Approach to Codifying New Manufacturing Methods (e.g., PM-HIP, LPBF, EBW)

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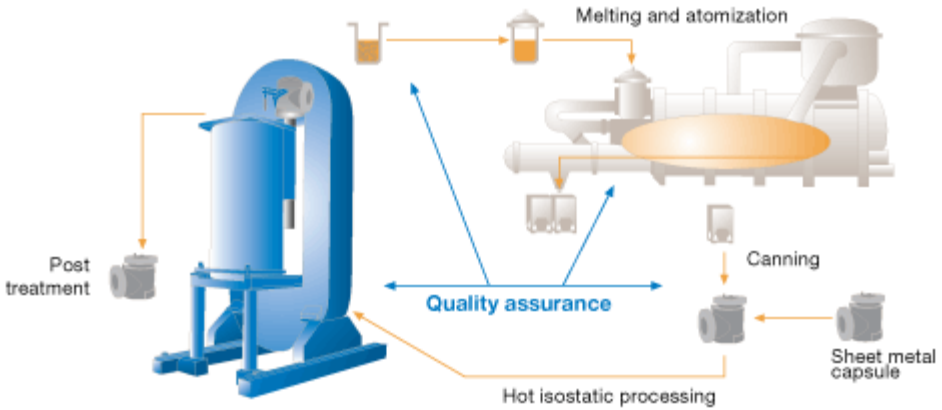
Outline

- What's missing today from the Code?
- What are the gaps that need to be addressed?
- What alloys need to be qualified?

- Four manufacturing methods reviewed herein:
  - Powder metallurgy-hot isostatic pressing
  - Cold spray welding/cladding
  - Laser powder bed fusion-additive manufacturing
  - Electron beam welding

Powder Metallurgy-Hot Isostatic Pressing (PM-HIP)

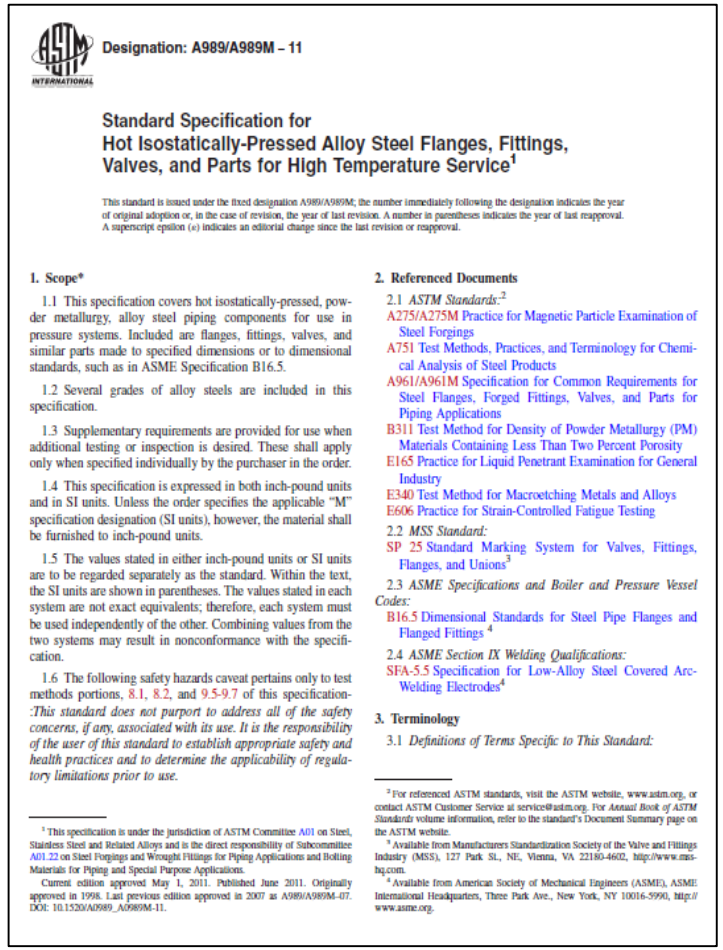
- **What's missing today from the Code?**
  - Permitted by several Code Cases (see next slide
- **What alloys need to be qualified?**
  - **Alloy 600M (N-580-2)**
  - **Alloy 625**
  - **Alloy 690**
  - **Alloy 718**
  - **Low Alloy Steel**



https://www.materials.sandvik/en-us/products/hot-isostatic-pressed-hip-products/production-process/

ASME Code Cases

- ASME Code Cases
  - **CC N-834** – 316L SS (nuclear)
  - **CC 2770** – Grade 91 (fossil)
  - **B31.1 CC** Approved—Grade 91
  - **Section VIII CC – Div. 1 and 2** -- 29Cr-6.5Ni-2Mo-N (S32906)—Duplex SS
- *Incorporation* ASTM A988, A989, and B834 into ASME Section II
- Section II—Appendix 5



Designation: A989/A989M – 11

Standard Specification for
Hot Isostatically-Pressed Alloy Steel Flanges, Fittings, Valves, and Parts for High Temperature Service[1]

This standard is issued under the fixed designation A989/A989M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This specification covers hot isostatically-pressed, powder metallurgy, alloy steel piping components for use in pressure systems. Included are flanges, fittings, valves, and similar parts made to specified dimensions or to dimensional standards, such as in ASME Specification B16.5.

1.2 Several grades of alloy steels are included in this specification.

1.3 Supplementary requirements are provided for use when additional testing or inspection is desired. These shall apply only when specified individually by the purchaser in the order.

1.4 This specification is expressed in both inch-pound units and in SI units. Unless the order specifies the applicable "M" specification designation (SI units), however, the material shall be furnished to inch-pound units.

1.5 The values stated in either inch-pound units or SI units are to be regarded separately as the standard. Within the text, the SI units are shown in parentheses. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the specification.

1.6 The following safety hazards caveat pertains only to test methods portions, 8.1, 8.2, and 9.5-9.7 of this specification-*:This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
A275/A275M Practice for Magnetic Particle Examination of Steel Forgings
A751 Test Methods, Practices, and Terminology for Chemical Analysis of Steel Products
A961/A961M Specification for Common Requirements for Steel Flanges, Forged Fittings, Valves, and Parts for Piping Applications
B311 Test Method for Density of Powder Metallurgy (PM) Materials Containing Less Than Two Percent Porosity
E165 Practice for Liquid Penetrant Examination for General Industry
E340 Test Method for Macroetching Metals and Alloys
E606 Practice for Strain-Controlled Fatigue Testing

2.2 *MSS Standard:*
SP 25 Standard Marking System for Valves, Fittings, Flanges, and Unions[3]

2.3 *ASME Specifications and Boiler and Pressure Vessel Codes:*
B16.5 Dimensional Standards for Steel Pipe Flanges and Flanged Fittings [4]

2.4 *ASME Section IX Welding Qualifications:*
SFA-5.5 Specification for Low-Alloy Steel Covered Arc-Welding Electrodes[4]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

[1] This specification is under the jurisdiction of ASTM Committee A01 on Steel, Stainless Steel and Related Alloys and is the direct responsibility of Subcommittee A01.22 on Steel Forgings and Wrought Fittings for Piping Applications and Bolting Materials for Piping and Special Purpose Applications.
Current edition approved May 1, 2011. Published June 2011. Originally approved in 1998. Last previous edition approved in 2007 as A989/A989M-07. DOI: 10.1520/A0989_A0989M-11.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Manufacturers Standardization Society of the Valve and Fittings Industry (MSS), 127 Park St., NE, Vienna, VA 22180-4602, http://www.mss-hq.com.

[4] Available from American Society of Mechanical Engineers (ASME), ASME International Headquarters, Three Park Ave., New York, NY 10016-5990, http://www.asme.org.

* This CC initiated by Sandvik

Powder Metallurgy-Hot Isostatic Pressing (PM-HIP)

- **What are the gaps that need to be addressed?**
  - ***Material standards*: Additional ASTM specifications need to be developed for Ni-base alloys and low alloy steel (A 508 equivalent)**
  - ***Code Cases:*** Needed for the additional alloys
  - ***Environmental data****:* stress corrosion cracking needs to be developed for Ni-base alloys
  - ***Low Alloy Steels:*** welding acceptability needs to be confirmed.
  - ***Fracture toughness****:* Needed for low alloy steels
  - ***Irradiation Data*** –Some data under development by EPRI/INL.
  - ***Creep data***– necessary for Division 5 applications

Powder Metallurgy-Hot Isostatic Pressing (PM-HIP)

- Near term needs
  - Low Alloy steel (A 508 equivalency)
    - Material specification
    - Section III Code Case
  - Nickel Base Alloys
    - Alloy 600M, 625, 690, 718
    - Code Cases
- Longer term
  - Grade 91
  - Type 316H
  - Alloy 617
  - Hardfacing alloys (composite PM-HIP)

Cold Spray Additive Manufacturing

- Technique results in a mechanical bond
  - Repair of existing material
  - Surface cladding

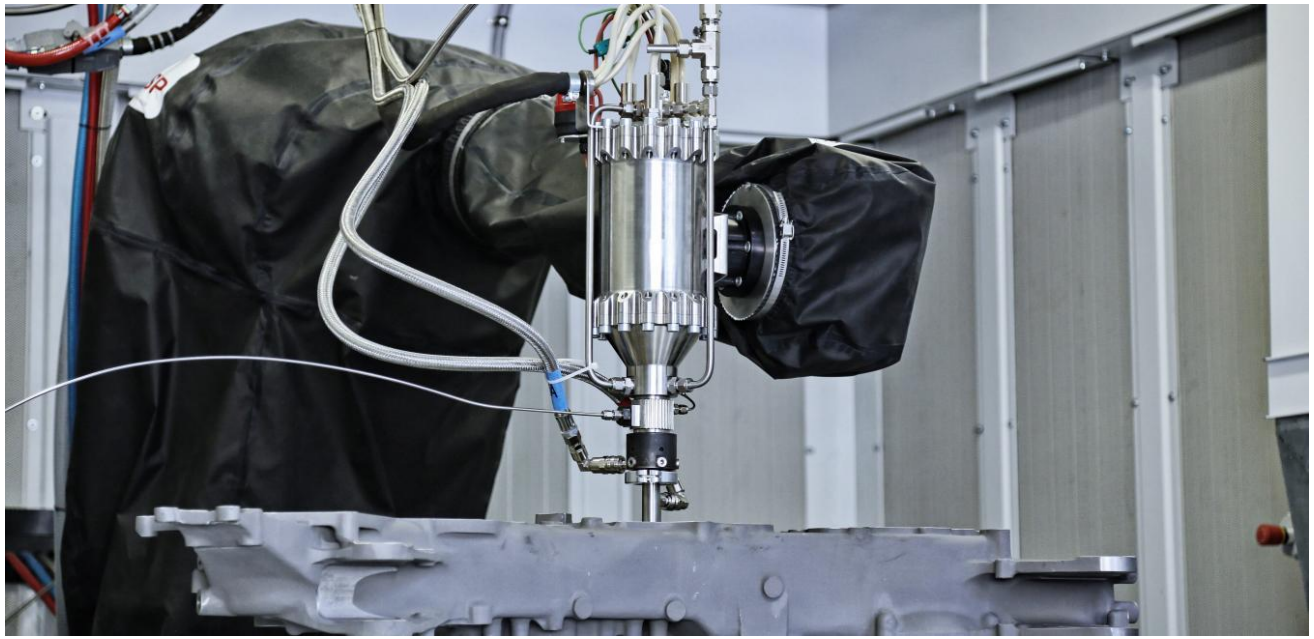


Image courtesy of GE reports

Cold Spray Additive Manufacturing

- What's missing today from the Code?
  - Process is not recognized by the Code
- **What alloys need to be qualified?**
  - **Austenitic stainless steel**
  - **Alloy 625**
  - **Alloy 690**
  - **Alloy 718**
  - **Low Alloy Steel**

Cold Spray Additive Manufacturing

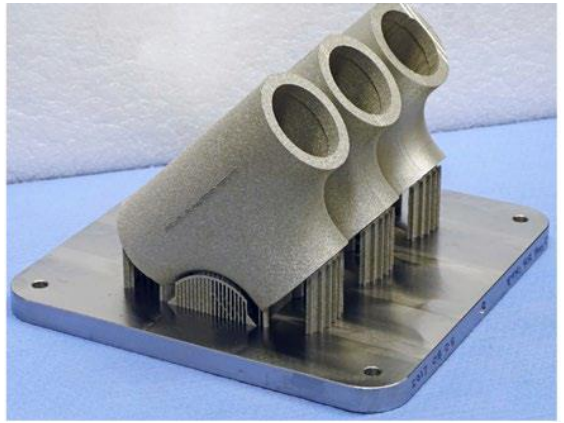
- What are the gaps that need to be addressed?
  - Material Standard necessary
  - Material sampling plan for mechanical properties
  - Process qualification requirements - not covered by Section IX
  - RT is typically used for castings
  - UT examination for bond
  - Alternative methods may be necessary

Laser Powder Bed Fusion-Additive Manufacturing

- **What's missing today from the Code?**
  - LPBF-AM is not currently addressed by ASME or NRC.
  - ASME BPTCS/BNCS *Special Committee on AM for Pressure Retaining Equipment* is currently assembling a Guidelines for "Control of PBF processes to fabricate and test AM pressure-retaining components."
  - Each ASME Book Section will then need to incorporate the guidance into the appropriate Book (I, III, VIII, etc.) for application
  - DRAFT Code Case for 316L SS LPBF-AM submitted to BPV-III (by Westinghouse/EPRI)

- **What alloys need to be qualified?**
  - Stainless steels: 316L, 304L, 316H, 709, 17-4PH
  - Nickel-based alloys: 617, 625, 690, 725, X-750, Alloy X
  - Titanium-based alloys: Ti6Al4V
  - Zirconium-based alloys: Zircaloys?

Laser Powder Bed Fusion-Additive Manufacturing



- **What are the gaps that need to be addressed?**

Materials Properties Gaps

- Time dependent and independent materials properties
- Fatigue (smooth and as deposited) properties
- Fracture toughness properties
- Irradiation and thermal aging properties
- SCC properties

Processing Gaps

- Processing—Establish essential variables (next slide)
- HIP vs no-HIP application and properties

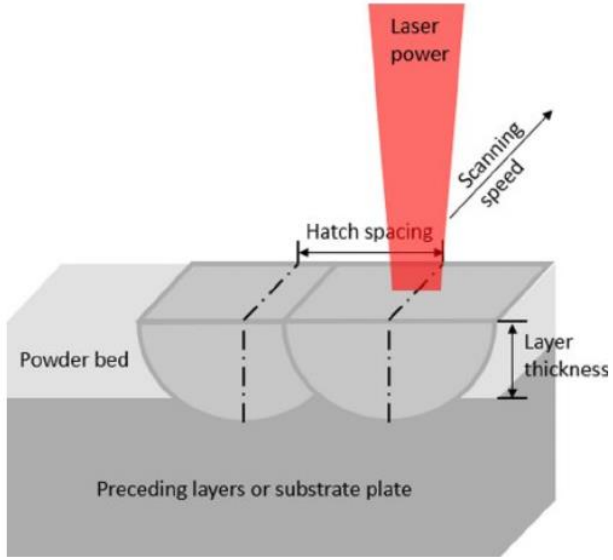
NDE Gaps

- Defect acceptance criteria
- Detection limits
- Disposition

Laser Powder Bed Fusion-Additive Manufacturing

Essential Variables may include:

- Laser power
- Exposure time
- Point distance
- Scanning speed
- Layer thickness
- Hatch spacing or hatch distance
- Stripe width
- Scan strategy
- Pulse characteristics
- Beam diameter
- Energy density
- Gas flow and gas composition
- Re-coater blade type
- Beam focus distance

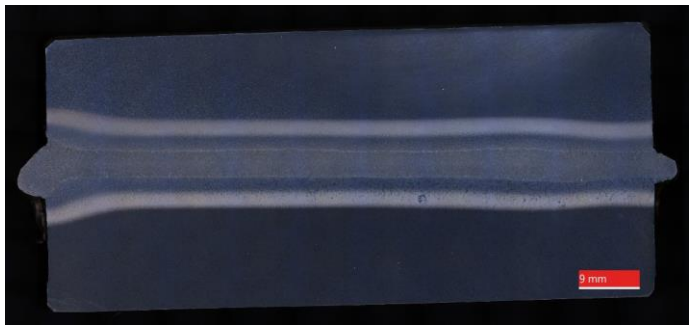


Overview of LPBF-AM deposition on a substrate plate

Electron Beam Welding
– List of Pertinent ASME Docs for EBW of Thick Section Components

Section III

- NB-4311 *Types of Processes Permitted*
  - Any process used shall meet the records required by NB-4320
- NB-4320 *Welding Qualifications, Records and Identifying Stamps*
- NB-5277 *Examination of EB Welds*



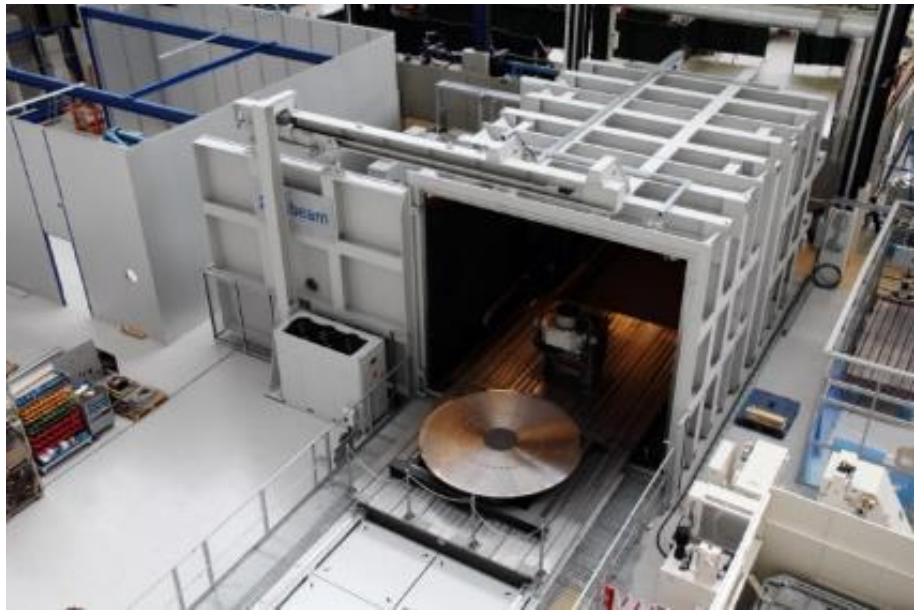
110mm (thick) EB Weld

Section IX

- QW-215 *Electron Beam Welding and Laser Beam Welding*
  - WPS qualification test coupons shall be prepared w/ the joint geometry duplicating that to be used in production.
  - If the production weld is to include a lap-over (completing the weld by rewelding over the starting area of the weld, as a girth weld), such lap-over shall be included in the WPS qualification test coupon.
  - The mechanical testing requirements of QW-451 shall apply.
- QW-260 – *Essential Variable Procedure Specifications (WPS) for Electron Beam Welding*
- QW-451 – *Procedure Qualification Thickness Limits and Test Specimens*
  - Groove-Weld Tension Tests and Transverse Bend Tests

Electron Beam Welding

- **What's missing today from the Code?**
  - EBW is already permitted for nuclear pressure retaining components under Section III, NB-4311 and Section IX QW-215.



Photograph provided courtesy: Nuclear AMRC (UK)

- **What alloys need to be qualified?**
  - No preheat on low alloy steel (SA 508 Class 1-2) – see next slide.
  - No additional requirements for Stainless steels or Nickel-based alloys

Electron Beam Welding

- **What are the gaps that need to be addressed?**
  - EBW is performed in a vacuum chamber, thus ***moisture/hydrogen*** is not present and not an issue.
  - For Low Alloy Steels, welding ***without preheat*** will need to be qualified and codified.
  - ***Irradiation Data*** – US & UK Naval programs have this information. Some data under development by Purdue/EPRI/ATR.
  - ***Long-term Thermal Embrittlement*** – Same, US & UK Naval programs
  - ***Residual Stress Data*** – Collaborative project (EPRI, U. of Manchester, Nuclear AMRC developed data). Also, TWI.
  - ***Operator Qualification*** – Difficult to convert conventional welder to EBW operators. CNC machinists can often be converted to EBW operators.

Summary – Major Gaps

- Powder metallurgy-hot isostatic pressing
  - Limited material acceptance (Nuclear)
  - Material data
  - Size limitations
- Cold spray welding/cladding
  - Not accepted currently by ASME BPVC
  - Additional alloys, Process qualification, NDE gaps
- Laser powder bed fusion-additive manufacturing
  - Not accepted currently by ASME BPVC
  - Additional alloys, processing gaps, NDE gaps
- Electron beam welding
  - No preheat (in vacuum)
  - Irradiation and long-term thermal embrittlement
  - Welding residual stresses

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