processes
  - Laser or Electron Beam processes available
  - Directed Energy Deposition processes
    - Powder or wire feed plus lasers or electron beams enable one to deposit/melt metal onto a substrate
    - Ultrasonic consolidation
- Other Direct Metal Approaches are less common
  - Welding
  - Plasma Deposition
  - Molten Droplet Printing
  - Metal Extrusion
  - Etc...

Powder Bed Fusion of Metals

- No North American Manufacturers
  - Available from many European Companies
  - Well “3DSystems” in France
- Laser-based processes (commonly known as “Selective Laser Melting”)
  - EOS (DMLS)
  - ConceptLaser (Laser CUS/ING)
  - 3DSystems (formerly Phenix Systems) (DMLS)
  - Renishaw (formerly MTT) (SLM)
  - SLM Solutions (formerly MTT) (SLM)
- Electron-beam based
  - Arcam (EBM)
Metal Powder Bed Fusion General Operating Principle

- The original machines used 100 watt CO₂ lasers and have upgraded to Yb-fibre lasers that can have 100-1000 watts.
- The majority of the systems are operated at room temperature and pressure and is maintained in a Nitrogen or Argon environment depending on the building material.
- The Technology is capable of scan speeds of 20 m/s, has variable focus diameters of 0.06 mm -0.1 mm.
- Build layer thicknesses range from 0.02 to 0.100 mm.

Fiber lasers -- the enabling technology

- Unlike conventional laser technology, the entire laser unit is contained in a standard, nineteen inch rack or compact OEM unit.
- Unlike many conventional lasers they have few moving parts (none!).
- Unlike conventional lasers they have a long life.
- Unlike conventional lasers that have very stable power outputs and beam parameters.

Laser Powder Bed Fusion
EOS Systems

M 280
- 200 and 400 Watt Yb fibre laser
- Build volume 250 x 250 x 325 mm
- Operation with nitrogen or argon atmosphere
- Highly developed process software (PSW) with many features for high process quality, user-friendliness etc.

• Approx. 460 EOSINT M systems installed worldwide
  • Approx. 300 of these are at NEW customer sites
  • Approx. 190 of these are EOSINT M 270
• More than 30 customers have multiple EOSINT M installations
  • Approx. 130 EOSINT M 280 are sold since December 2010

EOS System

M 290
250 x 250 x 325 mm
400 Watt Laser

M 400
400 x 400 x 400 mm
1000 Watt Laser

EOS Systems
EOS Peek into the Lab – EOS M 400-4

- Multi-head optics
  - 4 x 200 or 400 W lasers
- Proven DMLS quality known from EOSINT M 280
- Productivity can increase by a factor of 2-4 depending on the part
- Same Materials & Processes as EOSINT M 280 ensures the legacy of qualified production processes

Increased productivity for e-Manufacturing that has been qualified on EOSINT M 280

Depending on the application, EOS will offer a single or multi-field manufacturing solution

1) Laser power can be adapted for similarity purposes (e.g. 200 W)
   - In development, subject to technical changes

1) 1 x 1,000 W
2) 4 x 400 W

Focus on speed
- Big & bulky parts
- Surface roughness allowed
- Functional surfaces, typically finished

Focus on accuracy
- Rather small parts
- High resolution required
- Direct similarity to M 280

Application-specific approach

EOSTATE PowderBed – 1/2

Recasting & Exposure monitoring

Step 1: Flip-Book of a good job

Taking Fotos
- Camera integrated in ceiling of process chamber in the immediate vicinity of the optics (off-axis)
- Illumination has been optimized with regard to image recognition
- 2 pictures of entire build area per layer, one after exposure and one after recoating
- Less is more, e.g. 1.3 Megapixel standard industrial camera, less data for image recognition in real-time and real-time calculation

Viewing Fotos
- Touchscreen: most recently taken image + flip through past layers of current job
- Camera: history of the same build area, flip through layers of selected job + Flipbook (AVI export)
- Reciever speed
**FUTURE EOSTATE PowderBed – 2/2**

**Peek into the Lab: EOSTATE PowderBed – Step II & III**

- Step II and III allow software-based image recognition, error identification and closed-loop control
- Test software and image recognition algorithms have been developed, according to specific conditions and needs of the DMLS process
- Automatic assurance of recoating quality
- Allocation of detected failure to specific layer and part number
- Next step: Full integration in EOS software architecture and user-friendly GUI

**FUTURE EOSTATE MeltPool – 1/2**

**Principle of operation**

- Capturing light emissions from DMLS process with photodiode-based sensors
  - "On-Axis" configuration (= through the scanner)
  - "Off-Axis" configuration (= diode inside process chamber)
- Correlation of sensor data with scanner position and laser power signal

**Benefits**

- Sensing light intensity and signal dynamics, which are among the most relevant indicators for process behavior
- Photodiodes offer high temporal resolution adequate to the extreme dynamics of DMLS process
- Partnership with experienced industry partner Plasmo established, co-development ongoing
- Leveraging synergies of EOS process know-how and Plasmo’s industrial monitoring and data handling expertise
- Advanced melt pool monitoring fosters deeper process understanding
- Full process documentation and advanced tool for automatic quality surveillance
- Future potential for closed-loop control

**FUTURE EOSTATE MeltPool – 2/2**

**Current development status**

- R&D systems mounted on several EOS machines
- Testing of robustness and reliability of hardware, data handling, analysis and visualization
- Verifying parameterization for data analysis
- Test program comprise parameter variations, provoked errors and standard processes

**R&D – ongoing work**

- Deepening know-how about correlations of monitoring, data, process characteristics and part quality
- Verification and validation of data analysis and correlations
- Preparation of external pilot phase with selected pilot customers

**Source:** Plasmo

**Provoked errors**

Under development
### EOS Materials

<table>
<thead>
<tr>
<th>Material name</th>
<th>Material type</th>
<th>Typical applications</th>
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<tbody>
<tr>
<td>EOS MaragingSteel MS1</td>
<td>18 Mar 300 / 1.2730</td>
<td>Injection moulding, series tooling, engineering parts</td>
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<tr>
<td>EOS StainlessSteel GP1</td>
<td>Stainless steel 17-4 / 1.4542</td>
<td>Functional prototypes, series parts, engineering and medical</td>
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<tr>
<td>EOS StainlessSteel PH1</td>
<td>Stainless steel 18-8 / 1.4301</td>
<td>Functional prototypes, series parts, engineering and medical</td>
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<tr>
<td>EOS NickelAlloy IN718</td>
<td>Inconel™ 718, UNS N07718, AMS 5662, W.Nr. K-10008 etc.</td>
<td>Functional prototypes and series parts, high-temperature turbine parts etc.</td>
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<tr>
<td>EOS NickelAlloy IN625</td>
<td>Inconel™ 625, UNS N06625, AMS 5666F, W.Nr. K-10008 etc.</td>
<td>Functional prototypes and series parts, high-temperature turbine parts etc.</td>
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<tr>
<td>EOS CobaltChrome MP1</td>
<td>CoCrMo superalloy, UNS R5516, ASTM F7575 etc.</td>
<td>Functional prototypes and series parts, engineering, medical, dental</td>
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<tr>
<td>EOS CobaltChrome SP2</td>
<td>CoCrMo superalloy</td>
<td>Dental restorations, (series production)</td>
</tr>
<tr>
<td>EOS Titanium Ti64</td>
<td>Titanium light alloy</td>
<td>Functional prototypes and series parts, aerospace, motor sport etc.</td>
</tr>
<tr>
<td>EOS Aluminium AlSi10Mg</td>
<td>AlSi10Mg light alloy</td>
<td>Functional prototypes and series parts, engineering, automotive, etc.</td>
</tr>
<tr>
<td>DirectMetal 20</td>
<td>Bronze-based mixture</td>
<td>Injection moulding, tooling, functional prototypes</td>
</tr>
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### SLM Solutions GmbH Systems

#### SLM 125 HL
- Build Envelope 125 x 125 x 75 (125)mm
- Build Envelope reduction 50 x 50 x 50 mm
- Dimensions 1800x1000x800mm
- 100-200 Watts

#### SLM 280 HL
- Build volume 280 x 280 x 350 mm
- Fibre laser 400 W and/or 1000 W
- Laser power: 20 - 100 µm
- Building speed 35 cm/h
- Inert gas, Argon 4.6, 5 bar, max. 4 l/min

#### SLM 500 HL
- Build Volume 380x650x320mm
- 2- to 4- Laser Tools
- 400 - 1000W
**SLM Solutions GmbH Research**

- **Twin Scan-Heads**
  - Fibre laser 2x400 W and/or 2x1000 W
  - SM „Gaus“ and/or MM „Top Hat“ Profile
  - f-Theta or 3D Scan-Optic without F-Theta
  - Focal point 90 µm / 700 µm

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**SLM Solutions GmbH Materials**

<table>
<thead>
<tr>
<th>Material Name</th>
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<tr>
<td>Stainless Steel</td>
<td>1.4404, 1.4410</td>
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<td>Tool Steel</td>
<td>1.2344, 1.2709</td>
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<td>Co-, Cr Alloys</td>
<td>2.4723 / ASTM F75</td>
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<tr>
<td>Inconel / HX-Alloys</td>
<td>Inconel 625 and 718</td>
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<td>Titanium</td>
<td>Grade 1 - 5</td>
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<td>Titanium Alloys</td>
<td>TiAl6Nb7, TiAl6V4</td>
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<tr>
<td>Aluminium Alloys</td>
<td>AlSi12, AlSi10Mg, AlSi7MgCu</td>
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**ConceptLaser Systems**

- **M1 Cusing**
  - Target group: small components
  - Build envelope: 10 x 10 x 20 mm
  - Laser system: 100 W fiber laser
- **M2 Cusing**
  - Target group: small components
  - Build envelope: 250 x 250 x 250 mm
  - Laser system: 200 W fiber laser
- **M2 Cusing**
  - Target group: processing aluminum and titanium alloys
  - Build envelope: 250 x 250 x 250 mm
  - Laser system: 200 - 400 watt fiber laser
- **X Linear 2020R**
  - Target group: Very large components
  - Build envelope: 800 x 400 x 500 mm
  - Laser system: 2 x 1000 watt fiber laser
ConceptLaser Materials

<table>
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<td>1.4404 / CL 20ES</td>
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<td>Aluminum alloy</td>
<td>AISI 312 / CL 30AL</td>
</tr>
<tr>
<td>Aluminum alloy</td>
<td>AISI 10Mg / CL 31AL</td>
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<tr>
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<td>Ti6Al4V / CL 407 Ti</td>
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<tr>
<td>Titanium alloy</td>
<td>Ti6Al4V ELI / CL 417 Ti ELI</td>
</tr>
<tr>
<td>Hot-forming steel</td>
<td>1.2709 / CL 50WS</td>
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<tr>
<td>Rust-free hot-forming steel</td>
<td>CL 91RW</td>
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<tr>
<td>Nickel base alloy</td>
<td>Inconel 718 / CL 100NB</td>
</tr>
<tr>
<td>Cobalt/chrome alloy</td>
<td>remanium star CL</td>
</tr>
</tbody>
</table>

Renishaw Systems

AM250
- Build Envelope 250 x 250 x 300mm (360mm)
- Layer thickness 20-100 µm
- Fiber laser 200-400 Watts

AM400
- Build Envelope 250 x 250 x 300mm (360mm)
- Layer thickness 20-100 µm
- Fiber laser 200-400 Watts

RenAM 500M
- Build Envelope 250 x 250 x 350mm
- Layer thickness 20-100 µm
- Fiber laser 500 Watts

Open material parameters
Renishaw follows an open parameter ethos, providing our customers with freedom to optimise machine settings to suit the material being processed and the user’s specific geometry.

Materials
- Stainless steel 316L and 17-4PH
- H13 tool steel
- Aluminum Al-Si-12
- Titanium CP
- Ti-6Al-4V
- Ti-6Al-7Nb
- Cobalt/chrome (ASTM75)
- Inconel 718 and 625
**3Dsystems**

- **ProX DMP 300**
  - Build Envelope 250 x 250 x 300mm
  - Fibre laser 500 Watts

- **ProX DMP 200**
  - Build volume 140 x 140 x 100mm
  - Fibre laser 300 Watts

- **ProX DMP 320**
  - Build Volume 275 x 275 x 420mm
  - Fibre laser 500 Watts

Manufacturer Laser Sintering Systems that sinter any metals, alloys and ceramic parts in the same equipment.

---

**3DSystems Materials**

- **Final Products**
  - Best industry surface finish of 5 Ra micrometer
  - Wall build sizes to .004” thick
  - Part hole size of .004” to .008”
  - Select materials result in superior mechanical properties (+20%) compared to other processes due to patented roller-wiper system.

<table>
<thead>
<tr>
<th>Metals</th>
<th>Ceramics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steels</td>
<td>Alumina</td>
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<tr>
<td>Tool steels</td>
<td>Cermet</td>
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<tr>
<td>Non ferrous alloys</td>
<td>Inconel</td>
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<tr>
<td>Precious metals</td>
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<td>Maraging Steel</td>
<td>Bronze alloys</td>
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<tr>
<td>Aluminium</td>
<td></td>
</tr>
</tbody>
</table>

---

**Realizer Systems**

- **SLM 50**
  - Build Envelope 70mm dia. x 40mm
  - Desktop Machine
  - Fiber laser 20 - 50 Watts

- **SLM 100**
  - Build Envelope 125 x 125 x 100mm
  - Layer thickness 20-100 µm
  - Fiber laser 20-200 Watts

- **SLM 250**
  - Build Envelope 250 x 250 x 300mm
  - Layer thickness 20-100 µm
  - 200, 400 or 600 Watts

**Materials**

- Tool steel H 13
- Stainless steel 316 L
- Titanium
- Titanium V4
- Inconel
- Aluminum
- Gold
- Cobalt chrome
Laser Powder Bed Systems Material Properties

- Many different systems, applications materials and build styles!
- What about material properties?
  - If we assume that the systems use similar raw materials (true for direct processes).
  - And we assume that the machines are relatively similar (they use similar lasers and optical systems).
  - And we assume that the processing is optimized for each (perhaps not completely true).
  - Then we can assume that materials properties are transferable across systems.

Cobalt-Chrome / CoCrMo Alloys

- Cobalt-based superalloys
  - strong, corrosion resistant, high temp.
  - common in biomedical applications
- Properties
  - nickel free, contains < 0.05 % nickel
  - fulfills ISO 5832-4 and ASTM F75 of cast CoCrMo implant alloys
  - fulfills ISO 5832-12 and ASTM F1537 of wrought CoCrMo implants, except elongation (12 %) which can be improved to 21-24 % by HIP
  - Laser sintered density: ~ 100 %
  - Yield strength (Rp 0.2%): 980 - 1020 MPa
  - Ultimate tensile strength: 1370 - 1410 MPa
  - Remaining elongation: 8.5 – 12.5 %
  - Young’s Modulus: 200 – 220 GPa

Stainless Steels

<table>
<thead>
<tr>
<th>Property</th>
<th>316L DMLS Forged</th>
<th>316L DMLS Forged</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile strength, MPa</td>
<td>706...814</td>
<td>1000...831</td>
</tr>
<tr>
<td>Yield strength (Rp 0.2 %), MPa</td>
<td>570...644</td>
<td>795/1310</td>
</tr>
<tr>
<td>Elongation at Break, %</td>
<td>31...53</td>
<td>30...51</td>
</tr>
</tbody>
</table>

Note 1: Shows some performance benefits in comparison to traditional processes
Note 2: Also shows maturity of conventional processes
**Titanium**

<table>
<thead>
<tr>
<th>Property</th>
<th>Forged</th>
<th>Powder</th>
<th>MeltHIP</th>
<th>DMLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile strength [MPa]</td>
<td>860</td>
<td>850</td>
<td>1100</td>
<td></td>
</tr>
<tr>
<td>Young's Modulus [GPa]</td>
<td>-</td>
<td>120</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Elongation at Break [%]</td>
<td>10</td>
<td>13</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>

**Note 1:** Young's modulus and ultimate tensile strength fulfill requirements

**Note 2:** Elongation can be improved by post-processing

---

**Typical Laser Micro Structures**

- Cobalt Chrome
- Titanium

---

**Laser Powder Bed Medical Applications**

- Certified Dental Implant “TiXos” by Leader Italia
- Cage designed to fit bone and give proper screw placement
- Manufacturing of complex and filigree customized dental restorations and implants
Laser Powder Bed Aerospace Applications

- DMLS fuel Swirler injectors
- Components of an engine casing, thin walled
- Functional prototypes for developing helicopter gas-turbine engine components

Laser Powder-Bed Melting/Sintering Machine Differences

- Look into the technologies carefully to understand:
  - Laser scanning strategies
  - Atmospheric control
  - Thermal control
  - Accuracy
  - Build volume
  - Laser power
  - Laser type
  - Reliability
  - Materials handling
  - Support strategies
  - Production support

- These factors will greatly influence the types of materials which can be processed successfully

Powder Bed Fusion Electron Beam Melting
Electron Beam Melting

- A high energy beam is generated in the electron beam gun (50-3000W)
- The beam melts each layer of metal powder to the desired geometry (down to 50 µm layers)
- Extremely fast beam translation with no moving parts (up to 8,000 mm/sec)
- Vacuum process eliminates impurities and yields excellent material properties (<1x10^-4 mbar)
- High build temperature (1080ºC for TiAl) gives low residual stress -> no need for heat treatment

Electron Beam Melting

Electron Gun
Powder Distributor
Powder Container
Optics
Filament

EBM Systems

- Q10
  - Build Envelope 200 x 200 x 180mm
  - Layer thickness 50-100 µm
  - Medical
- A2X
  - Build Envelope 200 x 200 x 380mm
  - Layer thickness 50-180 µm
  - Aerospace High temp.
- Q20
  - Build Envelope Dia. 350 x 380mm
  - Layer thickness 50-100 µm
  - Aerospace Titanium
EBM Technology

- High build rate
  - Up to 1 cm³/min build rate
  - Up to 40 mm/h build height
  - Power efficiency
- Excellent material properties
  - Fully melted material
  - High density
  - Better than cast
  - Controlled grain size
  - High strength
- Reduced surface finish
  - High brightness cathode & new e-gun design
- Lower dimensional accuracy
  - Newer 50 micron layers is helping with this

EBM Materials

- With the high power available (up to 3.0 KW) the EBM® process can melt any powdered metal with a melting point temperature up to 3,400 °C (e.g. W), allowing an extensive range of materials.
- The materials currently supplied by Arcam are:
  - Titanium alloy Ti6Al4V (Grade 5)
  - Titanium alloy Ti6Al4V ELI (Grade 23)
  - Titanium CP (Grade 2)
  - CoCr alloy ASTM F75

Materials Development and Testing

Research Materials done by me
- Inconel 625 and 718
- Copper
- TiAl
- Tantalum
- Niobium
- Fe
- Rene 142
- Rene 80
- Haynes
- TiNb
- Maraging Steel
- Al Alloys

Material proven by others
- Stainless steels
- Tool steel (e.g. H13)
- Aluminum
- Hard ceramics (e.g. Si3N4)
- Beryllium
- Amorphous metals
- Invar

3/3/2017
EBM Ti 6-4 Materials Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>EBM</th>
<th>Wrought</th>
<th>DMLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile strength</td>
<td>950-1010 MPa</td>
<td>930-1015 MPa</td>
<td>1100 MPa</td>
</tr>
<tr>
<td>Yield strength (0.2%)</td>
<td>910-950 MPa</td>
<td>860-955 MPa</td>
<td>N/A</td>
</tr>
<tr>
<td>Young's Modulus</td>
<td>120 GPa</td>
<td>114 GPa</td>
<td>120 GPa</td>
</tr>
<tr>
<td>Elongation at break</td>
<td>12-16 %</td>
<td>11-14 %</td>
<td>8%</td>
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<tr>
<td>Surface hardness</td>
<td>30-35 HRC</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Fatigue strength at 10MPa</td>
<td>&gt;10,000,000 cycles</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

EBM Ti-6-4 Micro Structure

Homogenous fine-grain microstructure containing a lamellar alpha-phase with larger beta-grains. Better than cast Ti6Al4V. Naturally aged condition directly from the EBM process. The microstructure shows no sign of preferential orientation or weld lines.

Inco 718 Part

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melt Time</td>
<td>37.00 hours</td>
</tr>
<tr>
<td>Cool Down Time</td>
<td>8.00 hours</td>
</tr>
</tbody>
</table>
Inco 718 Part

Melt Time: 76:00 hours
Cool Down Time: 12:00 hours

EBM Productivity:
Stacking of Parts

- Cups have excellent geometry for stacking.
- Production example 80 cups:
  - Non-stacked: 126 h
  - Stacked: 82 h
- Build time reduction: ~35%

EBM Aerospace Applications

Material: γ-TiAl
Size: 8 x 12 x 325 mm
Weight: 0.5 kg
Build time: 7 hours / blade
**Background to Gamma Titanium Aluminide (γ-TiAl)**

γ-TiAl is a "dream material" for structural aerospace applications:

- Low density, about 50% of Ni-base superalloys
- Oxidation and corrosion resistance
- Excellent mechanical properties at high T (up to 800°C/1500°F)
- Specific strength
- Stiffness
- Creep
- Fatigue

Expected to replace Ni-base superalloys, in weight-critical applications Studied since the 1970's, but still few industrial applications of γ-TiAl

Conventional fabrication of γ-TiAl is not straightforward:

- Hard and brittle at RT
- Internal defects, porosity
- Inhomogeneous microstructure
- Residual stresses
- Complicated heat treatments
- High scrap rates

Advantages of the EBM process:

- Few internal defects (compared to casting)
- Homogeneous microstructure
- Very fine grain size (good fatigue properties)
- No residual stresses
- Little waste material – powder can be recycled
- TiAl powder chemically stable, no risk of dust explosions

Could EBM be the Holy Grail of γ-TiAl manufacturing?

**Camera Advantage**

- Camera auto calibrates with machine
- Machine beam process calibration
- Up to five images every layer
3D Reconstruction of LayerQam Images

EBM-vs-Laser Processes
- EBM characteristics versus Lasers
  - Energy efficiency
  - 50-100 spot beam splitting for contouring
  - High density & elongation properties – elevated temperature powder bed
  - Very fast build time
  - High power (3 kW) in a narrow beam
  - Incredibly fast beam translation speeds
    - for galvanometers, magnetically steered
  - Only works in a vacuum
    - Gases (even inert) deflect the beam
  - Does not work with polymers or ceramics
  - Needs electrical conductivity
  - Poorer surface finish
  - Poorer dimensional tolerance
  - Uses more “science” and “mathematics” in its control system architecture
    - Heat transfer equations, energy equations, etc.

Directed Energy Deposition Techniques
- Methods for depositing fully dense metal parts from powders or wires
  - Controlled spraying of powders or feeding of wire onto a substrate, where it is melted and deposited
- Four primary commercialized technologies for Lasers
  - RPM Innovation
    - Laser Deposition Technology (LDT)
  - Optomec Laser Engineered Net Shaping (LENS) system
    - a.k.a. Directed Material Deposition System (DMDS)
    - Developed by Sandia National Labs
  - PCM Direct Metal Deposition (PCM)
    - a.k.a. Directed Light Fabrication (DLF)
    - Developed by Univ. of Michigan
  - AccuFusion Laser Consolidation (LC)
    - Developed by National Research Council of Canada
- Many other research groups studying & commercializing similar processes
  - AeroMet Laser Additive Manufacturing (LAM), Fraunhofer, Los Alamos National Labs, and more...
General Directed Energy Deposition Benefits

- Can add features or material to a pre-existing structure
  - Great for repair, rib-on-plate, etc…
- Excellent microstructure and material properties
- Ability to join materials which could not be joined otherwise
- Minimal effect on substrate microstructure

General Directed Energy Deposition Drawbacks

- Poor surface finish and accuracy (except LC)
- Overhangs are difficult to achieve
- Slow process
  - Usually only economical to add features to existing parts/geometries rather than building entire part
  - Inverse correlation between speed and accuracy
- Material properties are different than cast or wrought
- Correlation between processing and material properties is understood for many materials, but not well controlled using closed loop control in most machines

RPM Innovation

- RPM 557 Capabilities:
  - 1.5 X 1.5 X 2 meters envelope
  - 3 kW IPG Fiber Laser
  - Tilt & rotate table
  - Controlled atmosphere to < 10 ppm O2
RPM Innovation

Optomec LENS™ Process
- Multi Nozzle Powder Delivery
- Metal Powder melted by Laser
- Layer by layer part repair
- 5-Axis range of motion
- Closed Loop Controls
- Controlled Atmosphere (<10ppm O₂)

Optomec LENS™ Process

LENSTM In Action
Copyright 2003 Optomec Design
### Optomec LENS™ Process

![Optomec LENS™ Process Image]

**Optomec LENS™ Systems**

- **LENS 450 System**
  - 100mm x 100mm x 100mm process work area
  - 400W IPG Fiber Laser
  - 3 axis motion control X,Y,Z
  - Single powder feeder

- **LENS MR-7**
  - 200mm x 200mm x 200mm process work area
  - 500W IPG Fiber Laser
  - 3 axis motion control X,Y,Z
  - Gas purification system maintains O2 < 10ppm
  - Dual powder feeders with gradient capability
  - 380 mm diameter ante chamber

- **LENS 850R**
  - 900mm x 1500mm x 900mm process work area
  - 5 axis motion control X,Y,Z with tilt & rotate table
  - Gas purification system maintains O2 < 10ppm
  - 2 powder feeders
  - kW IPG Fiber Laser

### Optomec LENS™ Applications

**Critical Component Repair**
- **Industry Need:**
  - Repair high value components that have worn out of tolerance
- **Value Proposition:**
  - Reduce repair times up to 50%*
  - Reduced repair costs up to 30%*
  - Total costs of repair regarding to new part price:
    - 13% Ti 6-4 (300 EUR new part / 40 EUR LENS repair)
    - 42% Inconel 718 (200 EUR new part / 80 EUR LENS repair)
- **Solution:**
  - LENS 850R system from Optomec
  - Spherical Metal Powder
Optomec LENS™ Applications

LENS Application – Turbine Component Repair
- Material: IN718
- Engine: AGT1500
- LENS Process Advantages: Properties, Low Heat Input, Near Net Shape
- In Production at Anniston Army Depot, $5M saved in first year

LENSTM Functionally Graded Materials

<table>
<thead>
<tr>
<th>Ti-6Al-2Sn-4Zr-6Mo</th>
<th>Ti-22Al-23Nb</th>
</tr>
</thead>
<tbody>
<tr>
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LENS Materials

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Titanium</td>
<td>CP Ti</td>
<td>Ti-6-4</td>
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<tr>
<td></td>
<td>Ti-6-2-4-2</td>
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</tr>
<tr>
<td></td>
<td>Ti-22Al-23Nb</td>
<td>N690</td>
<td></td>
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<tr>
<td>Nickel</td>
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<td></td>
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Materials Used in R&D

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<tr>
<td>Titanium</td>
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<td></td>
<td>Ti-22Al-23Nb</td>
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<td>Hematite</td>
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<tr>
<td>Titanium</td>
<td>Titanium</td>
<td>Titanium</td>
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</tr>
</tbody>
</table>
General Material Comments about Directed Energy Deposition

- Rapid solidification enables unique material properties.
- Microstructure at the bottom of parts is different than the middle, which is different than the top.
  - Conduction-limited process
- Microstructure is different for thin-wall versus thick parts.
- Need closed-loop control for materials with lots of phase changes or for repeatable microstructures.
- Can do combinatorial alloying.

Other Issues with Powder-Based Processes

- Powders should be selected with care
  - Metal powders are expensive
  - Using more than one material in a machine might be difficult
  - Choose your powder supplier carefully
  - PREP, Plasma atomized or Gas atomized are preferred methods of production
- Small diameter metal powders are generally flammable and byproducts of processing may be very flammable
  - Ensure you buy a safe machine...ask questions of the vendor
  - Ensure you have very rigorous procedures and stick to them
  - Ensure personal protective equipment is present and correct
  - Have a plan if everything goes wrong
  - Minimize risk
  - Remove the chances of error

Electron Beam Directed Energy Deposition
Sciaky Process

- An Electron Beam serves as the energy source
- The EB is used to create the melt pool from wire feedstock
- Add layers until the desired geometry is complete

Acronyms

- Direct Manufacturing (DM)
- Electron Beam Free Form Fabrication (EBFFF, EBF3, EBF3?)
- Electron Beam Additive Manufacturing (EBAM)
**Sciaky Advantage**

- Large structures targeted, specifically webbed forgings
- Well suited to low annual usage requirements
- “Buy-to-Fly” ratio
- Take advantage of “Dual Process” capability, EBW and EBDM
- Work with customers to identify “Best Fit” projects

**Electron Beam Additive Mfg**

**Additional issues with Directed Energy Deposition**

- You may need further equipment to allow you to finish parts
  - Wire EDM to remove parts from the substrate
  - Bead blast
  - Polishing equipment
  - Machining
  - NDT metrology and microscopy
**Sheet Lamination**

**Ultrasonic Consolidation**

- Ultrasonic energy is used to create a solid-state bond between two pieces of metal: aluminum, copper, brass, nickel, steel, titanium, etc.
- Peak temperatures < 0.5T melt
- Recrystalization at interface
- Local formation of nano-grain colonies
- Plastic-flow morphology

**Ultrasonic Consolidation Process**

- Rotating Transducer/Horn System
  - Horn
  - Transducer
  - Metal Base Plate
  - Metal Tape

- US vibrations from transducer
- Welded tape
- US horn has textured surface to grip tape
- US vibrations

**Base plate: milling for flatness**
Ultrasonic Consolidation Materials

- Material pair proven for ultrasonic welding
- Material pair tested for ultrasonic spot weld

Ultrasonic Consolidation Applications - Energy Absorption

- Charpy testing shows characteristic laminar behavior
- Ballistic applications
  - Layered structure provides energy absorption
- Crack arrest applications
  - Crack growth along interfaces may be promoted in fatigue applications
- Surface/component upgrades

Ultrasonic Consolidation Applications - Embedding

- Complicated internal features can be created and enclosed due to additive nature
- Electronic circuits can be encased in metallic part for protection and anti-tamper
- Embedded RFID
Ultrasonic Consolidation Wrap-Up

- Support materials will allow complex, direct part manufacture
- Multi-material capabilities and embedding of fibers leads to tremendous material property flexibility
- Encapsulation of components within a structure is possible and has great potential for complex systems

Hybrid Systems

The AMBIT™ multi-task system, developed by Hybrid Manufacturing Technologies, is an award winning patent pending series of heads and docking systems which allows virtually any CNC machine (or robotic platform) to use non-traditional processing heads in the spindle and conveniently change between them. Changeover is completely automated and only takes 10-25 seconds.

Hybrid Systems

Direct Energy Deposition

Hybrid Machine Combines Milling and Additive Manufacturing
Overall Summary & Conclusions

- Metal Part Manufacture is now possible using many different AM techniques
  - Tooling and Metal Part prototyping are common applications
  - Direct Manufacturing of Novel Designs, Compositions and Geometries is being actively pursued
  - Pattern approaches are readily available through service bureaus, investment casting companies, and other service providers
  - Indirect approaches are less common but have many benefits and are readily available, particularly for non-structural, artistic applications
  - Direct approaches are becoming increasingly available and reliable, but remain expensive for many types of geometries and volumes

Acknowledgements

- Special thanks to the following for sending slides and information for this presentation:
  - Terry Hoppe and Jesse Roiitenberg; Stratasys
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  - Jim Fendrick; SLM Solutions
  - Daniel Hund; ConceptLaser
  - Sandeep Rana; Phoenix Systems
  - Ulf Ackelid; Arcam
  - Mike O'Reilly; Optomec
  - Scott Stecker; Sciaqy
  - Mark Norfolk; Fibrasonic
  - Ken Church; nScrypt

Industry Support: The Additive Manufacturing Consortium

Mission: Accelerate and advance the manufacturing readiness of Metal AM technologies

Goals:
- Participation from Academia, Government, and Industry
- Present timely case studies/research
- Execute group sponsored projects
- Collaborate on Government funding opportunities
- Forum for discussion/shaping roadmaps
CY16 AMC Project Themes

- Continue to build upon current body of work
  - Phase 3: 625
  - Phase 3: 718,
  - Phase 2: High Strength Aluminum Alloys
- Incorporate NDI into project execution
- Cross-platform validation of PBF machines and powder suppliers

EWI is advancing metal AM to enable broader adoption by industry

- Reality
  - More than the 3D Printing Process
  - Requires Manufacturing support to be true additive manufacturing
- Industry Support
  - Another tool in the tool box
  - Understand application of conventional manufacturing.
  - Trusted Agent
  - Innovation

EWI AM Focus Areas

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Questions

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http://ewi.org/technologies/additive-manufacturing/
EWI is the leading engineering and technology organization in North America dedicated to developing, testing, and implementing advanced manufacturing technology for industry. Since 1984, EWI has offered applied research, manufacturing support, and strategic services to leaders in the aerospace, automotive, consumer electronics, medical, energy, government, and defense and heavy manufacturing sectors. By matching our expertise to the needs of forward-thinking manufacturers, our technology team serves as a valuable extension of our clients' innovation and R&D teams to provide premium, game-changing solutions that deliver a competitive advantage in the global marketplace.

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