Welding and PWHT of P91 Steels

VALVE MANUFACTURERS
ASSOCIATION OF AMERICA

7-8 March , 2013

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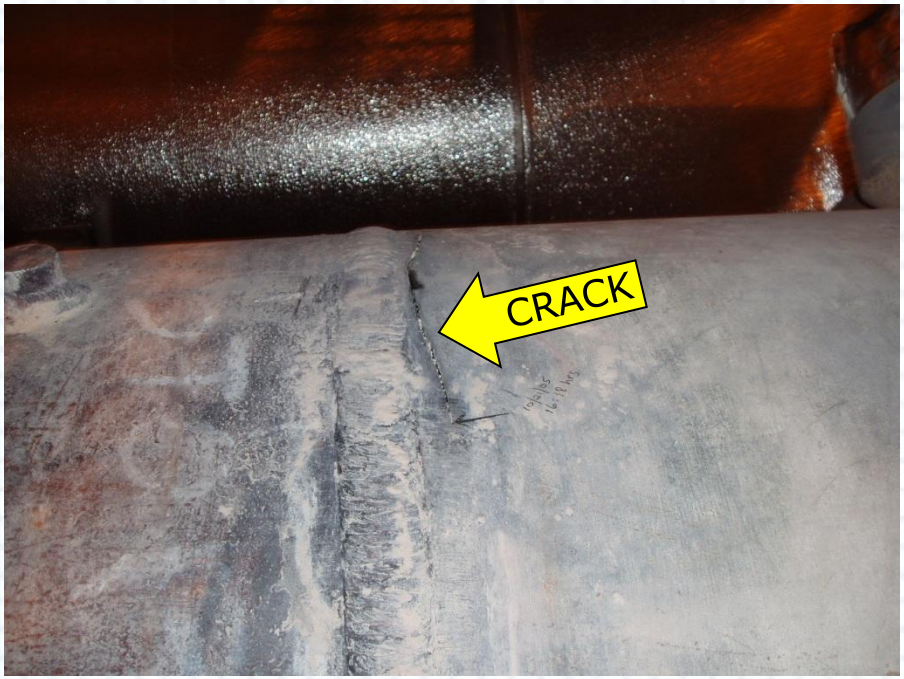
EUROWELD, Ltd.
255 Rolling Hill Road
Mooresville, NC 28117 USA


8 1:29PM


13 12:53PM


CRACK


KNIFE

Oooops!

Nowhere Near A Weld !

Items in Common ?

- P91
- Less than 2 years of service
- Require Weld Repair
  - Permanent (?)
  - Temporary

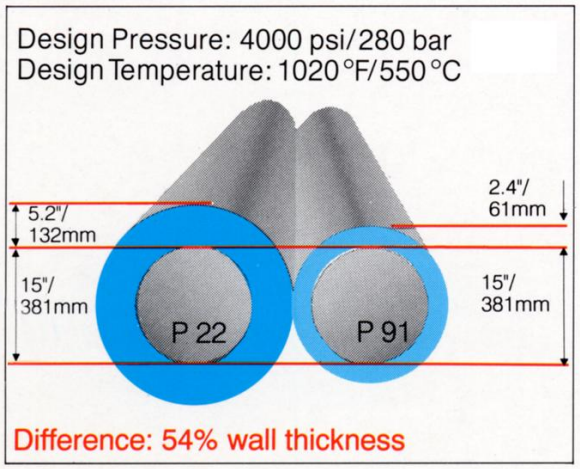
Creep Strength-Enhanced Ferritic Steels (CSEF)

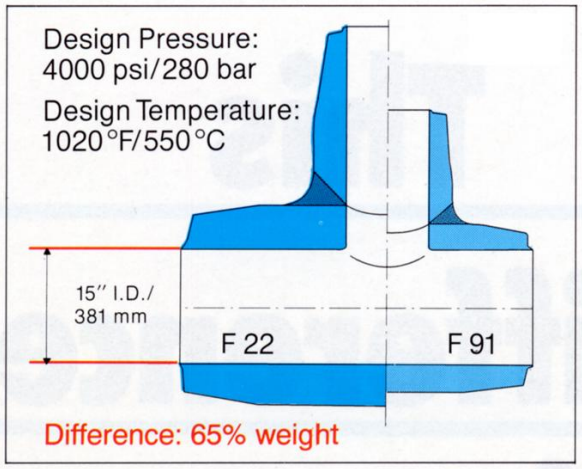
CSEF's are a family of ferritic steels whose creep stength is enhanced by the creation of a precise condition of microstructure, specifically martensite or bainite, which is stabilized during tempering by controlled precipitation of temper-resistant carbides, carbo-nitrides, or other stable phases.

… i.e., unlike other CrMo's, <u>microstructure</u> rules!

Why P(T)91?

- **Better** Thermal Conductivity
- **Lower** Coefficient of Linear Expansion
- **Strength !**





P(T)91 is…

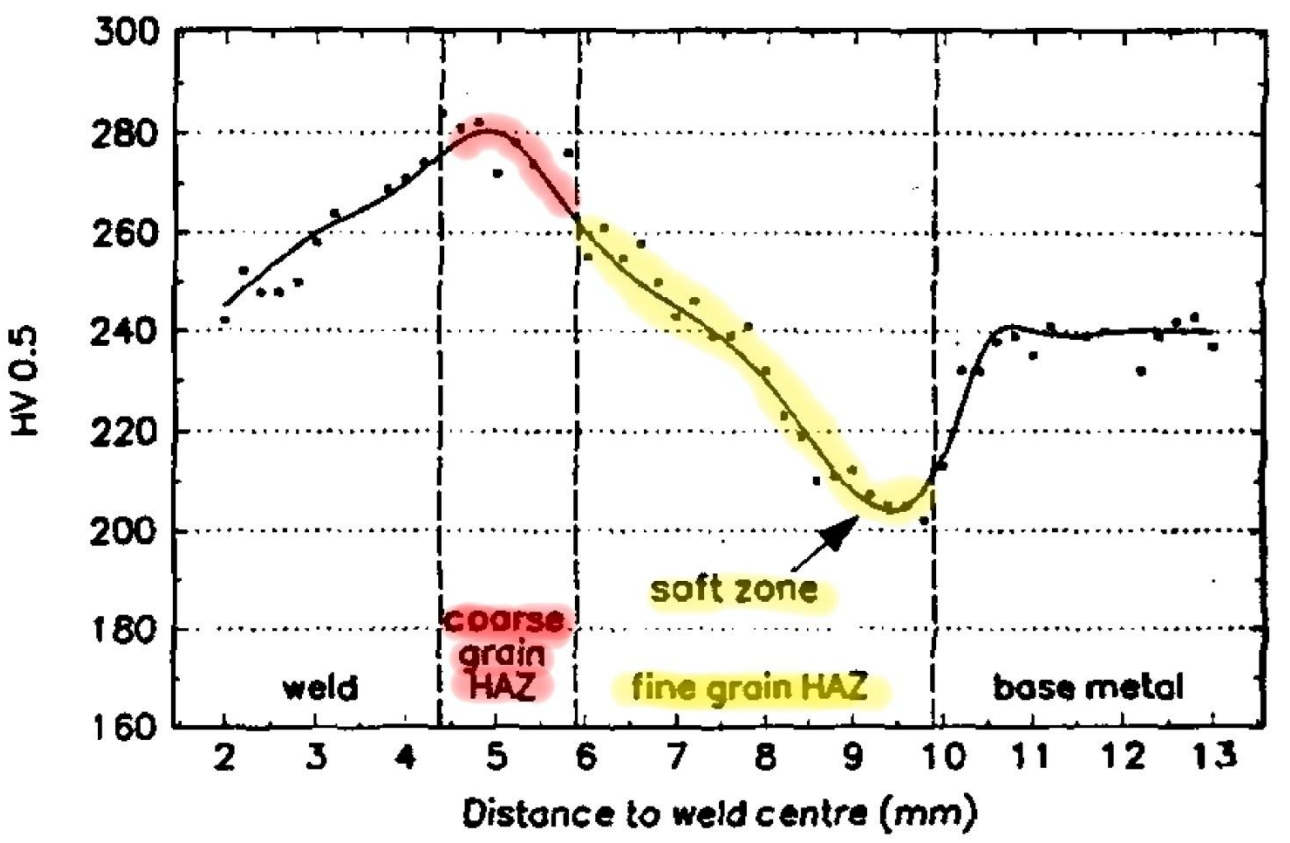
NOT

just another CrMo !

Challenges

- Welding
- Design
- Heat Treatment
- Lowest Bidder

P91 HAZ is Different !



Welding: P(T)22 v. P(T)91

	T/P 22	T/P 91
Preheat	Always ?	Always !
PWHT	Sometimes	Always !
N & T (after cold work or forming)	Sometimes	Always !
CMTR	Rarely	Always !
Toughness	Rarely (Power Industry)	Not Req'd, but….
Post Bake	Rarely	Optional (except none for GTAW ?)
Cool to <100C	No	Yes ! (?)
Bead Sequence	Rarely	Always !
Inert Gas Purge	No	Always ! (?)

Welding is the easy part !

	Specifications	Size	Heat/Lot No.	Manufacturer
Base Metal	SA 387, Grade91	2"	R9332-2A	Lukens
Weld Metal	EB9	2.4mm	V411/3	Euroweld
Flux	WP 380	-	238	Bovario Schweisstechnik

Hardness	
Base Metal	N/A
Weld Metal	N/A
HAZ	N/A

Process	SAW	Parameters
Preheat/Interpass	450°F/600°F	Amps: 400 Volts: 29.4 Travel: 15ipm KJ/in: 47.04
PWHT	3 Hrs. @ 1400°F±25°	WFS: 100 Flux Burden: 3/4" Wire Extension: 1"

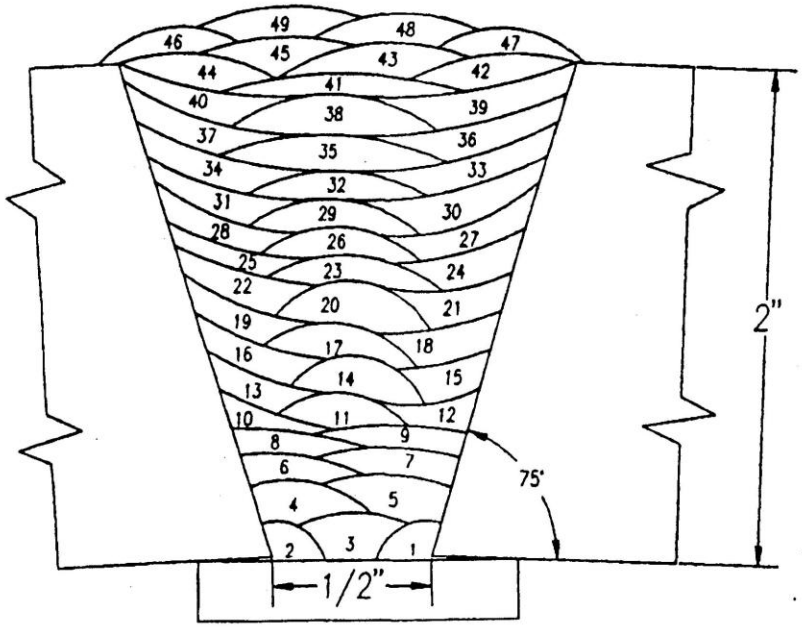
Side Bends	N/A	N/A

Radiographic Report	
AWS-A-5.1 Ref. ASTM-E142	
Isotope: IR192	Thru Wall
Test: Accepted	

Specimen	Ultimate, ksi	Yield, ksi	Elongation, In2", %	Failure Location
T1	100.9	84.2	21.5	Weld Metal

	C	Mn	P	S	Si	Ni	Cr	Mo	V	Nb	Ti	Co	Cu	Al	As	Sn	N	O
B.M.	.09	.44	.012	.002	.35	.17	8.66	.94	.231	.087	NA	NA	.13	.036	NA	NA	.055	NA
Wire	0.10	.56	.002	.002	.27	.69	9.02	1.01	.21	.06	<.004	NA	.01	<.005	<80ppm	<.003	.036	<50ppm
W.M.	0.078	0.39	0.005	0.003	0.58	0.70	8.39	0.97	0.20	0.037	0.001	0.003	0.04	0.006	<0.001	0.004	0.042	0.055

49 Beads !



Impact Test Data		
Location (1/4t)	Foot-Lbs. Specimen	Average
Base Metal @4°C/40°F	44,53,54	50.3
Weld Metal @24°C/75°F	Cooled to RT then PWHT 1400°±25	
	46,53,52,46,54,45	49.3
	Extended Preheat 500°F then PWHT 1400°± 25	
	46,45,40,41,37,49	43
HAZ	N/A	

SPECIALTY WELDING & MACHINING INC.

9304 BIRCHWOOD PIKE, HARRISON, TN 37341-9381
PHONE (423) 344-4876 FAX (423) 344-1341

EVALUATION TEST RESULTS of 9Cr SAW for EUROWELD, Ltd.

DATE: November 22, 1999	FILE NAME: EU9CRSAW
DRAWN BY: J. W. Hales	
APPROVED BY: J.W. Hales	SCALE: NONE

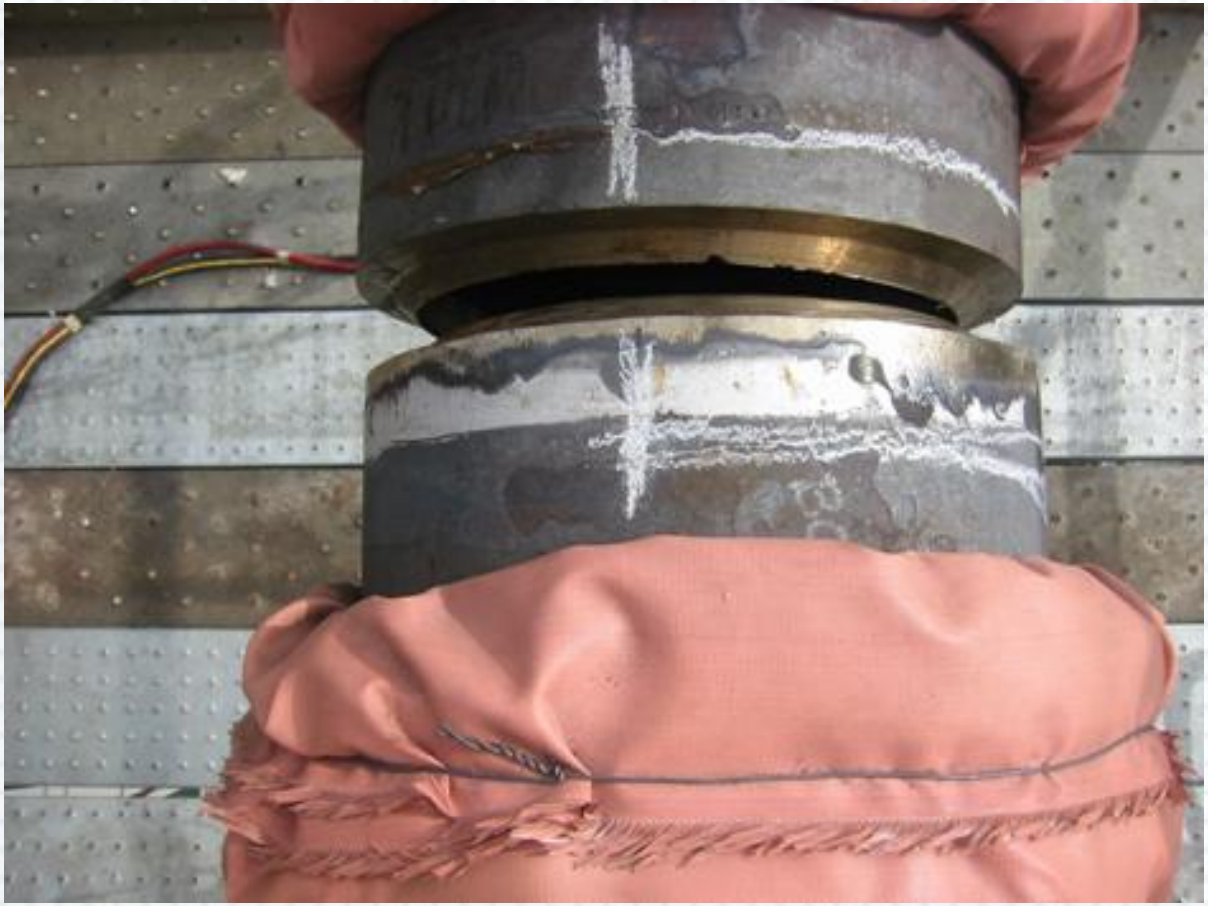
TOLERANCES UNLESS SPECIFIED: .X .XX .XXX ANGLES ± .100 ± --- ± --- ± 1/2°

X

DRAWING No.: 99030 RE

SHEET 1 OF 1

Fit-up !



Purge

- Purging the root is NOT an option !
  - 99.997% Ar (Welding Grade ?)
  - N, satisfactory, but…

GMAW & B9

NOT Recommended !

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 ????

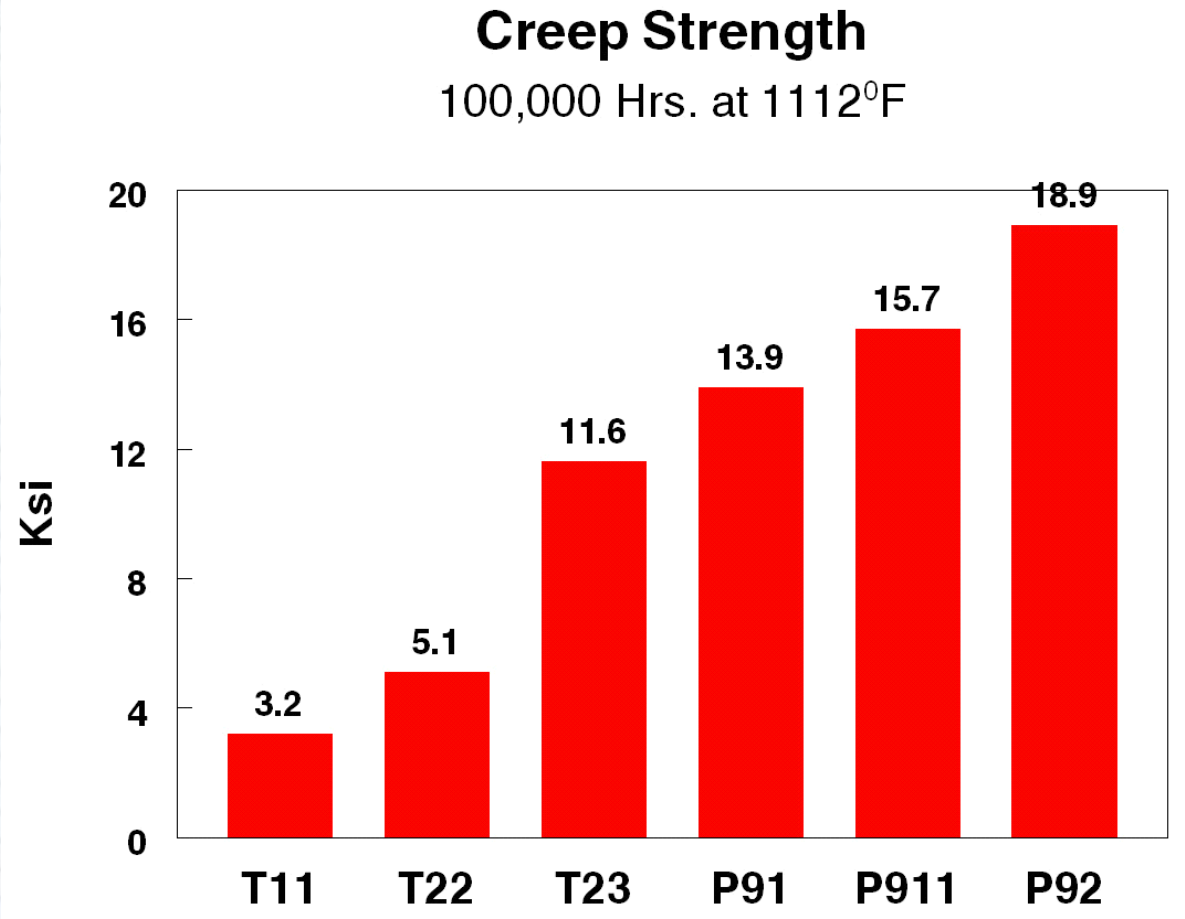
Design

- 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

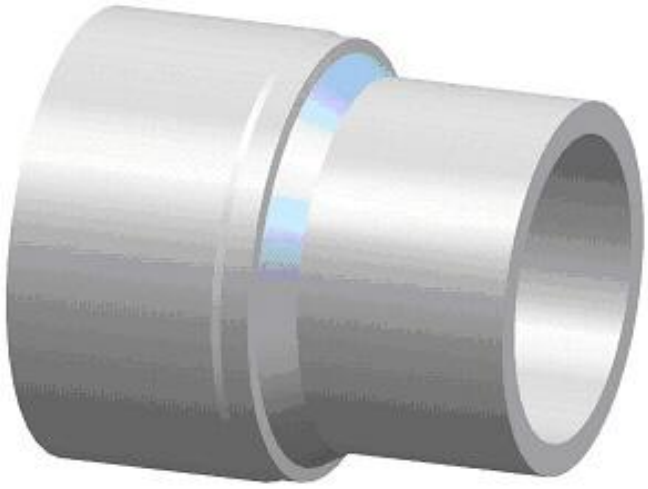
- Why have some of the early installations given great service?
  - The designers, fabricators & installers followed ALL the rules.
  - Operate with conservative design margins (thickness) [AEP & DPL]
  - Operate at ~ 1050F, or lower
  - "Low Bidders" not involved yet

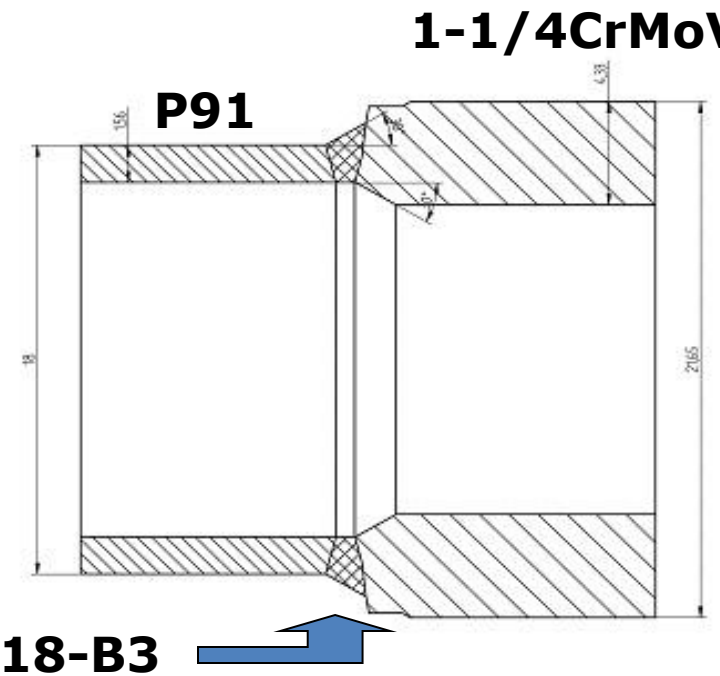
Caution: Dissimilar Welds !



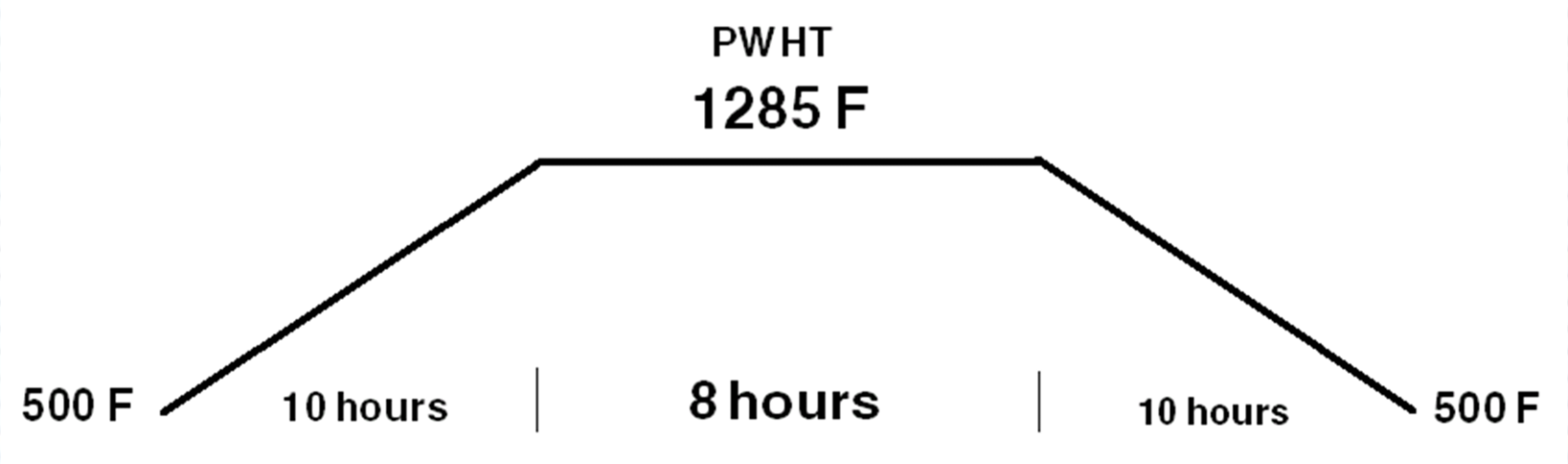
But… Strength Difference isn't the only issue!

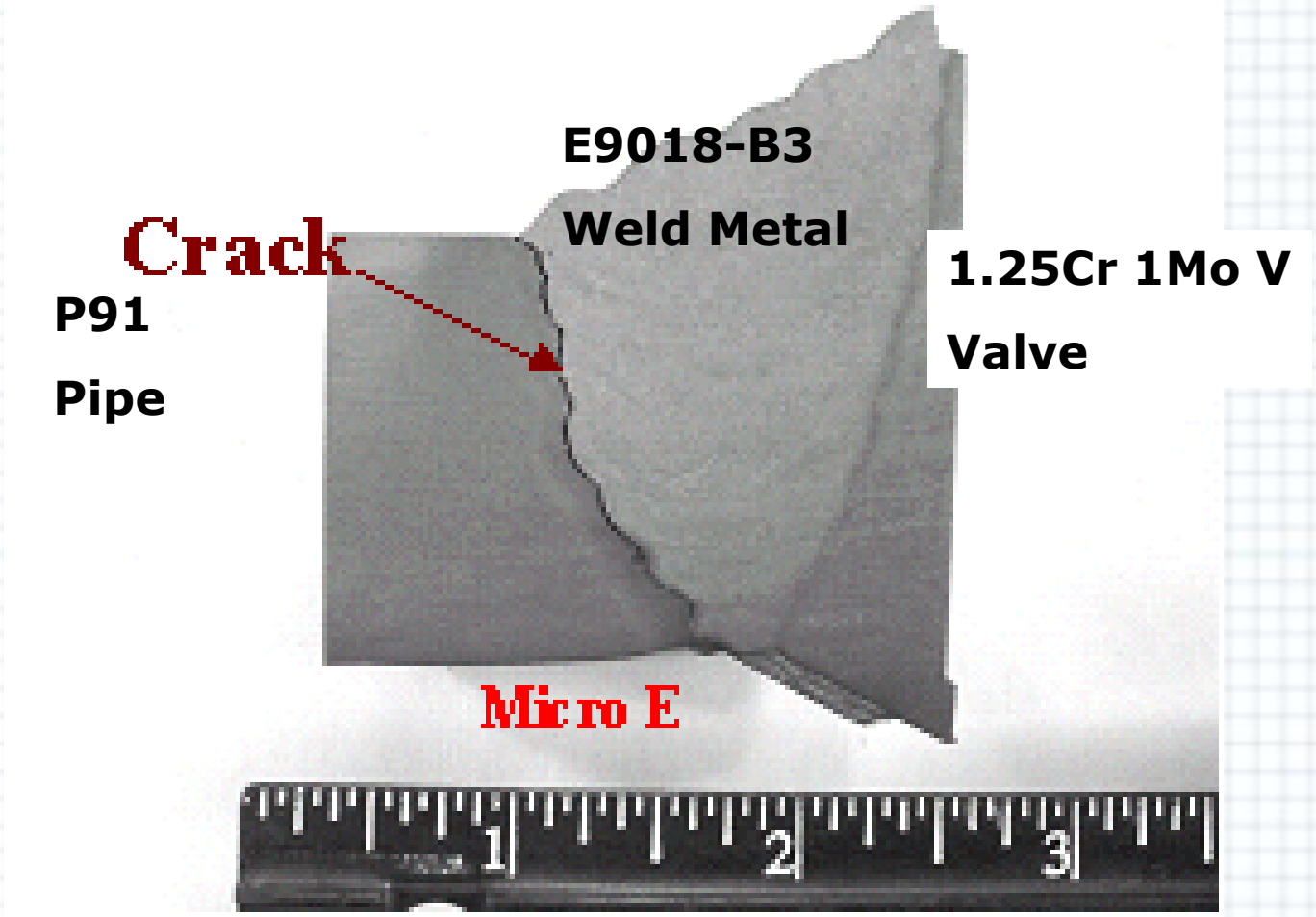
Design



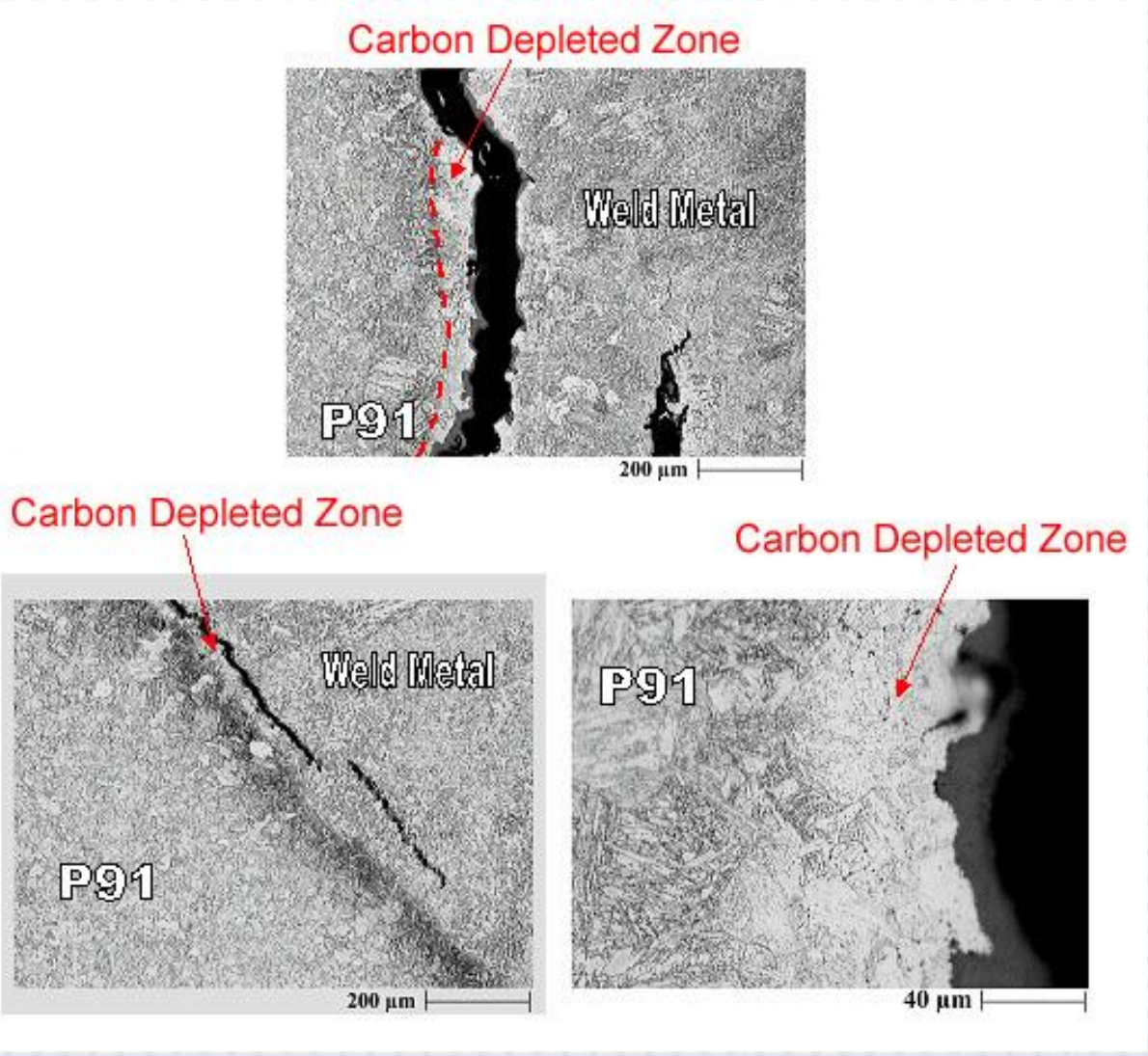


Design




E9018-B3
Weld Metal
Crack
1.25Cr 1Mo V
Valve
P91
Pipe
Micro E
1
2
3

Design & PWHT


Carbon Depleted Zone
Weld Metal
P91
200 µm
Carbon Depleted Zone
Weld Metal
P91
200 µm
Carbon Depleted Zone
P91
40 µm

Preheat & PWHT

- Expect it !
- Plan on it !
- Get a quality vendor !
- Do it !
- No Exceptions !!!!!!!!

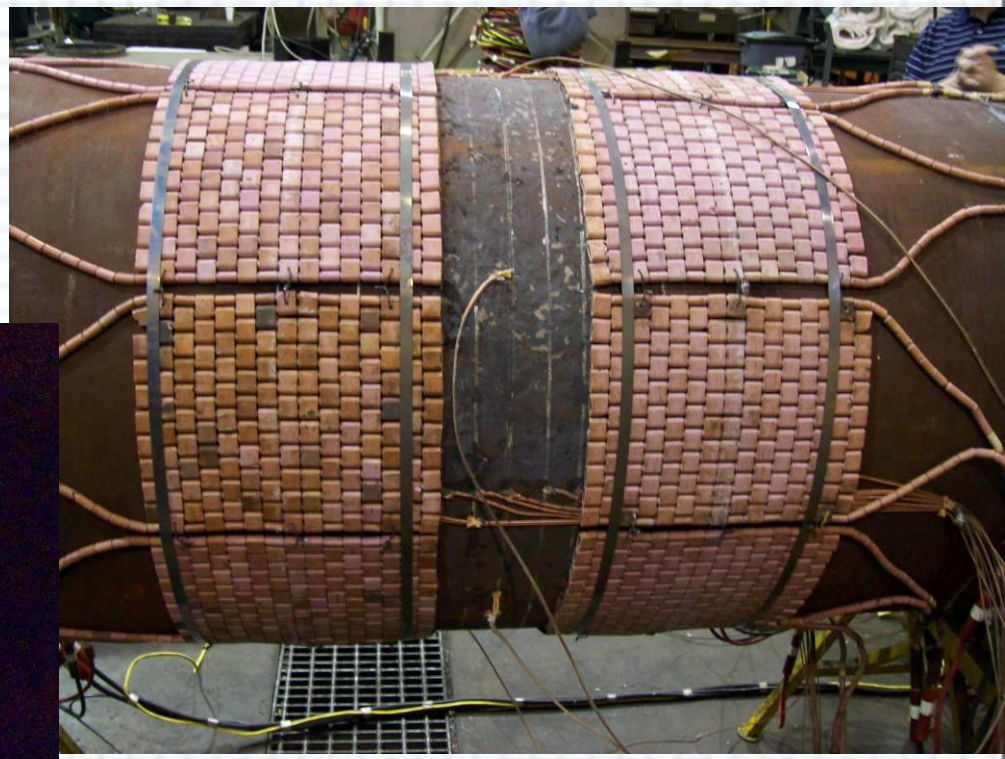
Traditional Preheat

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

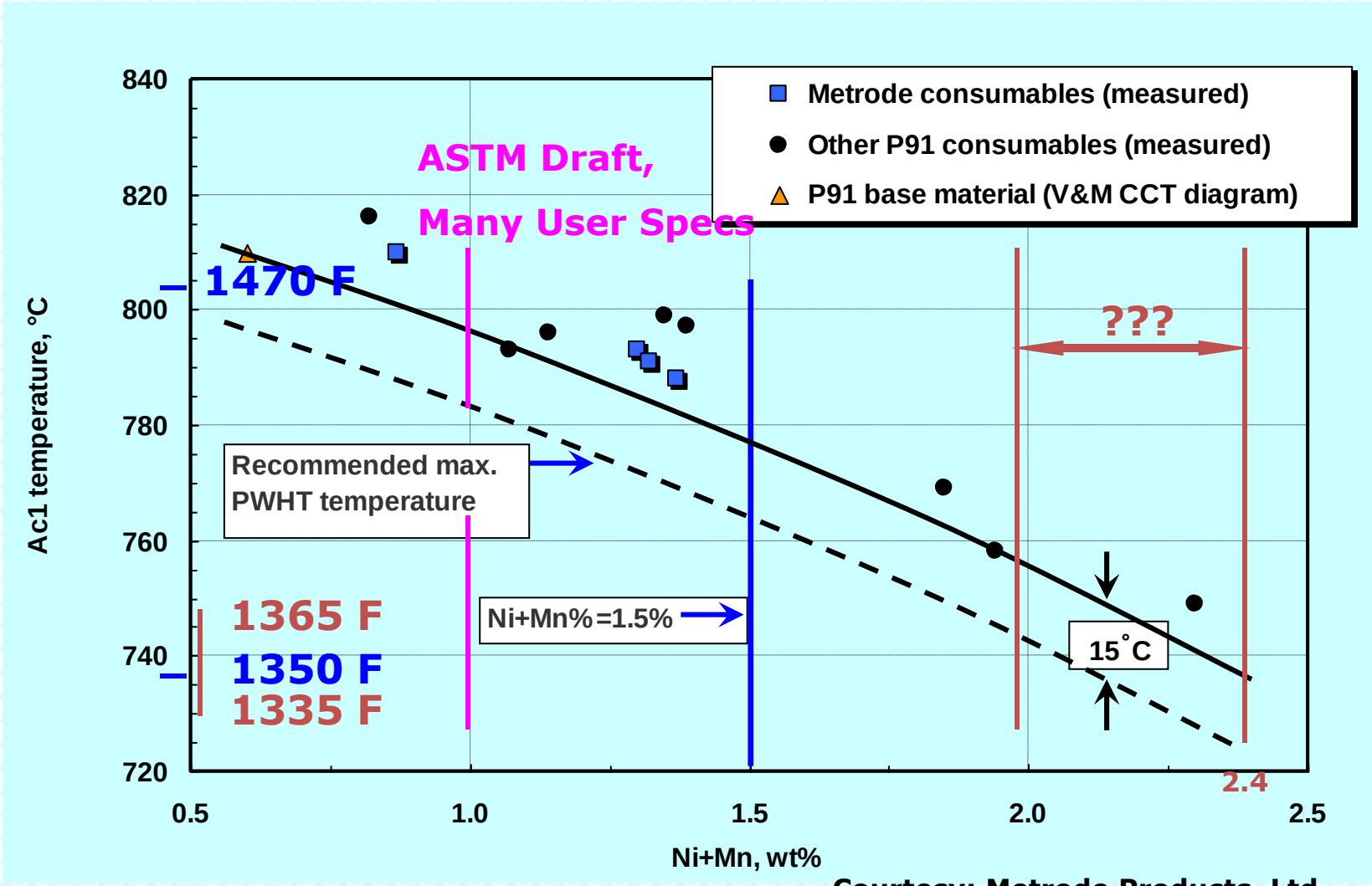
PWHT

- 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



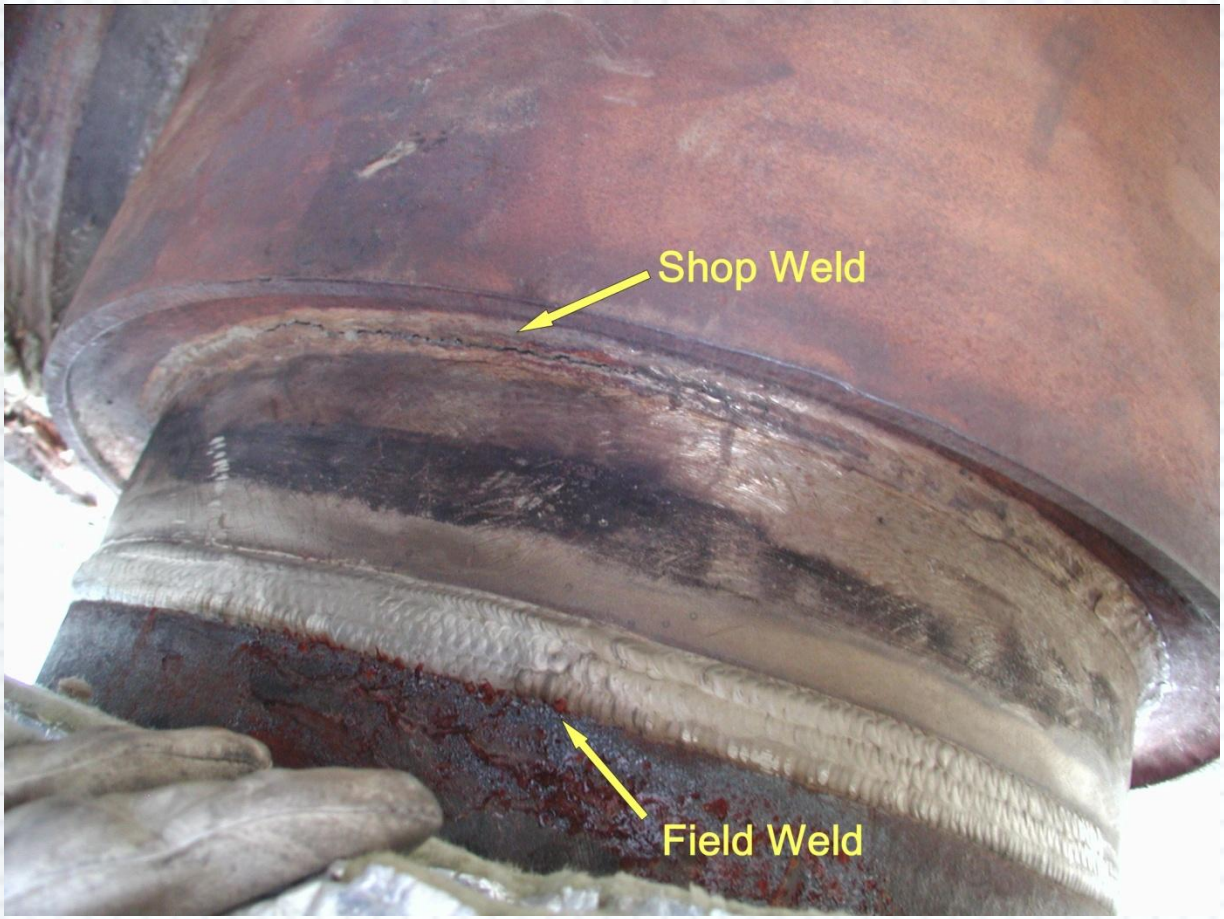
Courtesy: Metrode Products, Ltd.

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

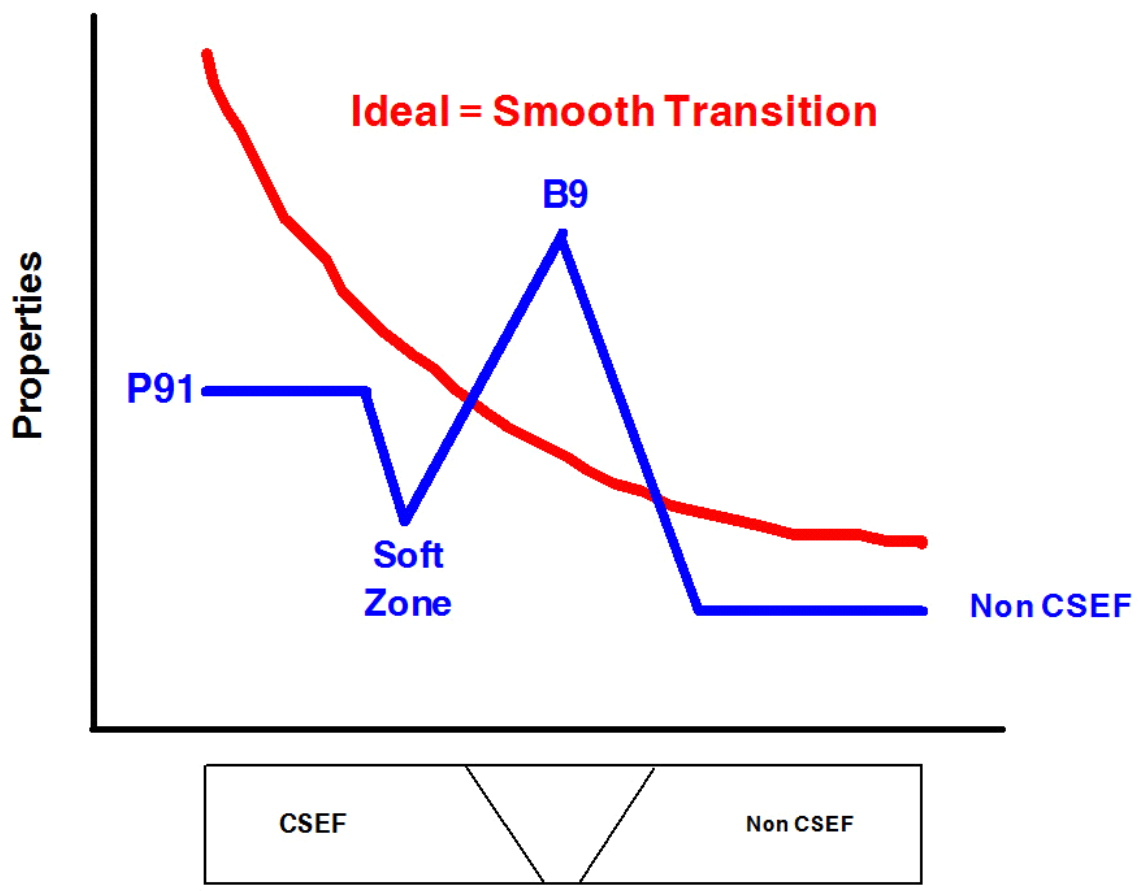


Hi vs. Low PWHT Temperature Practice

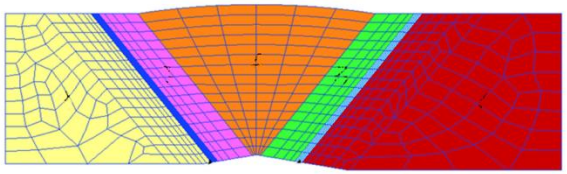
PWHT

- 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
B9
P91
Properties
Soft
Zone
Non CSEF
CSEF
Non CSEF

PWHT Temps (B31.1)



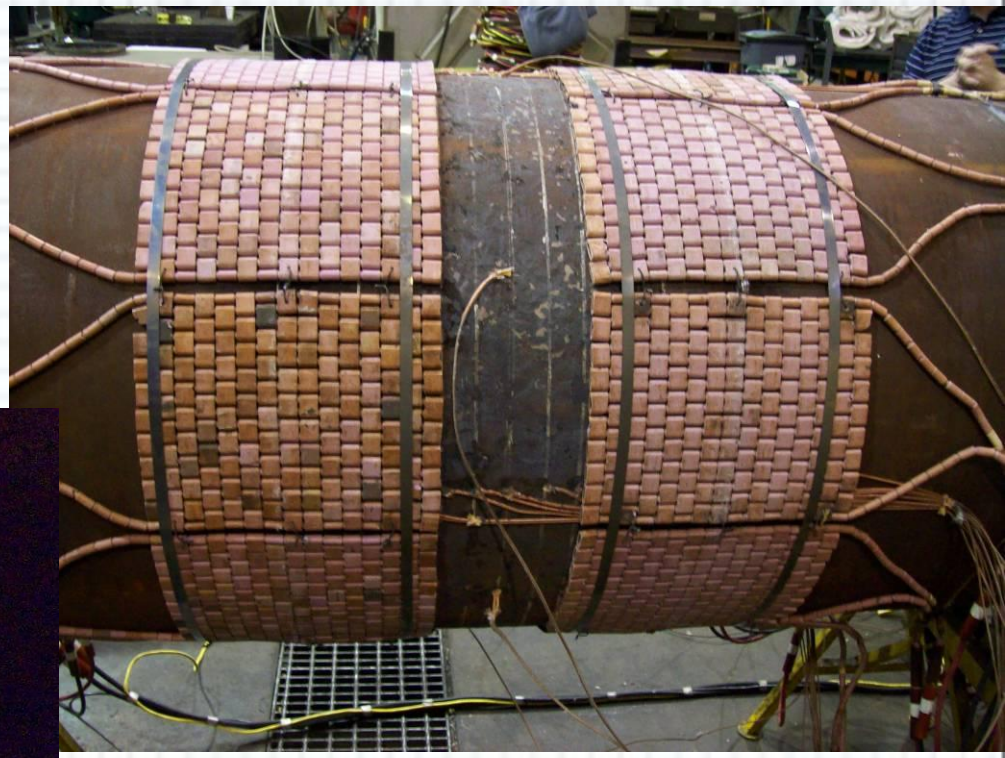
...the other issue.....

ASME P-No.	PWHT Temp, F Ranges	Ac1, F
8		[350]
1	1100 -1200	1340
4	1200 -1300	1430
5 A&B	1300 –1400	1480
15E	1350 -1425	1475

PWHT

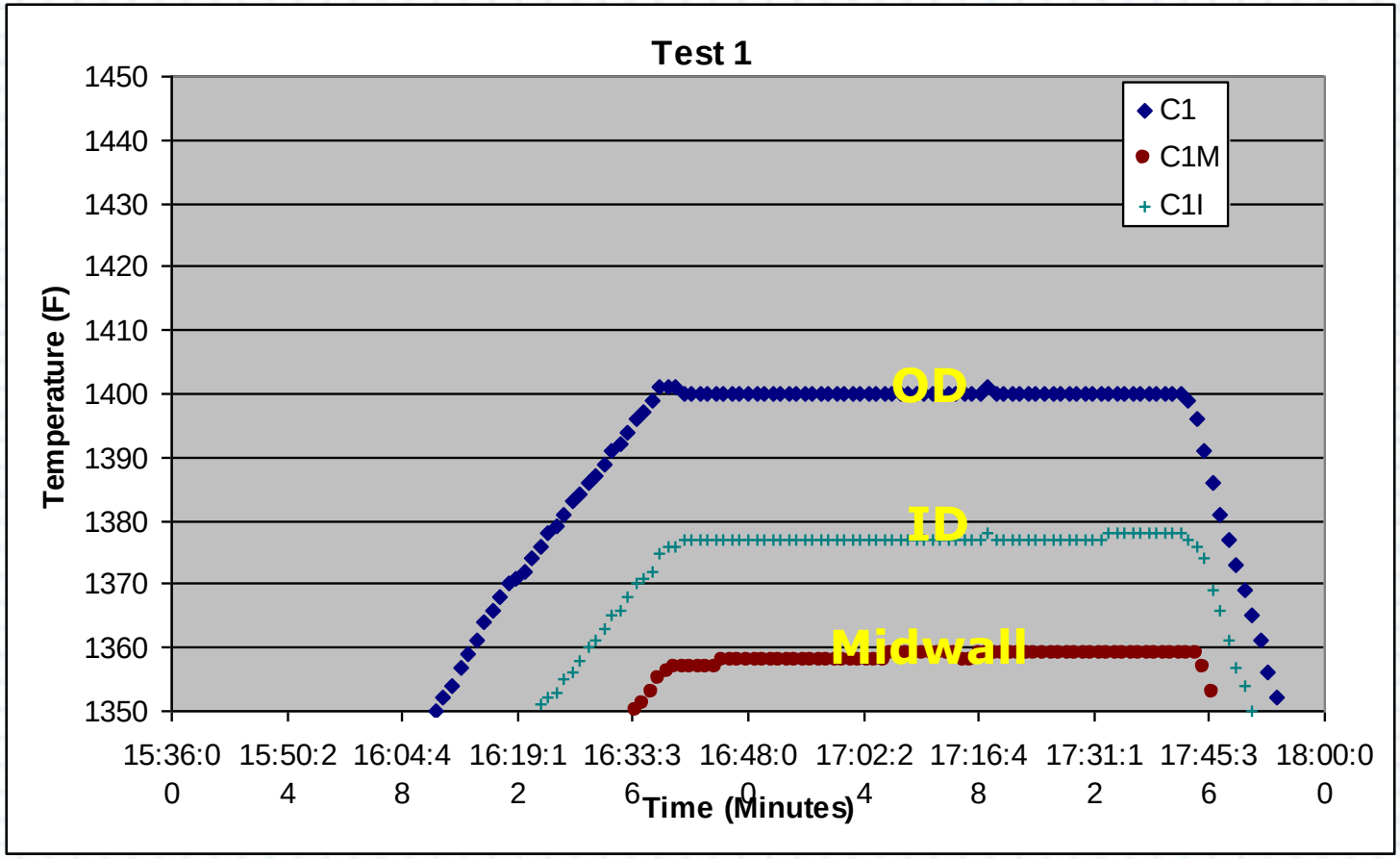
- **Overtempering**
  - Heating below the AC1, but for extended time
  - Will not cause Type IV Failure
  - Not an issue for normal fabrication
- **Intercritical Heating (Between Ac1 & Ac3)**
  - Promotes Type IV Failures
  - Can Degrade P(T)91 to P(T)9
  - Replace material or N&T ENTIRE Component
- **Water flowing in component during PWHT not advisable …**

Preheat ?

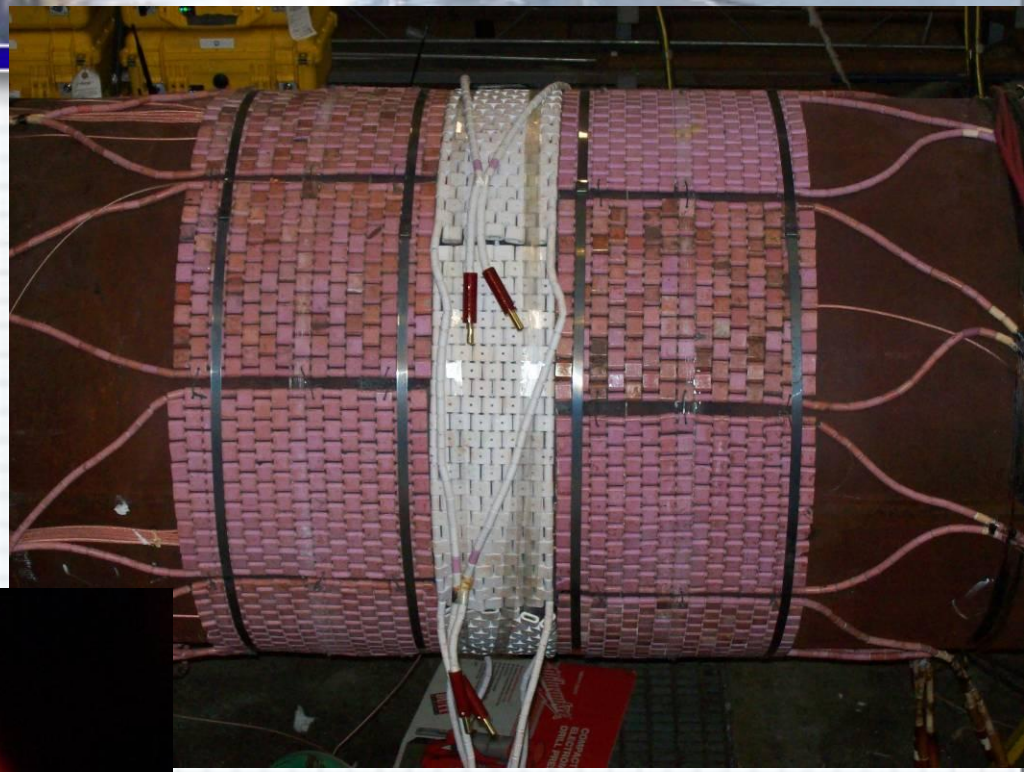


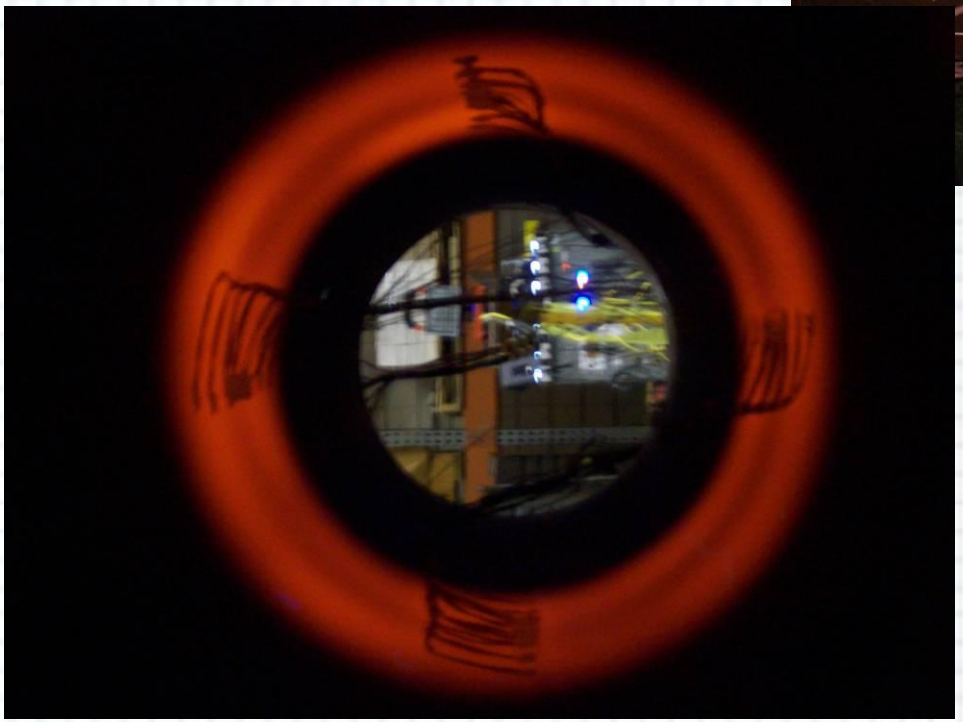
NOT PWHT !

Result of Typical PWHT



Proper PWHT





PWHT Recommendation

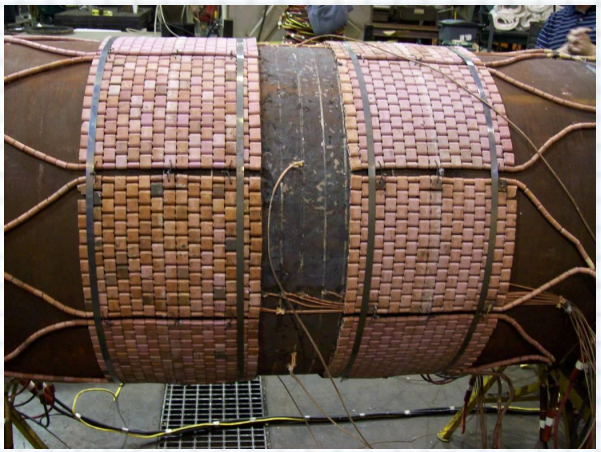
- **American Welding Society D10.10,** ***Recommended Practices for Local Heating of Welds in Piping and Tubing***

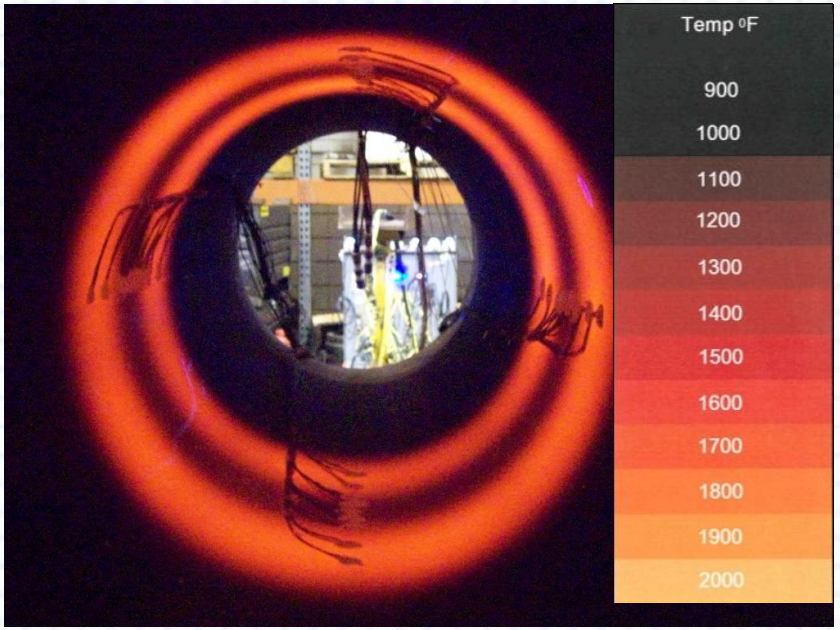
  … FYI …

- **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?