Welding and PWHT of P91 Steels

VALVE MANUFACTURERS ASSOCIATION OF AMERICA

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Mooresville, NC 28117 USA
Oooops!

Nowhere Near A Weld!
Items in Common?

- P91
- Less than 2 years of service
- Require Weld Repair
  - Permanent (?)
  - Temporary
Creep Strength-Enhanced Ferritic Steels (CSEF)

CSEF’s are a family of ferritic steels whose creep strength is enhanced by the creation of a precise condition of microstructure, specifically martensite or bainite, which is stabilized during tempering by controlled precipitation of temper-resistant carbides, carbo-nitrides, or other stable phases.

... i.e., unlike other CrMo’s, **microstructure** rules!
Why P(T)91?

- **Better** Thermal Conductivity
- **Lower** Coefficient of Linear Expansion
- **Strength**!
$P(T)_{91}$ is... NOT just another CrMo!
Challenges

• Welding
• Design
• Heat Treatment
• Lowest Bidder
P91 HAZ is Different!
# Welding: $P(T)_{22}$ v. $P(T)_{91}$

<table>
<thead>
<tr>
<th></th>
<th>$T/P$ 22</th>
<th>$T/P$ 91</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preheat</strong></td>
<td>Always ?</td>
<td>Always !</td>
</tr>
<tr>
<td><strong>PWHT</strong></td>
<td>Sometimes</td>
<td>Always !</td>
</tr>
<tr>
<td><strong>N &amp; T (after cold work or forming)</strong></td>
<td>Sometimes</td>
<td>Always !</td>
</tr>
<tr>
<td><strong>CMTR</strong></td>
<td>Rarely</td>
<td>Always !</td>
</tr>
<tr>
<td><strong>Toughness</strong></td>
<td>Rarely (Power Industry)</td>
<td>Not Req’d, but….</td>
</tr>
<tr>
<td><strong>Post Bake</strong></td>
<td>Rarely</td>
<td>Optional (except none for GTAW ?)</td>
</tr>
<tr>
<td><strong>Cool to &lt;100C</strong></td>
<td>No</td>
<td>Yes ! (?)</td>
</tr>
<tr>
<td><strong>Bead Sequence</strong></td>
<td>Rarely</td>
<td>Always !</td>
</tr>
<tr>
<td><strong>Inert Gas Purge</strong></td>
<td>No</td>
<td>Always ! (?)</td>
</tr>
</tbody>
</table>
Welding is the easy part!
49 Beads!
Fit-up !
Purge

• Purging the root is NOT an option!

  – 99.997% Ar (Welding Grade ?)

  – N, satisfactory, but...
To achieve high temperature creep properties, deoxidizers (Si, Mn, Zr, etc.) are intentionally kept low in the base metal and weld metal, which prevent proper wetting action and tie-in of the molten weld puddle.
Using 5/32” GTAW Wire Doesn’t Help!
Design

• Problems in less than 1000 hours!
  – Dissimilar Welds & Transitions

• Problems in less than 5,000 hours!
  – Weld Geometry
  – Process Selection

... Use of P(T)91 where it isn’t needed ????
Design

• In many cases, P(T)91 does **NOT** relax during operation...
  – At **1050F, Very Conservative**, if thicknesses were not designed too close to the allowables....
  – Major consideration for **dissimilar weldments**
    • P(T)91 to P(T)22; or worse, to P(T)11 or CS!
Design

• Why have some of the early installations given great service?
  – The designers, fabricators & installers followed **ALL** the rules.
  – Operate with **conservative design margins** (thickness) [AEP & DPL]
  – Operate at ~ **1050F**, or lower
  – “Low Bidders” not involved yet
Caution: Dissimilar Welds!

Creep Strength
100,000 Hrs. at 1112°F

But... Strength Difference isn’t the only issue!
Design

1-1/4CrMoV

P91

E9018-B3
Design

PWHT
1285 F

500 F  10 hours |  8 hours |  10 hours | 500 F
Pipe

Valve

E9018-B3

Weld Metal

1.25Cr 1Mo V

Valve

P91

Pipe

Crack

Micro E
Design & PWHT

Carbon Depleted Zone

Carbon Depleted Zone

Carbon Depleted Zone
Preheat & PWHT

• Expect it !
• Plan on it !
• Get a quality vendor !
• Do it !
• No Exceptions !!!!!!!!
Traditional Preheat

**NOT Acceptable for P91 !**
Preheat/Interpass Temps

• **Preheat is somewhat forgiving...**
  - > 400F Usually Adequate (less for GTAW)

• **Preheat maintenance is NOT forgiving**!

• **Localized heating with oxy-fuel torches is difficult to control & NOT recommended**

• **Interpass is usually affected by mass**
Preheat - Example

Notice Anything?
Post Baking Prior to PWHT?

• Practices ...
  – Preheat Temperature (~400F) up to 600F
  – 15 min. to 4 hrs.

• However, If...
  – Low Hydrogen Welding Consumables
  – Proper Preheat
  – Proper Cleanliness

• Post baking can be optional...but a good idea....
Lower to Room Temp?

• Conventional Metallurgical Wisdom:
  – Cool completed weld (< 200F) prior to PWHT
  – Permit/force complete transformation to martensite
  – Fact: It may never be 100%

• What if I don’t?
  – May increase creep strength...
  – But, may lose some service life ...
PWHT

• Base metal isn’t the problem
  – It’s the weld metal!

• Untempered, As-Welded “B9” Welds
  – Up to 210 ksi ultimate strength
  – ~ 50 Rockwell C
  – Resembles a tool steel
  – May be prone to Stress Corrosion Cracking prior to PWHT
Delay or Omission of PWHT

• Intergranular stress corrosion (IGSCC) possible if exposed to moisture or dampness

• Transgranular stress corrosion (TGSCC) possible if exposed to sulfur species contaminants
PWHT

- Temp range limited/affected by Nickel + Manganese content of weld metal.

  - Ni + Mn lower the lower critical transformation temperature

  - This issue addressed in ASME I, PW-39 & B31.1, Table 132.

  - You NEED Actual Composition of Weld Metal; “Typical Test Certs” are Unacceptable!

  - Narrow range: 1350 – 1425 F, if you don’t know the Ni+Mn %
Ni+Mn Weld Metal
Current BPV I & B31.1 Rules

• Don’t know? 1350 to 1425F
• <1.5% but > 1.0%, 1350 to 1450F
• < 1.0%, 1350 to 1470F
• May use 1325F min. if ≤ 0.5” thick
P91 weld metal Ac1 temperature vs Ni+Mn - P92 is about 15 deg C higher

Recommended max. PWHT temperature

Ni+Mn%=1.5%

15°C

1470°F

1365°F

1350°F

1335°F

1350°F

1470°F

Ni+Mn=%

Ac1 temperature, °C

Metrode consumables (measured)

Other P91 consumables (measured)

P91 base material (V&M CCT diagram)

Courtesy: Metrode Products, Ltd.
New Issue!

• Many foreign fabricators used weld metal with high Ni+Mn (1.8-2.4%)

• Performing PWHT at “North American” temperature levels on field welds or repairs may induce temperatures on adjacent shop welds above their Ac1.

• PMI of near shop welds advisable.

So... new rules in ASME IIA; 1.0 Max!
New Issue – Hi vs. Low Ni

Hi vs. Low PWHT Temperature Practice
PWHT

- Dissimilar Welds Challenging
  - P(T)91 to P(T)22, 11, CS, or SS
  - Must temper the P(T)91 HAZ but not sacrifice the other material
  - Difficult where B9 Weld Metal is Used
Ideally...

Ideal = Smooth Transition

Properties

P91

Soft Zone

B9

Non CSEF

CSEF

Non CSEF
## PWHT Temps (B31.1)

...the other issue.....

<table>
<thead>
<tr>
<th>ASME P-No.</th>
<th>PWHT Temp, F Ranges</th>
<th>Ac1, F</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td></td>
<td>[350]</td>
</tr>
<tr>
<td>1</td>
<td>1100 -1200</td>
<td>1340</td>
</tr>
<tr>
<td>4</td>
<td>1200 -1300</td>
<td>1430</td>
</tr>
<tr>
<td>5 A&amp;B</td>
<td></td>
<td>1480</td>
</tr>
<tr>
<td>15E</td>
<td></td>
<td>1475</td>
</tr>
<tr>
<td></td>
<td>1300 –1400</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1350 -1425</td>
<td></td>
</tr>
</tbody>
</table>
PWHT

- **Overtempering**
  - Heating below the AC1, but for extended time
  - Will not cause Type IV Failure
  - Not an issue for normal fabrication

- **Intercritical Heating** (Between Ac1 & Ac3)
  - Promotes Type IV Failures
  - Can Degrade P(T)91 to P(T)9
  - Replace material or N&T ENTIRE Component

- **Water flowing** in component during PWHT not advisable...
Preheat ?

NOT PWHT !
Result of Typical PWHT

Test 1

Time (Minutes)  Temperature (F)
C1  C1M  C1I

15:36:0  1350  OD
15:50:2  1360  OD
16:04:4  1370  OD
16:19:1  1380  OD
16:33:3  1390  OD
16:48:0  1400  OD
17:02:2  1410  OD
17:16:4  1420  OD
17:31:1  1430  OD
17:45:3  1440  OD
18:00:0  1450  OD

Midwall
Proper PWHT
PWHT Recommendation

• American Welding Society D10.10, *Recommended Practices for Local Heating of Welds in Piping and Tubing*
  
  ... FYI ...

• ASME SC I & B31.1 do NOT provide information or criteria to assure a proper PWHT
Soft Spots.....

• Why do we sometimes observe soft spots in the base metal 6-8” away from the weld?

• Perhaps, now we know!
Prompted New Rules...

• Scott Bowes’ presentation!
New Rules, ASME IIA

• Minimum hardness criteria are being discussed for all P91 base metal product forms
  – Maximum hardness limits exist
  – New Proposal: 190 HBW min.

• Documentation of Repairs for Castings

• 1.0 Ni + Mn Max
Upcoming Code Changes (AWS)

- CrMo Filler Metal Specifications
  - A/SFA5.5, A/SFA5.23 & A/SFA5.28
    - B9 becomes B91 or B92
    - T23 becomes B23
    - T24 becomes B24
ASME IX; P-Number 15

- 15A - OPEN
- 15B - OPEN
- 15C - 2¼ Cr (up to 3%)
- 15D - OPEN
- 15E - 9% Cr [P91 & P92]
- 15F - 12% Cr
Conclusions

• Evaluate the Design

• PWHT is Critical. Not an Option!
  – Require “CMTR” or 3.1 (EN10204)
  – Ni + Mn of Weld Metal Matters for PWHT!

• Follow the rules
  – Beware of the Low Bidder
  – You CANNOT cut corners
Conclusions, cont.

- Caution: Dissimilar Connections
- PWHT is Key to Success
- Keep up with Code Changes
- P(T)91 is NOT just another CrMo!
Questions?