Technical Basis to Minimize Post Weld Heat Treatment Requirements

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Technical Update, December 2002

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This document describes research sponsored by EPRI

The publication is a corporate document that should be cited in the literature in the following manner:

Technical Basis to Minimize Post Weld Heat Treatment Requirements—Feasibility Study, EPRI, Charlotte, NC: 2002. 1003291

REPORT SUMMARY

Background

Significant differences in the required post weld heat treatment (PWHT) temperature exist between different sections of the ASME Code. Several of the Codes do not have an upper limit which cal allow possible material degradation if the lower critical temperature of the material is exceeded. This project developed recommended PWHT temperatures for low alloy steels based on the materials and not where they are installed in the power plant.

Objectives

- Develop suggested PWHT temperatures based on materials properties.
- Support changes to the various ASME Code sections to make the required PWHT temperatures more consistent.

Approach

Material PWHT requirements were developed during a program sponsored by the Repair and Replacement Applications Center (RRAC) in 2000. A contractor was hired to perform a literature review of current PWHT practices. A white paper was then presented at the ASME B31.1 and ASME Boiler Code Week to support changes to the piping and pressure vessel codes.

Results

The required PWHT temperature for materials containing 1 ½ Cr in ASME B31.1 was lowered to a range of 1200F to 1300F. This change protects the material from potential damage resulting from PWHT in the intercritical range. Time and labor saving will also be realized during construction and repair operations by lowering the required minimum PWHT temperature

EPRI Perspective

Within the ASME Code, each section of the Code requires different PWHT for the same material. B31.1 allows PWHT temperatures as high as the lower critical of 1-¼ Cr materials. Heat treatment at temperatures this high could severely degrade the material resulting in less than desired life. The extra time required to heat the material above the temperature to provide relief of stresses and increases in weld metal toughness can extend outages and result in extra costs for the utility.

ACKNOWLEDGEMENTS

The work presented in this report was performed by Phil Flenner, Flenner Engineering Services, Kalamazoo, Mi. The author would like to recognize Phil for his help in pushing changes through B31.1 to bring the required PWHT temperature of P-No. 4 materials closer to the other book sections.

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SUMMARY

Significant differences in the Postweld Heat Treatment (PWHT) temperatures exist between several Codes that are commonly used in Fossil and Nuclear Power Plants. One of the most significant differences occurs for P No. 4 materials where B31.1 and B31.3 require PWHT in a target range of 1300-1375°F but Section I and Section VIII only specify a minimum temperature of 1100°F. The conclusion of this report is that neither of the requirements is technically justified. The required PWHT temperature should be expressed as a range rather than just a minimum and the minimum temperature specified should not be lower than 1200°F. The recommendation therefore is that the PWHT temperature range for P No. 4 materials should be 1200-1300°F

Background

The Repair and Replacement Applications Center (RRAC) of the Electric Power Research Institute (EPRI) recommended that B31.1 and B31.3 should lower the Postweld Heat Treatment (PWHT) temperature range for P No. 4 materials[1]. This paper is intended to support that change within the B31.1 and B31.3 Codes but it may also be used to support changes in various Boiler and Pressure Vessel Code Sections.

Current Code Requirements

The various codes that are required to be used in the power and process industries have a significant variation in the rules for PWHT. In some cases, these variations may be justified based on service conditions addressed by the applicable code. Minor variations are not generally a safety concern but may be an economic issue. Real concerns result when requirements seem to be marginal from a technical standpoint. The following addresses such an area where the current code requirements are marginal from a technical standpoint. This is the PWHT temperature requirement for P No. 4 materials.

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[1] Coleman, K., Gandy, D., and Hudgins, G., Consistent Post Weld Heat Treatment Between Code Sections, EPRI RRAC Interim Report 1001297, December 2000, Pp.2-3,4 and 3-1.

B31.1 - Power Piping Code

For P No. 4 materials (nominally 1-1 ¼ Cr Mo materials), Table 132 of the B31.1 Code for Power Piping requires the weld to be heated to a temperature within the range of 1300-1375°F for a period of time dependent on the thickness of the component. There are exemptions that could apply. The B31.1 Code does allow the temperature range to be modified. On the lower end of the temperature range, Paragraph 132.1 and Table 132.1 allows PWHT to be performed at a temperature of as much as 100°F less than 1300°F but with a significantly extended heat treatment time. Paragraph 132.2(A) of B31.1 allows the upper temperature limit to be modified up to the lower critical temperature (although the current upper temperature limit is already at or near the lower critical temperature for the P No. 4 materials). The approximate lower critical temperatures for the two P No. 4 materials listed in Table 129.3.2 are 1375 °F and 1430 °F.

A study[2] of the origin of the current PWHT temperature range for P No. 4 materials in B31.1, which was done for the ASME Task Group on PWHT, was inconclusive. It was noted that the ASA B31.1-1955 Code Edition listed the minimum PWHT temperature for "ferritic alloy steels" as 1200°F. The USAS B31.1.0-1967 Code listed the PWHT temperature range as 1300-1400°F. The ANSI B31.1-1973 Code contained different requirements for PWHT of Boiler External Piping (BEP) and Non-Boiler External Piping (NBEP) due to the transfer of the technical requirements for BEP into B31.1 from ASME Section I. The BEP PWHT requirement was 1100°F minimum (as it is currently in ASME Section I). The NBEP PWHT temperature requirement remained 1300-1400°F (although errata had stated the minimum temperature to be 1330°F). The winter 1978 Addenda to ANSI B31.1-1977 combined the requirements for BEP and NBEP with the result that the PWHT temperature range for P No. 4 materials was established at the current requirement of 1300-1375°F.

B31.3 – Process Piping Code

The B31.3 Code for Process Piping, Table 331.1.1, has the same PWHT temperature range for P No. 4 materials as B31.1, 1300-1375°F. There are also similar exemptions which could apply.

[2] Flenner, P., B31.1 PWHT Temperature Requirements for P No. 4 Materials, Letter to ASME BPTCS Task Group on PWHT, April 30, 1997.

Section I – Power Boilers

ASME Section I, Power Boilers, Table PW-39, only specifies a minimum temperature of 1100°F for required PWHT of P No. 4 materials. Again there are similar exemptions but there are also additional exemptions dependent on the type of weld being made.

The PWHT temperature requirement appears to have been an original recommendation of a Section I Task Force chaired by R.C.Fitzgerald in 1956[3]. This report recommended the basic requirements that exist today but without the additional exemptions based on the type of weld being made. The report however, referenced a report by J.C. Souder[4] which recommended a higher minimum PWHT temperature of 1200°F for P No. 4 materials. The Fitzgerald letter only stated that the recommendations were "more representative of the thinking and practices of the large Boiler manufacturers than were the Souder recommendations."

Section VIII, Div 1 – Pressure Vessels

ASME Section VIII, Div. 1, Pressure Vessels, Table UCS-56, is very similar to Section I in that the same minimum temperature of 1100°F for required PWHT of P No. 4 materials is specified. In addition, the exemptions allowed are also similar to Section I although not as inclusive.

Lundin and Khan[5] determined that some heats of the P No. 4 material have an increased susceptibility to reheat cracking if the PWHT temperature is not high enough. Their recommendation was that the PWHT temperature should exceed 1300°F. This recommendation was further refined by Prof. Lundin[6] to use PWHT temperatures of 1250-1325°F minimum dependent on the carbon content and the existence of tramp

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[3] Fitzgerald, R.C., Taskforce Report – Preheat and Postheat Requirements, Section I, Letter to H.E.Aldrich, November 20, 1956.

[4] Souder, J.C., Minutes of Task Group Meeting of November 2, 1955, Letter to Members of ASME Task Group on Correlation of Stress Relief, Radiographic and Welding Requirements for Ferritic Alloy Materials, November 25, 1955.

[5] Lundin, C.D. and Khan, K.K., Fundamental Studies of the Metallurgical Causes and Mitigation of Reheat Cracking in 1¼Cr – ½Mo and 2¼Cr – 1Mo Steels, Welding Research Council Bulletin 409, February 1996, P. 114.

[6] Lundin, C.D., Avoiding Reheat Cracking, Paper Presented at WRC Conference "*Welding – Do It Right The First Time*", New Orleans, LA, March 11-13, 2002.

elements such as sulfur and aluminum. McEnerney[7] suggested that the minimum PWHT temperature for P No. 4 materials should be raised to 1200°F in ASME Section VIII, Pressure Vessels. This recommendation was made in part because the CEN Code uses a PWHT range of 1166-1256°F and in part because of the findings of Lundin and Khan (Ref. 6).

Results of Available Tests

The following graph was provided within the EPRI Report (Ref. 1) and shows the effects of PWHT at different temperatures. The P No. 4 material was quenched in preparation for the PWHT. The as-received material had a hardness of 79 R_b[8].

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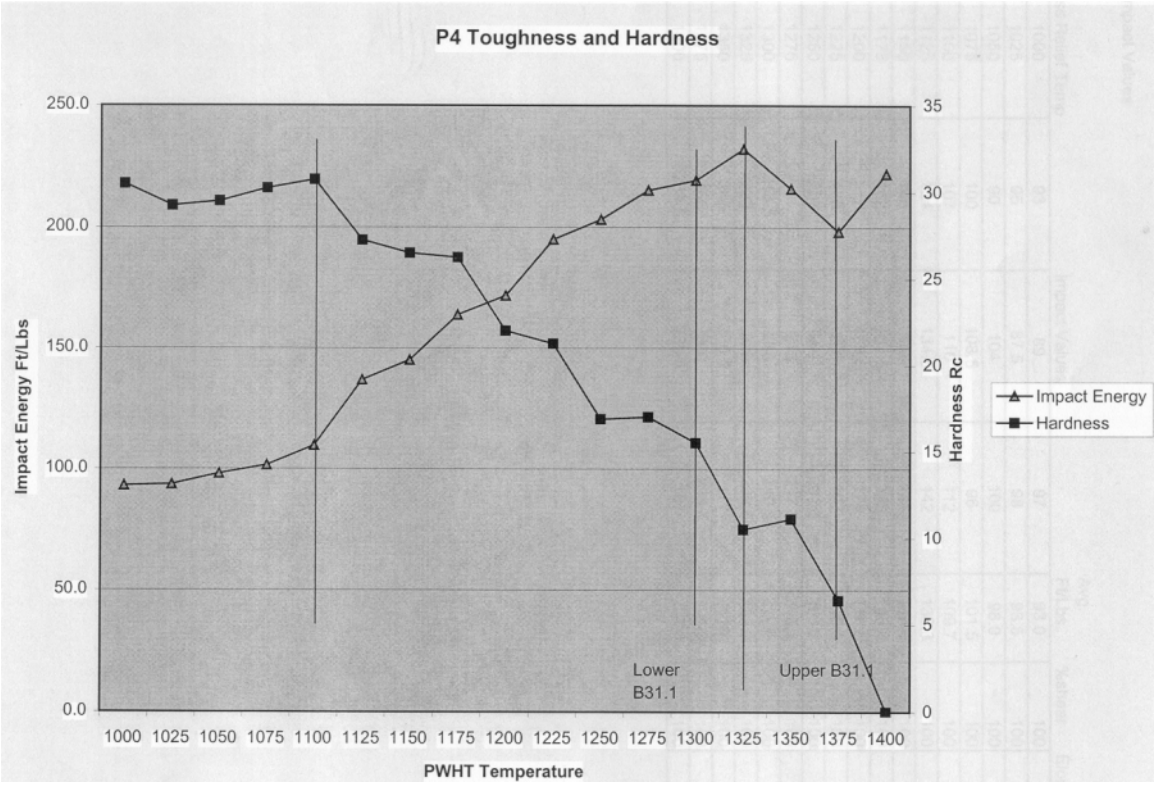
[7] McEnerney, J.W., BC 96-248 (Subcommittee VIII Action Item Concerning PWHT), Letter to VIII SG F&I Members, November 11, 1997.

[8] Coleman, K., Grewe, J., Consistent Application of PWHT Between Code Sections (Task 89), Presentation to RRAC Subscribers Meeting, June 14-15, 2001.


P4 Toughness and Hardness
Impact Energy Ft/Lbs
Hardness Rc
PWHT Temperature
250.0
200.0
150.0
100.0
50.0
0.0
35
30
25
20
15
10
5
0
1000 1025 1050 1075 1100 1125 1150 1175 1200 1225 1250 1275 1300 1325 1350 1375 1400
Lower B31.1
Upper B31.1
Impact Energy
Hardness

Technical Review

EPRI sponsored testing on P No. 4 materials (Ref. 1) has shown that these materials exhibit a rapid change in the hardness and impact properties in the range required by the ASME B31.1 Code for Power Piping. These changes have been attributed to exceeding the material lower critical temperature. The tests showed the effects of PWHT at different temperatures on quenched base metal specimens. The hardness and toughness values were reasonably consistent with heat treatment up to 1100°F. With heat treatments above that temperature, the hardness values steadily decreased and the toughness values increased until a heat treatment temperature of 1325°F was reached. At that temperature the toughness values began to drop and the hardness values dropped more rapidly.

Another argument presented in the EPRI Report (Ref. 1) is the difficulty in doing a PWHT on dissimilar material joints (e.g., between P No. 1 or P No. 3 and P No. 4). This argument was based on the fact that the lower critical temperatures of the lower P No. materials are quite close to the required B31.1 and B31.3 minimum PWHT temperature for the P No. 4 material. If the PWHT minimum temperature could be established below the current value in B31.1 and B31.3, additional margin would be obtained.

The EPRI sponsored report (Ref.1) suggested that the B31.1 and B31.3 minimum PWHT temperature could be reduced to 1100°F to match the minimum PWHT temperature in Section I. The report by Lundin and Khan (Ref. 5) does not support the lower temperature PWHT however, due to potential reheat cracking. In addition, while the evidence exists that the PWHT at 1100°F does begin to affect the properties of the P No. 4 material, the change at this low temperature was insignificant. If the hardness is compared between the base metal (as-received) prior to quenching (79 R_b) and the hardness after quenching followed by PWHT at 1100°F (~30 R_c), it would appear that there remains a significant strength difference after the PWHT. In a weld, this strength difference would show up as a rapid change in hardness and strength as the weld and the HAZ are traversed. While some reduction in residual stresses could be expected at 1100°F, there does not seem to be much tempering to provide more ductility in the material. The low PWHT temperature of 1100°F therefore does not appear to be adequate unless there is some significant high temperature operation that would effectively continue to temper the weld area.

Given the evidence shown by the EPRI tests (Ref. 1) and Lundin and Khan (Ref. 5), the PWHT minimum temperature of 1100°F is unreasonably low while the minimum temperature of 1300°F is high, particularly when considering the proximity of the lower critical temperature to the maximum PWHT temperature (1375°F) contained in B31.1 and B31.3. Souder (Ref. 4) and McEnerney (Ref. 6) both suggested a minimum temperature of 1200°F for Section I and Section VIII, respectively. This appears to be a practical solution. A PWHT at 1200°F minimum would yield significant changes in the properties (increase in toughness and reduction of hardness) of the P No. 4 material.

The maximum PWHT temperature should allow for heat treatments high enough to avoid reheat cracking in susceptible P No. 4 materials. The EPRI Report (Ref. 1) recommended a maximum temperature of 1325°F. However, the B31.1 and B31.3 Codes generally limit the PWHT temperature ranges to 100°F (an exception occurs for P No. 3 material in B31.3) to provide a tighter target temperature for the user. Since the B31.1 Code already allows the maximum PWHT temperature to be above the stated maximum in Para. 132.2(A) (up to the lower critical temperature), it seems reasonable to maintain the 100°F range.

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CONCLUSIONS

The PWHT temperature range for P No. 4 materials should be modified to 1200-1300°F in all of the ASME Codes referenced in this report. However, the specific target of this report was the B31.1 Code for Power Piping. This report may be used to support the proposed change to the B31.1 Code via Tentative Revision No. TR 01-18. The report may also be used to support similar changes in the other Codes (B31.3, Section I, and Section VIII).

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RECOMMENDATIONS

The PWHT temperature range should be 1200-1300°F. The suggested change for B31.1 should be:

Current B31.1 Code, Table 132, P No. 4:

P-Number From Appendix A	Holding Temperature Range, °F(°C)	Holding Time Based on Nominal Thickness	
		Up to 2 in. (50 mm)	Over 2 in. (50 mm)
P-No. 4 Gr. Nos. 1,2	1300 (700) to 1375 (750)	1 hr/in. (25 mm) 15 min minimum	2 hr plus 15 min for each additional inch over 2 in. (50 mm)

Proposed B31.1 Code, Table 132, P No. 4:

P-Number From Appendix A	Holding Temperature Range, °F(°C)	Holding Time Based on Nominal Thickness	
		Up to 2 in. (50 mm)	Over 2 in. (50 mm)
P-No. 4 Gr. Nos. 1,2	1200 (650) to 1300 (700)	1 hr/in. (25 mm) 15 min minimum	2 hr plus 15 min for each additional inch over 2 in. (50 mm)

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