Advances in Powder Metallurgy-Hot Isostatic Processing for Pressure Retaining Applications

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Today’s Presentation

• Today’s Large Component Manufacturing
• Improving Nuclear & Fossil Component Quality
• What Is Powder Metallurgy?
• EPRI’s Role Toward Improved Component Manufacturing
• Component Manufacturing & ASME Code Cases
• Vision for the Future…
Today’s Heavy Section Component Manufacturing Technologies

Casting

Forging
Heavy Forgings
Large Castings & Extrusions

Courtesy of Goodwin Castings

Courtesy of Wyman Gordon
Quality Issues Associated With Today’s Manufacturing Techniques

Poor Quality Castings

Voids/Porosity in Castings

Alloy 690 Forging

Ferrite Stringers in SS plate

Can We Improve the Way We Manufacture Components???
Another Option…

Powder Metallurgy and Hot Isostatic Processing

– Near-net shaped (NNS) for complex and/or large components
– Excellent inspectability
– Eliminates casting quality issues & rework
– Precise chemistry control
– Alternate supply route
– Hard-facing application
The Process Begins with Powder Production…

Gas Atomization

Gas source
Vacuum induction melter
Nozzle
Chamber
Collection chamber
Powder

Courtesy of Carpenter Technology
Powder Metallurgy-Hot Isostatic Processing

**Powder Making**
- Atomisation
- Sieve
- Blend

**HIP Capsule Fabrication**
- Cut and Shape Sheet Metal
- Weld
- Leak Test
- Capsule Fill
- Bake Out
- Seal
- HIP

Courtesy of Steve Mashl, Z-Met Corporation
Hot Isostatic Processing (HIP)

Apply High Pressure
(>15,000psi/100 MPa)

High Temperature
(>2000F/1093C)

Results in Stress-free Application

(courtesy of Metal Technology Company, Ltd)
ASME Code Case Development

- Chemical Composition
- Grain Size
- Drawings & Images
- Microstructure
- Density & Inclusion Content
- Tensile/Yield Properties to 1000F (& stress/strain curves)
- Toughness
- Fatigue
- Weldment Properties
Grade 91 (9Cr-1Mo steel) -- Powder Metallurgy/HIP

- Good tensile/yield/creep properties
- Good toughness: >78 ft-lbs (106 Joules)
- No Porosity, homogenous microstructures
- Inspection, near forging quality

ASME Code Case 2770 & Data Package—Section I—Approved April 2013

ASTM A989
Tensile and Yield Strength of Grade 91 PM-HIP
Ductility & Micrographs of Grade 91 PM-HIP

![Graph showing the relationship between temperature and ductility metrics for different grades of PM-HIP material.](image)

![Micrograph image showing a close-up view of a material's microstructure.](image)
SMAW and GTAW Weldments
LMP and Time to Rupture Plots

Heat Y1550B
Tempered 1375°F (746°C)/4.5h

Grade 91 Database

Heats Y1549B & Y1551B
Tempered 1430°F (777°C)/4.5h

550°C (1022°F)
600°C (1112°F)
650°C (1200°F)

Closed Symbols = Ruptured
Open Symbols = Running
Solid Black Line = Grade 91 Avg.
Dashed Black Line = Grade 91 - 1.65σ

Stress (Mpa)
Time to Rupture (hours)
316L Stainless Steel
--Powder Metallurgy/HIP

- Good tensile/yield properties
- Good toughness: >122 ft-lbs (165 Joules)
- No Porosity, homogenous microstructures
- Good Fatigue properties
- Inspection, near forging quality

ASME Code Case N-834 & Data Pkg, plus NRC Review—Sect III-Approved Sept 2013

ASTM 988
EPRI Research on PM-HIP

- DOE/EPRI Project—Innovative Manufacturing Process for Nuclear Power Plant Components
- Alternative Method to apply Hard-facing Materials—Functionally Graded Alloys
- Elimination of Dissimilar Metal Welds
- Alloy 690 Control Rod Drive Materials
- DOE NEET Program—Heavy Section Materials Roadmap
Alloys of Interest to the Electric Power Industry

- 304L and 316L SS
- IN625 and IN690
- SA508 Class 1, Grade 3
- Grade 91
- Hard-facing Materials—Cobalt free
- Corrosion Resistant Cladding
- HTGR Applications—IN282 & IN740
- Oxide Dispersion Strengthened (ODS) Alloys
Applications & Components

**Fossil & Nuclear**
- Valve Bodies, Valve Seats & Stems
- Pump Housings & Impellers
- Turbine Blade Leading Edges
- RPVs & Nozzles
- Nozzle-to-safe-ends
- Small Modular Reactor Vessels
- Turbine Rotors, Discs, and Casings
- Functionally Graded Alloys
- Elimination of Dissimilar Metal Welds

**RPV Internals**
- Control rod drive tubes
- Fuel Channels from SiC
- Tube Sheets
- Corrosion Resistant Claddings
- Fuel Support Bowls/Castings
- Jet Pump Beams
- Shroud supports
- Chimney partitions
- Inlet Mixer Assemblies
Major Atomized Powder Producers & Large Commercial HIP Units in the World

- Bohler Edelstahl
- Carpenter Powder Products
- Erasteel
- Metso
- Sandvik Powdermet AB
- Kennametal

<table>
<thead>
<tr>
<th>Company</th>
<th>HIP Unit Size (diameter x length in inches)</th>
<th>Country</th>
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<tbody>
<tr>
<td>Kinzoku Giken</td>
<td>81 x 164</td>
<td>Japan</td>
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<tr>
<td>BodyCote</td>
<td>71 x 130</td>
<td>Sweden</td>
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<tr>
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<td>58 x 146</td>
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<td>ATI</td>
<td>51 x 115</td>
<td>USA</td>
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<tr>
<td>Alcoa Howmet</td>
<td>59 x 80</td>
<td>USA</td>
</tr>
<tr>
<td>Alcoa Howmet</td>
<td>42 x 97</td>
<td>USA</td>
</tr>
<tr>
<td>Kittyhawk</td>
<td>47 x 79</td>
<td>USA</td>
</tr>
<tr>
<td>Avure (MegaHIP)</td>
<td>124 x 197 (proposed)</td>
<td>Proposed</td>
</tr>
</tbody>
</table>
Considerations Toward Overall Valve Costs

- Eliminates Component Rework & Quality Issues
- On-time Production (no more missed schedules)
- Reduced Valve Section Thickness over Castings
- Simple Geometries can be machined to final dimensions
- Near-Net Shaped Manufacturing – Minimizes Machining

Images courtesy of Weir Valves
Where are the Costs in PM-HIP for Valve Applications?

Assuming production of >20 medium/large valves:

- Design, engineering, and manufacture of the tooling or dies for can/capsule production (<10%)
- General materials & assembly of can/capsule (25-45%)
- Alloy powder & degas/sealing (15-25%)
- Hot Isostatic Pressing and can removal (~25%)

Clearly new methods that do not rely on “stick-built” can/capsule production could have a huge impact on the overall cost!!!
Advanced Valve Manufacturing

EPRI & ORNL -- Project Leads

Valve Design (Valve Mfr)
- Simple Geometry
- Reduce X-Sectional Thickness

Industrial Advisors:
- Carpenter
- Avure

Atomized Powder Mfg
Carpenter

Rapid Tooling Mfg
ORNL

Can/Capsule Mfg via Flexform Technology—half shell

Assembly/Welding

HIP (Vendor)

Machining

Mechanical Testing
Summary

PM-HIP for Structural & Pressure Retaining Applications:

- Large, complex, near-net-shape components
- Alternate supply route for long-lead time components
- Improves inspectability
- Hardfacing application
- Eliminates rework or repair in castings – a huge benefit for Grade 91 components
- Get on board & help drive the technology forward for valves!!!
Acknowledgements

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Together…Shaping the Future of Electricity