Hybrid Additive Manufacturing Technologies for Repair of Military Components

Ken Sabo, Michael Tims, Juan Valencia, David Eash, and Rob Mason

Diminishing Manufacturing Sources and Material Shortages (DMSMS) 2017 Conference
Tampa, FL

OUTLINE

- Problem Statement
- Additive Manufacturing (AM) as a Repair Technology
- Utility of Hybrid AM for Repair Applications
- Advantages of Hybrid AM
- Current Issues with Laser Powder-Based Hybrid AM
- Summary

Problem Statement

- **Maintenance of DoD platforms requires difficult-to-source, expensive and / or long-lead-time component manufacturing**
  - **The ability to repair, rather than replace, such components would offer schedule and cost benefits**
- **Repair processes must not degrade critical properties (e.g., mechanical properties and dimensions) of components**

Additive Manufacturing as a Repair Technology

- **Additive Manufacturing (AM) continues to be considered for both commercial and Department of Defense (DoD) applications**
  - **Rapid prototyping**
  - **Obsolete part repair**
  - **Rapid evaluations / fit-up**
- **Numerous projects are underway to demonstrate the feasibility of using AM for component repair**

EXAMPLE PROJECT- America Makes – Laser Powder Directed Energy Deposition (LPDED) for Repair

- Team:
  - Leaders: Optomec (prime); CTC; Applied Research Laboratory at Pennsylvania State University; Connecticut Center for Advanced Technology; EWI; TechSolve
  - Primary Technical Support: General Electric Aviation; Lockheed Martin; United Technologies Research Center; Rolls Royce
  - Contributors: M-7 Technologies; Missouri University of Science and Technology; Rolls Royce Corporation; Stratonics; University of Connecticut; Wolf Robotics; various powder suppliers
  - Additional Team Members: University of Louisville; Texas A&M; South Dakota School of Mines
- Objectives:
  - Develop guidelines on optimum powder feedstock characteristics for high part quality
  - Conduct improvements in process monitoring and control
  - Develop design allowables and guides (Lead: CTC)
  - Recommend Air Force part repair and sustainment applications (Lead: CTC)
- Material: Ti-6Al-4V
- POP: July 2014 – September 2016

Turbine Support Bearing Housing, After Repair

AM as a Repair Technology (cont'd.)

- **Metal AM parts that are built up as a whole lack quality metrics, standards, and in-process monitoring and control that are accepted and approved by industry / DoD**
  - **Limits consideration of AM in many areas, including repair**
- **There is a need to develop and demonstrate AM processes that can rapidly and consistently repair metal parts for DoD applications**

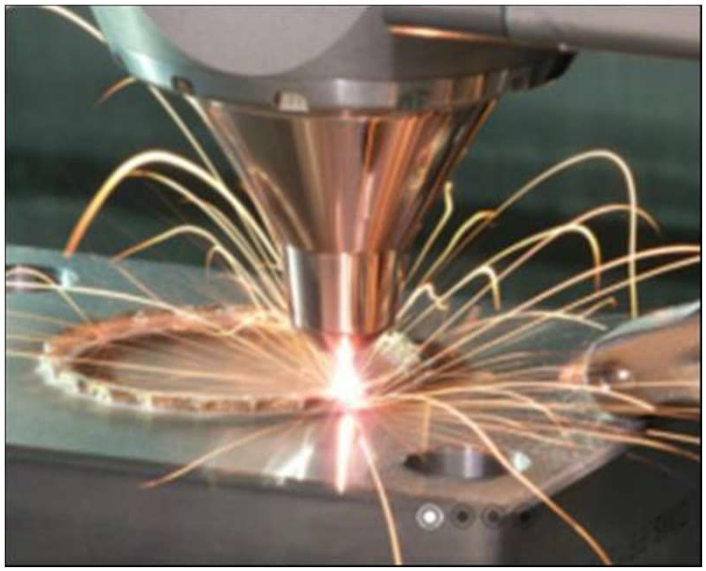
Utility of Hybrid AM for Repair Applications

- **Utilizes CNC material removal machines in which laser-based material deposition heads have been installed**
  - **Deposition heads build up material onto part(s) (or shaped preform) from feeders, which add one or more powder(s) to molten pool on part being repaired**

Utility of Hybrid AM for Repair Applications (cont'd.)

Five-Axis Hybrid AM Milling Center
Working envelope: 120" × 40" × 30"

Utility of Hybrid AM for Repair Applications (cont'd.)



Laser Deposition

Tool Holder Storage

- Typical feed rates up to 5.5 lb / hr
- Deposition heads universally interchangeable

Mechanical Properties of Inconel 718 – Repaired vs. Wrought

	Mean Values from Ambit Repair	Hot-Rolled Bar w/o Heat Treatment
Yield Strength (N/mm^2)	587	591
Tensile Strength (N/mm^2)	931	965
Elongation (%)	31.7	46
Reduction of Area (%)	31.2	58
Hardness (HRC)	23	23

Table reference: Yamazaki 2016

Photos courtesy of Hybrid Manufacturing Technologies

Potential Hybrid AM Repair Opportunities

- Worn surfaces
  - Resurfacing
- Corroded surfaces or fractured part
  - Machine damaged region, add new material, machine to final geometry
- Addition of thick, protective metallic / ceramic coating
  - Added material may differ from that of substrate
  - Add ceramic powders to metal powders to form metal matrix composite
- Build out features on common wrought product form (bar, plate, tube, etc.)
  - Reduce machining
  - Improve buy-to-fly ratio

Blade tip repair

Features added to tube

Photos courtesy of Hybrid Manufacturing Technologies

Example: Blade Repair Using Hybrid AM

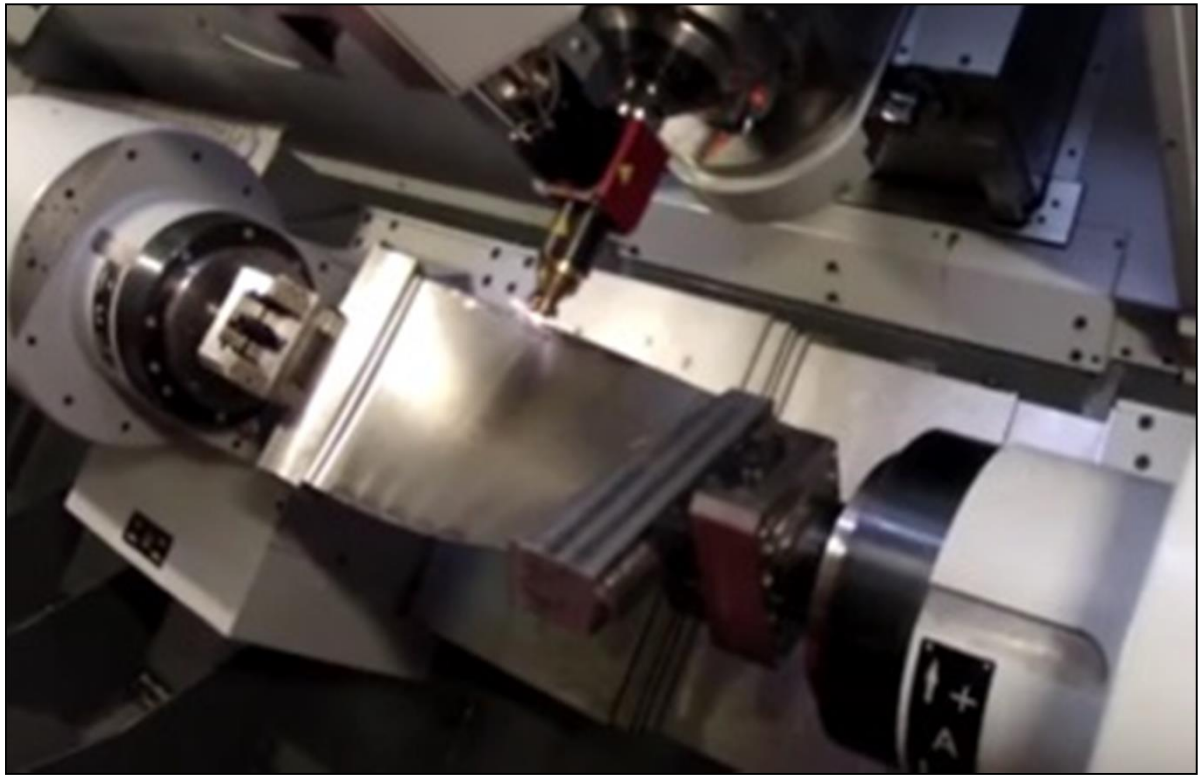


Photo courtesy of Hybrid Manufacturing Technologies

CTC Concurrent Technologies Corporation

Advantages of Hybrid AM

- AM and machining in one milling center
  - One machine setup
- Work envelope only limited by milling center
- Parts can be machined and prepped prior to AM operations
  - Ensures clean and consistent surface areas for material build-up
- Repair using wide range of materials
  - Stainless steel
  - Nickel based alloys
  - Cobalt based alloys (including Stellite)
  - Tool steels
- Minimal heat input to part

Advantages of Hybrid AM (cont'd.)

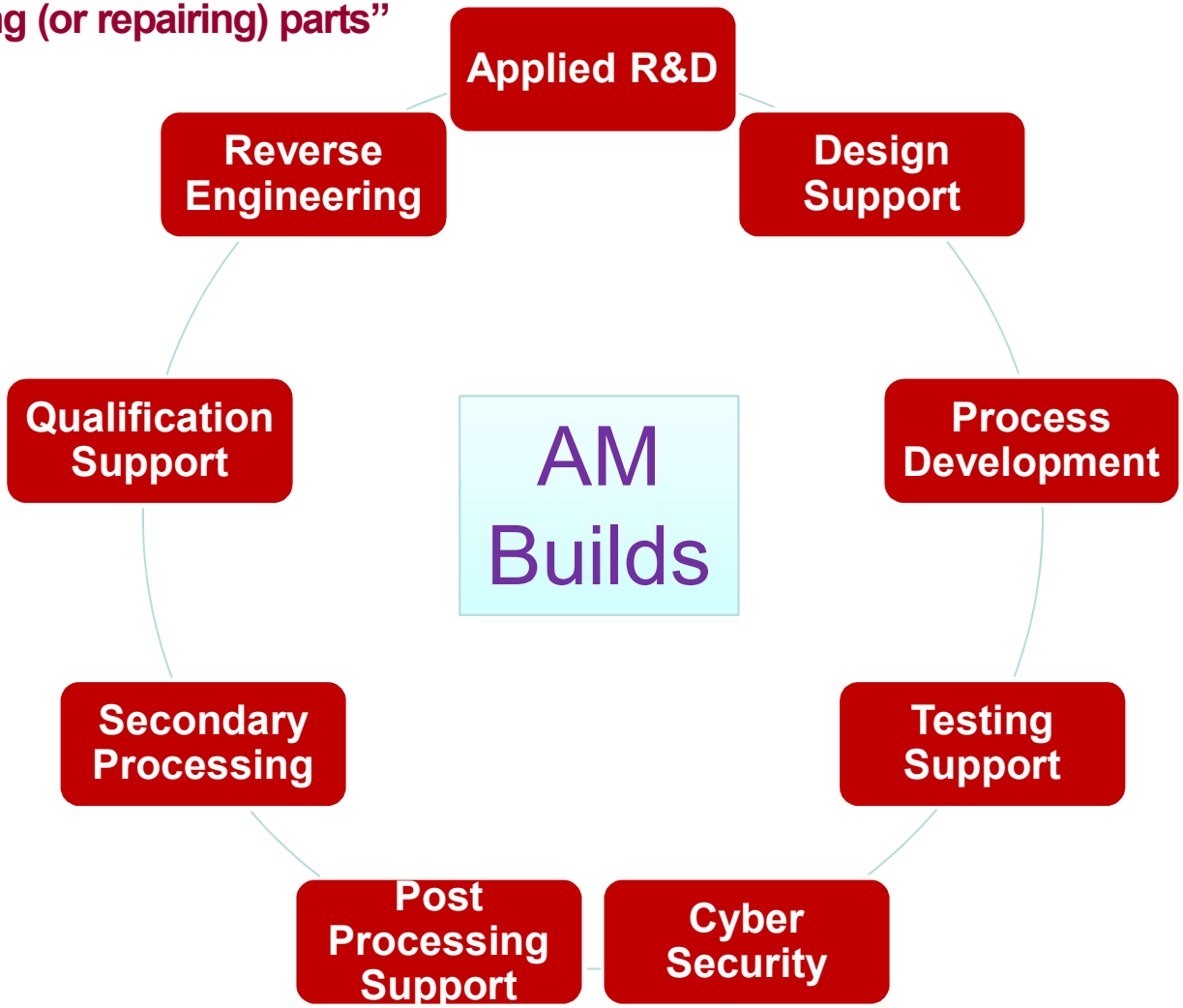
- In-situ controls for quality and deposition adjustments
- Allows wide range of DoD parts to be repaired
- Leverages existing parts, drawings, experiences
  - Required engineering performance is known
- Nature of repair and buildup of material(s) may facilitate qualification more rapidly, even if only on part-by-part (or application-specific) basis
- Allows DoD to leverage AM with less risk than for entire parts made by AM

Current Issues with Laser Powder-Based Hybrid AM

- **Acceptance criteria for repairs still needs to be determined**
  - **Standards for repair inspection procedures**
- **Suitable parts, materials, procedures and secondary processes (such as hot isostatic pressing and heat treatment) still required**
  - **Need to follow holistic approach for AM processing**
- **Safely limited to non-reactive metals**

CTC Approach to AM

Its not "just building (or repairing) parts"



Summary

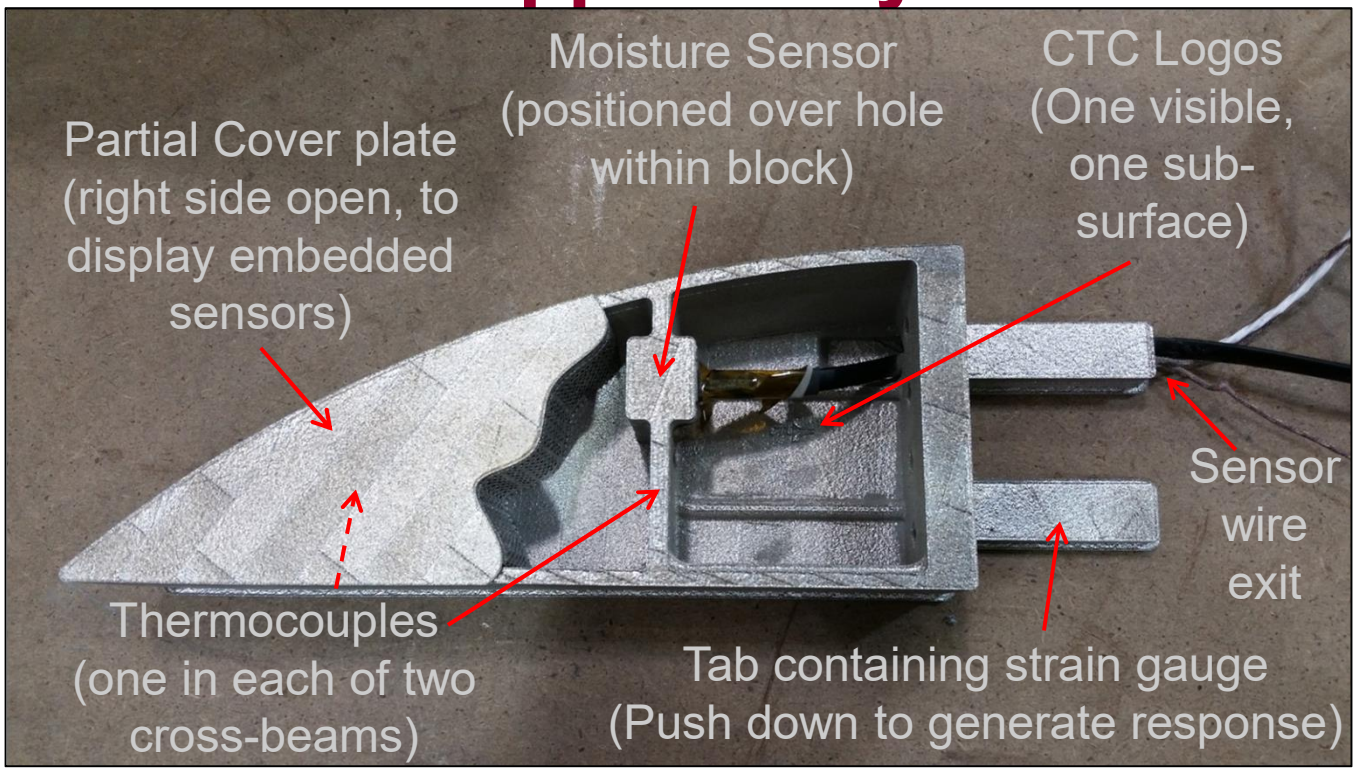
- AM continues to mature as alternative for DoD applications
  - Repair procedures are gaining traction
  - Less confidence in as-built parts due to quality and standardization concerns
- Hybrid AM can be used to rapidly repair and qualify metal parts, with a high degree of confidence
  - Laser deposition technique with numerous non-reactive metallic/ceramic materials for repair
  - Alternative for repair of worn, fractured or environmentally sensitive parts
  - Integrates into existing CNC machining centers
    - One setup for additive and subtractive processes
- End product is a repaired, mechanically and dimensionally compliant component that avoids long lead times and high cost of procuring new components

Contacts

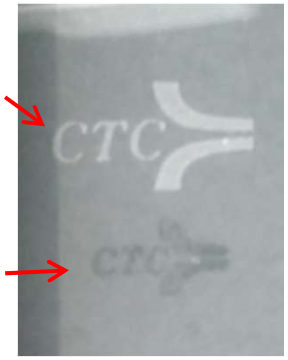
- Ken Sabo
  - Senior Director, Additive Manufacturing and Materials
  - 814-269-6819
  - sabok@ctc.com
- Mike Tims
  - Advisor Engineer
  - 814-269-2515
  - tims@ctc.com
- Rob Mason
  - Principal Materials Scientist
  - 814-269-6480 (office), 727-743-4924 (cell)
  - masonr@ctc.com

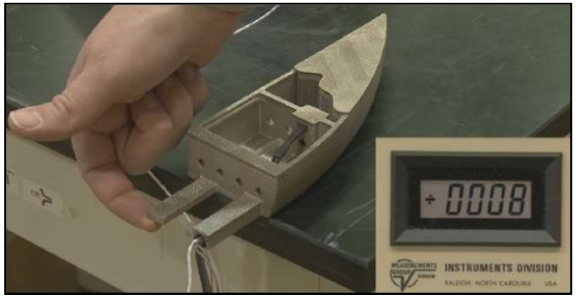
Backup Slides

Potential Opportunity: Embedded Sensors

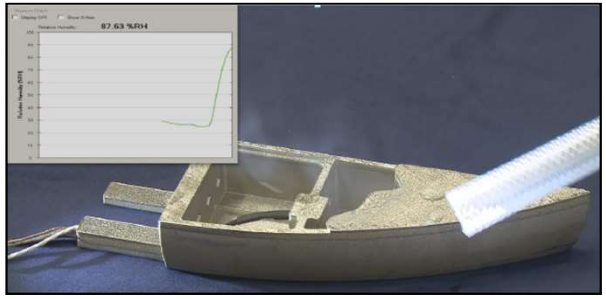


Overall part dimensions are 8.96″ x 2.81″ x 1.41″ thick





Strain gauge



Moisture sensor

Thermocouple