LOCAL POST WELD Heat Treatment for Pressure Vessels & Case history

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Post Weld Heat Treatment (PWHT) is a controlled heat treatment process performed after welding under certain conditions to produce certain desirable changes in its properties. Its primary objectives are tempering, relaxation of residual stress, reduce hardness and hydrogen removal.

Weld residual stresses are the result of internal forces occurring without any external forces when the heating of the weld area relative to the adjacent material experiences restrained thermal expansion. Tensile residual stresses are induced in areas near the weld deposit due to the restraint of the adjacent (colder) base metal.

These residual stresses increase the likelihood for crack initiation and propagation and depending on the process conditions and service environment, may increase the risk of stress corrosion cracking, fatigue cracking, and ultimately brittle fracture.

Most PWHT governing codes recommend that a work piece undergo PWHT in a furnace to ensure that all weldments are uniformly heated to avoid thermally induced stresses. However, codes allow for local PWHT where a local section of a much larger work piece, such as a pressure vessel, is allowed to be heated locally, provided that harmful temperature gradients are avoided.

Key Regions in Local PWHT

The ***three main regions*** utilized in the local PWHT are defined below and illustrated in figure 1 [1]

Soak Band (SB): through-thickness volume of metal that is required to be heated to within the post weld heat treatment temperature range. As a minimum, it shall consist of the weld metal, the HAZ, and a portion of the base metal adjacent to and on each side of the weld being heated.

Heated Band (HB): surface area over which the heat is applied to achieve the required temperature in the soak band. The heated band consists of the soak band width on the outside surface of the component, plus any adjacent base metal necessary to both control the temperature and achieve an acceptable temperature on the inside of the pipe or tube.

Gradient Control Band (GCB): surface area over which insulation or supplementary heat source, or both, may be placed. The gradient control band encompasses the soak band, the heated band, and sufficient adjacent base metal to ensure that harmful temperature gradients are not generated within the heated band.

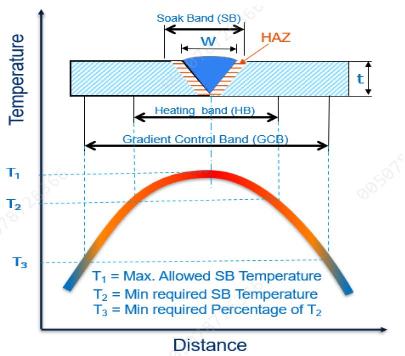

Figure-1: Definition of Terms for Local Circumferential Band Heating of Weld.

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Variability in Local PWHT Standards

Despite general agreement on the principles of local PWHT, significant variations exist across different codes regarding SB, HB, GCB sizing, and holding time/temperature. This can be recognized by comparing the PWHT requirements between different sections of ASME BPVC and ASME B31 piping codes.

If the HB and GCB are not properly calculated and applied, it can lead to inefficient release the residual stresses or possibly distortion of the heated part. The high residual stresses increase the probability of in-service cracking especially for services subjected to environmental cracking (eg. Caustic SCC). In some cases, the application of Finite Elements Analysis (FEA) is required due to the geometrical limitations of the part or the presence of the structural discontinuity in the vicinity of the weld. Figure-2 shows a case of distortion in a vertical vessel resulted from improper application of local PWHT [2].

Figure-2 Distortion in a vertical vessel resulted from improper application of local PWHT [2]

Service Requirements

In certain service environments, failure mechanisms such as alkaline stress corrosion cracking (ASCC) or hydrogen stress cracking (HSC) may be operative. These failure mechanisms can be driven by factors such as residual tensile stress and/or hardened microstructure. As a result, exemption from PWHT based upon thickness is not relevant when such environments are present. Codes generally do not recognize the service environment. Hardness is sometimes used as an index of susceptibility to stress corrosion in certain environments.

When the objective of PWHT is to achieve specific hardness requirements, it is important to recognize that fabrication code minimum temperatures may not be adequate. An example for that is the recommended hold temperature for PWHT in amine and caustic cracking service to be 635 ±15°C (1175 ±25 °F) [13] against 595 °C (1100 °F) in ASME BPVC Sec VIII div.1 for P No.1 materials. Figure-3 Provides graphical representation for Interrelation of the various cracking mechanisms.

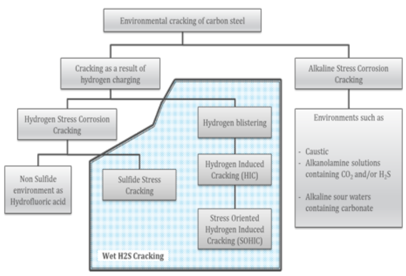

Figure-3 Interrelation of the various cracking mechanisms [13]

Residual Stresses

Welding involves the deposition of molten metal between two essentially cold parent metal faces. As the joint cools the weld metal contracts but is restrained by the cold metal on either side; the residual stress in the joint therefore increases as the temperature falls. The magnitude of these residual stresses can be as high as the yield strength of the weld metal.

To reduce this high level of residual stress, the component is reheated to a sufficiently high temperature. As the temperature is increased the proof strength falls, allowing deformation to occur and residual stress to decrease until an acceptable level is reached. Figure-5 shows change in yield (proof strength) of three common materials.

It is important to note that the threshold residual stress levels in such cases are often less than those required for brittle fracture related concerns, and more detailed requirements may therefore apply. [4]

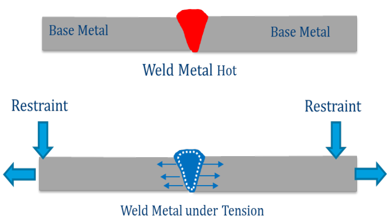

Figure-4 Tensile residual stress during cooling of weld metal

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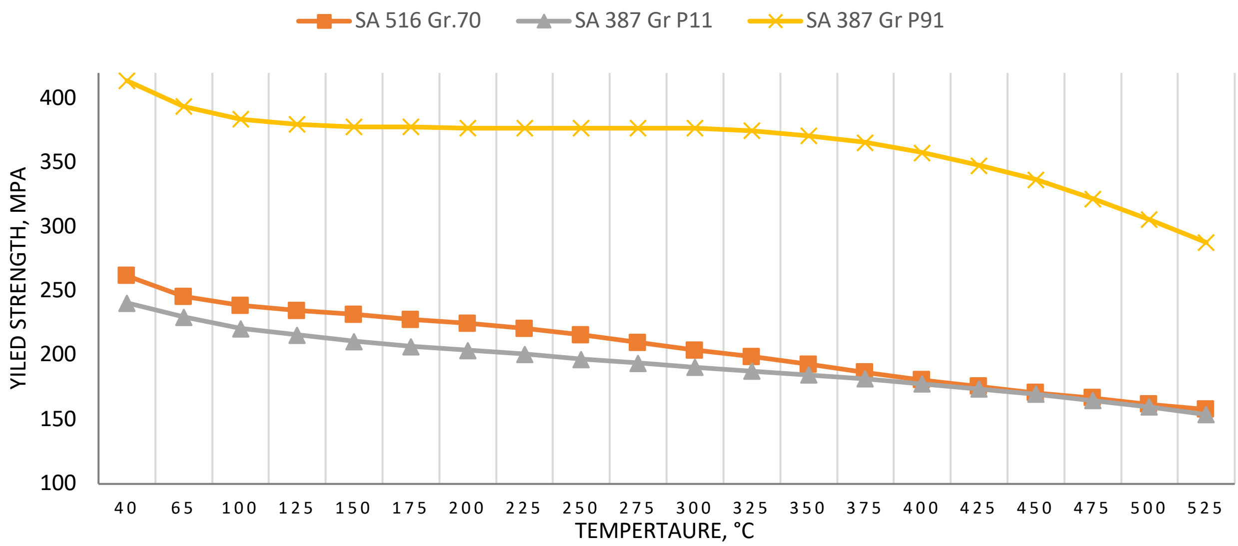

Figure-5 Comparison of yield strength of SA516 Gr. 70, SA387 Gr. P11 and SA387 P91[12]

(SB, HB, GCB) between different codes. While residual stresses can be reduced by application of a PWHT, this option is not always available in the case of Corrosion Resistant Alloys (CRAs). Other methods of controlling residual stresses are the use of alternating or specific weld directions to minimize distortion as well as successive weld layers tempering back the underlying weld.

Design of grooves to reduce weld metal volume, preheating of weld, and assembly procedures with proper restraints can all aid in reducing distortion. [10]

There are differences in the guidelines for the PWHT application between different codes; Table-1 provides comparison between different codes for the requirements of local PWHT bands.

Table-1: Comparison between different codes requirements

Code	SB Size	HB Size	GCB Size
ASME BPVC sec VIII div.1 and 2	t or 2in (50 mm) whichever is less on either side of weld	Temperature gradient is not harmful (no specific guidelines)	Temperature gradient is not harmful (no specific guidelines)
ASME BPVC Sec I	t or 2in (50 mm) whichever is less on either side of weld(1)	Controlled temperature to prevent harmful gradient (no specific guidelines) (1)	Controlled temperature to prevent harmful gradient (no specific guidelines) (1)
ASMP B31P	3t(1)	No specific guidelines (1)	No specific guidelines (1)
WRC 452 and AWS D10.10	Follow ASME BPVC SEC VIII	SB+2$\sqrt{R\,t}$ on either side of the weld (3)	HB+2$\sqrt{R\,t}$ on either side of the weld(3)
PD 5500 and AS 1210 (2)	Weld + HAZ	5$\sqrt{R\,t}$ Centered at the weld (3)	10$\sqrt{R\,t}$ Centered at the weld(3)

Notes:
(1) ASME BPVC Sec I and ASME B31P includes separate appendixes for materials under P no. 15E (e.g. P91 grade)
(2) PD 5500 and AS 1210 referenced from WRC 452.
(3) R is the inside radius, and t is the nominal thickness.

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Impact on Notch Toughness

In certain cases, PWHT may introduce reheat cracking and/or a reduction in notch toughness [7]. the effect of PWHT on notch toughness of weld metals varies widely according to material composition, strength level, flux, heat input, and the target temperature and hold time of PWHT.

Starting from edition 2014 of ASME B31.3, PWHT is no longer a mandatory requirement for any wall thickness provided that multi-pass welding is employed, and a minimum preheat is applied at 95 °C (200 °F) for thicknesses greater than 25 mm (1 inch).

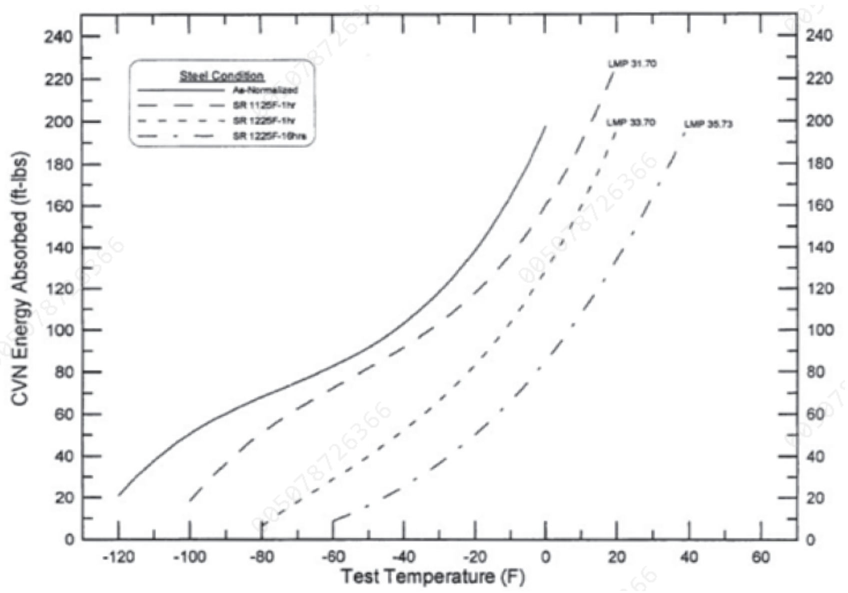

Figure 6: The Effect of PWHT on CVN Energy for SA-516-70 as a Function of Temperature for Different Stress Relief Conditions [11]

Special Consideration for P91 materials and Creep-Strength Enhanced Ferritic (CSEF) Steels

The 9Cr-1Mo-V steel, designated as P91, is a martensitic-type low carbon steel that exhibits enhanced creep and creep-rupture properties that are achieved by a combination of alloy composition and heat treatment. These steels are referenced in Section IX of the ASME Code as creep-strength enhanced ferritic (CSEF) [22].

Specifically developed for service at temperatures where design stresses are limited by the creep and creep-rupture strengths, this steel exhibits poor notch toughness and susceptibility to stress corrosion cracking in the as-welded condition. In addition, the metallurgical characteristics require careful control of welding parameters to minimize hydrogen induced cracking. P91 is only one example of steels that are part of the CSEF steels being promoted for service in the creep range. [7]

CSEF steels including grade P91 has special considerations for the application of PWHT as captured separately in EPRI publications, ASME Sec. I mandatory appendix VIII and ASME B31P non-mandatory appendix B and ASME B31P.

Table-2: Comparison between different codes requirements for CSEF P no. 15E materials

Code	SB Size	HB Size	GCB Size
ASME BPVC sec VIII div.1(1)	t or 2in (50 mm) whichever is less on either side of weld	Temperature gradient is not harmful (no specific guidelines)	Temperature gradient is not harmful (no specific guidelines)
ASME BPVC Sec I Mandatory appendix VIII	- 1.5 t In each side of weld for NPS <= 4in - 6 t In each side of weld for NPS <= 4in - 10 t on each side of weld for NPS > NPS 8 in	SB + on each side	HB + 4t on each side
ASMP B31P	- 1.5 t in each side of weld for NPS <= 4in - 6 t In each side of weld for NPS <= 4in - 10 t on each side of weld for NPS > NPS 8 in	No specific guidelines (1)	No specific guidelines (1)
WRC 452 and AWS D10.10	Follow ASME BPVC SEC VIII	SB+2$\sqrt{R\,t}$ on either side of the weld	HB+2$\sqrt{R\,t}$ on either side of the weld
PD 5500 and AS 1210 (1)	Weld + HAZ	5$\sqrt{R\,t}$ Centered at the weld	10$\sqrt{R\,t}$ Centered at the weld

Notes:
(1) No special size for P no. 15E materials

In addition to the special sizing of SB, HB and CGB provided in ASME BPVC sec I and ASME B31P for P nio.15 E materials, the codes provide special considerations of the composition of the filler metal used in welding. In note (3) of table UCS-56-11 in ASME BPVC sec VIII dvi.1 the percent of Ni + Mn in the filler metal limits the PWHT holding temperature for percent less than 1.0 %, PWHT temperature shall be 790°C and for percent between 1.0 and 1.2, PWHT shall be 780°C and for higher than 1.2%, PWHT temperature shall be 10 °C lower than the lower critical transformation temperature. Similar requirements listed in notes of table PW-39-5 in ASME BPVC Sec I

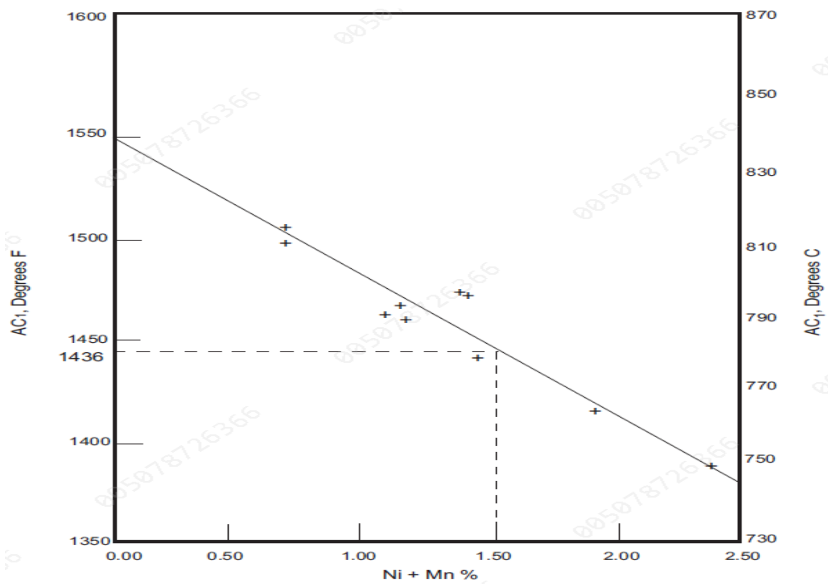

Figure-7: Effect of Ni + Mn on AC1 of P91 weld metal

In Para 131.6 in ASME B31.1, it required to cool the P no. 15E materials below the approximate martensite finish temperature (Mf) before application of PWHT providing the approximate Mf is 190°C for filler material having Ni _ Mn <=1.2 % and 95°C for filler metal having Ni + Mn > 1.2 %. Notice the major impact of the filler wire composition.

An important note in table UCS-56-11, PWHT for P-No.15E materials in ASME BPVC Sec VIII div.1 (note (3) (c) (2)) limited the maximum operating temperature for any vessel constructed using filler metal with Ni + Mn in the excess of 1.2% to maximum 525°C (975°C). Suh comment can be overlooked by designer or manufacturer of the vessel.

The quantity of Ni + Mn affects the Ac1 as shown in Figure 7. In order that PWHT temperature does not exceed the lower critical temperature Ac1, Ni + Mn content is typically limited to provide safeguard against austenite reformation during PWHT. [14]

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CALCULATED EXAMPLE,

assuming steam pipe at outlet of a boiler fabricated from P91 material with size NPS 20 in and 30mm thickness and below the required SB, HB and GCB by different codes and standards as listed in table-3 and figure-8

Table-3: Working example for P91 pipe, NPS 20 in and thickness 30 mm

Code	SB, mm	HB, mm	GCB, mm
AWS D10.10 / WRC 452	90 (1)	418	746
ASME sec VIII div.1	120(1)	Not specified	Not specified
ASME P31P appendix B	300	350	590
ASME BPVC sec I Appendix VIII	600	840	1080

From the example results, notice the big differences between the requirements for different codes for this specific material

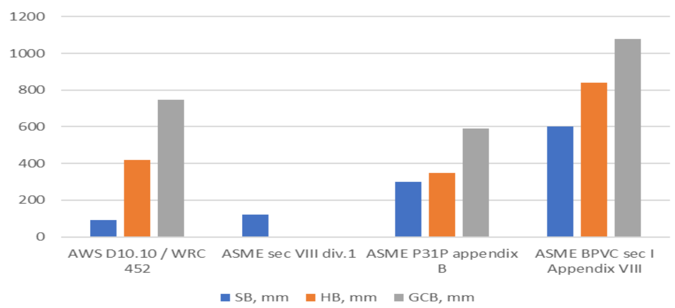
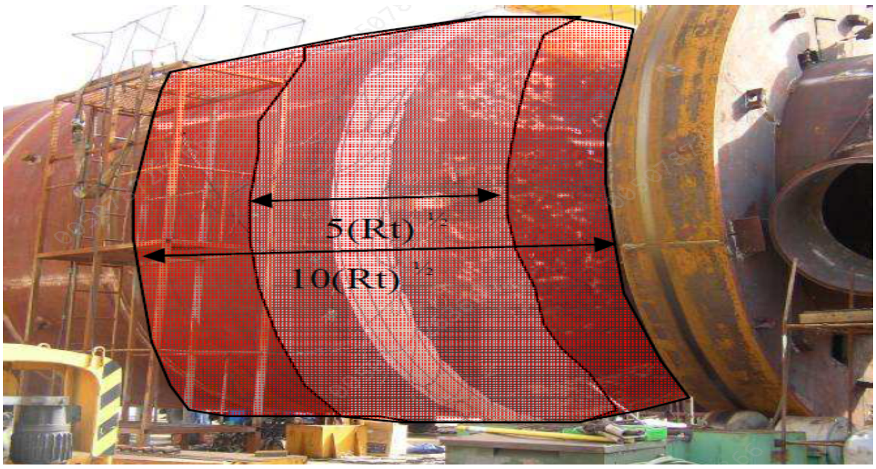


Figure-8: Working example for P91 pipe, NPS 20 in and thickness 30 mm

CASE HISTORY

The photo in figure-9 is for a 90 mm thickness P11 (1.25 Cr- 0.5 Mo) vessel TAKEN during the fabrication local PWHT process of the closure weld. The white band is the insulation applied (GCB) which covers only the soak band while the other imaginary dark red band is the extent of the GCB as it should be per the requirements of BS5500 as identified in WRC 452. That was a result of the misinterpretation and misunderstanding of the local PWHT requirements, especially the design code of the vessel (ASME BPVC sec VIII div.1) do not specify the HB or the GCB size. This weld cracked after few years of operations due to the improper application of the PWHT. [15]



CONCLUSION

Local PWHT is a highly effective stress-relief technique when applied correctly, but its success hinges on precise adherence to code-specific requirements and metallurgical principles. Differences in PWHT criteria across standards necessitate a thorough evaluation to optimize treatment parameters for each application. In critical applications, advanced techniques like FEA can provide valuable insights into optimizing PWHT execution to prevent failures and ensure long-term component integrity.

REFERENCES:

[1] Standard Heat Treatments for Piping, ASME B31P-2023

[2] Establishing Recommended Guidance for Local Post Weld Heat Treatment Configurations Based on Thermal-Mechanical Finite Element Analysis, E2G

[3] Recommended Practices for Local Heating of Welds in Pressure Vessels, WRC 452

[4] Recommended Practices for Local Heating of Welds in Piping and Tubing, AWS D10.10

[5] ASME BPVC Sec VIII div.1

[6] ASME BPVC Sec I

[7] Degradation of Notch Toughness by a Post Weld Heat Treatment (PWHT), ASME STP-PT-033

[8] Repair of Pressure Equipment and Piping

[9] National Board Inspection Code, NBIC

[10] Use of Corrosion Resistant Alloys in Oil Field, NACE TR1F192

[11] Welding Research Council Bulletin 481: The Effect of Post Weld Heat Treatment and Notch Toughness on Welded Joints and on Normalized Base Metal Properties of A516 Steel

[12] ASME BPVC sec II-part D.M

[13] Methods and Controls to Prevent In-Service Environmental Cracking of Carbon Steel Weldments in Corrosive Petroleum Refining Environments, NACE SP0472-2020

[14] Use of 9Cr-1Mo-V (Grade 91) Steel in the Oil Refining Industry, API TR 938-B

[15] Cracking of a Closing Weld in a Secondary Autothermal Reformer in a Mega Methanol Plant, D M Firth, Q Rowson, A Saunders-Tack, C Thomas, K Lichti and J Soltis, Quest Integrity NZL Limited.