ADDITIVE MANUFACTURING:
CODE IMPLICATIONS OF MAKING COMPONENTS FROM WELD METAL

PRESENTED AT NBBI 89TH GENERAL MEETING
MAY 10, 2021

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What’s in a Name: Additive Manufacturing or Welding?

» Additive Manufacturing - parts are “builds”
  – 3D Printing
  – DED (directed energy deposition)
  – WAAM (wire arc additive manufacturing)

» Welding – parts are “weld metal”
  – Shape Welding, Weld Metal Buildup
  – Most commonly GMAW
  – Some hot wire laser, GTAW and Electron Beam
» See Melfi Video 1
Key Benefits of Additive Manufacturing

- Reduce Lead times
- Design Freedom
- Fast & Functional Prototypes
- Mitigate Supply Chain Risk
- Less Waste
Best Uses for Weld Metal AM

**Value Lever**

- **Reduce Cycle Time**
  - Large castings and forgings
  - Repair parts
  - Functional prototypes

- **Reduce Material Waste**
  - High chip removal
  - Low yield components
  - High cost materials

- **High Tooling or Fabrication Cost**
  - Large or complex tools
  - Complex casting molds & cores

- **Simplify Joining**
  - Tubular connections
  - Multiple joints or weldments
  - Modularized, in-the-field joining

- **Enhance Performance**
  - Light-weighted components
  - Shape modifications
  - Design flexibility

**Use Case**

- **Example**
  - ![Image of large casting and forging]
  - ![Image of repair part]
  - ![Image of complex casting mold and core]
  - ![Image of tubular connection]
  - ![Image of modularized joining piece]
Rapid Turnaround

» No tooling required (design & produce)
» Digital design and production are fundamentally integrated
  – From CAD to part same day!
» No castings ‘cartel’

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Lead Time for Large Parts

<table>
<thead>
<tr>
<th>Lead Time: ~10 months</th>
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<tbody>
<tr>
<td>Large, complex locomotive casting</td>
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<tr>
<td>Planning, prelim design, FMEA</td>
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<tr>
<td>Solid model of molds, cores</td>
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<tr>
<td>Core Validation &amp; Revisions</td>
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<tr>
<td>Casting Simulations</td>
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<tr>
<td>Core plug patterns/wall thickness</td>
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<tr>
<td>Design cope, drag patterns, rig’g</td>
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<tr>
<td>Validate tooling &amp; move to foundry</td>
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<tr>
<td>Build, pour, shake 1st part</td>
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<tr>
<td>Test &amp; inspect</td>
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<tr>
<td>Design, build, validate in WAM</td>
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</tbody>
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Component: Integrated Front End
Weight: 2,300 lbs.
Dimensions: 50” x 55” x 40”
(Courtesy GE Corporate Research)
Replace obsolete parts

» Critical component of production machinery

» Obsolete and no longer available

» Challenging to fabricate → high cost / long lead time

» Designed and printed < 3 days

» Created 3D CAD from old 2D drawings

» Printed with built in fluid channel
Prototypes to validate new valve design

» Challenges
  – Long lead times for steel castings; 6 months for first casting, 3 months for revised castings
  – Typically three design iterations (more than 1 year manufacturing time)

» Solutions
  – Modified design for Additive
  – Printed & ready for machining in less than a week
  – Total cost similar to one-off castings
Tooling for Aerospace Composites

» **Carbon Fiber Lay-up Molds**
  - Facesheet comes in direct contact with carbon fiber
    - Thermal profile
    - Dimensionally stable
    - Vacuum integrity

» **Boeing-Wisk Invar mold**
  - Collaborative design between Boeing R&T and Lincoln
    - Total length: 10ft
    - 3D printed sub-structure

» Tooling as large as 3,100 lbs
Structural Connections Video

» See Melfi Video 2
Offshore TKY Joints

Joint development with Ohio State University’s Center for Design and Manufacturing Excellence

Challenges

- “Blind” complex welds
- Stress risers at weld joints → fatigue failure
OSU Topology Optimization

See Melfi Video 3
Offshore TKY joints

» Traditional TKY modified and enhanced for Additive
  – Hollow cylinders
  – Intersections gusseted
  – Eliminated sharp transitions

» Takes advantage of the ability to print non-planar layers “in space”

36” L x 30” H x 16” W 5 ½” tube OD
Of High Interest: Castings Conversion

**Use Case:** WAM for on-demand direct production of large castings (rotating machinery example).

» **Problem:** Complex systems often require challenging assembly of large components.

» **Castings Classification:** Expendable mold castings such as sand and investment castings best suited to WAM.

» **Materials:** Steels, stainless steel, aluminum, nickel-alloys and bronze.

» **Geometry:** Enormous castings possible; wall thicknesses can range from 1/8” to several inches, even within the same part; opposing channels, and radiating geometries are possible.

» **Benefits:** In addition to reductions in lead time, cost and performance advantages demonstrated by WAM over cast components.

**Total System Cost to User, Complex Assembly ($000s)**

**HIGH VALUE MATERIAL**

- Casting: 83
- WAM: 76
- WAM + Redesign: 64

- OH: 36
- Labor: 29
- Mat’l: 24

- Reduction: -23% to -34%

**LOWER VALUE MATERIAL**

- Casting
- WAM
- WAM + Redesign

**Of High Interest:** Castings Conversion
So, What’s the Big Deal???

» Weld “buildup” rules exist in Section IX

» In the ‘70s it was hard to get castings or forgings
  – Large blocks were made from weld metal and then machined
  – Welded with SAW or even strip overlay (still in service)

» No BPV rules for how castings, forgings, pipe or plate are made
Section IX Actions

» Designs are already out there using “weld metal AM” parts

» Pressure from industry for Section IX to establish rules
  – Often from sectors outside BPV

» An enormous amount of data was available for GMAW

» The first code case was written exclusive to GMAW

» Review and Comment ballot was sent to Construction Codes
Rules for Making Items from Weld Metal

» GMAW Section IX Code Case was approved in April

» Uses a bracketed qualification approach
  – Qualify the lowest and highest cooling rates that will be used in production
  – Qualify thin and thick sections, if both will be used in production
  – Tension, impact, composition and bend tests are required
  – Mechanical testing in the “worst-case” direction (Z-direction)

» The balance of rules essentially follow Section IX
Parts can be made, but can they be used?

» The code case is already in use in non-BPV applications

» No material listing exists in Section II
   – An outside (ASTM, EN, etc.) specification is needed to establish a material in Section II

» Sections III and VIII are considering equivalence rules
   – Replacement for castings should be simple
   – Replacement for plate, pipe and forgings should be possible
What about inservice repairs. . .

The components are very WELDABLE !!
Questions / Discussion

more information and cool videos at: https://additive.lincolnelectric.com