# Welding and Repair Technology Center: Temperbead Welding Guidance

2011 TECHNICAL REPORT

# Welding and Repair Technology Center: Temperbead Welding Guidance

EPRI Project Manager
D. Couch

ELECTRIC POWER RESEARCH INSTITUTE

3420 Hillview Avenue
Palo Alto, CA 94304-1338
USA

PO Box 10412
Palo Alto, CA 94303-0813
USA

800.313.3774
650.855.2121

askepri@epri.com

www.epri.com

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THE FOLLOWING ORGANIZATION, UNDER CONTRACT TO EPRI, PREPARED THIS REPORT:

**Flenner Engineering Services, LLC**

**NOTE**

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

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The following organization, under contract to the Electric Power Research Institute (EPRI), prepared this report:

Flenner Engineering Services, LLC
6537 Wyndham Drive
Kalamazoo, MI 49009

Principal Investigator
P. Flenner

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# Product Description

The Welding and Repair Technology Center is an industry leader in providing technical input and ASME Code Committee support in advancing the use of the temperbead welding techniques in order to eliminate the need for post-weld heat treatment (PWHT) of carbon and low-alloy materials. Most current ASME codes require PWHT for new construction welds once a specified thickness is reached. Some ASME construction codes allow limited temperbead techniques to be used on repair welds when the PWHT has already been performed. However, the use of this technique is not consistent across the codes. PWHT is an expensive and time-consuming operation, particularly for repair welds for which the schedule is a factor. This guideline presents a consistent approach to the development, qualification, and implementation of the temperbead welding technique. The underlying goal in presenting such an approach is to advance the appropriate use of the temperbead welding techniques in the future. The guideline is intended to address nuclear applications primarily but may be used in other applications where applicable.

## Results and Findings

This guideline combines the various code requirements and applications to the implementation practices of utilities that have used the temperbead welding technique. Current limitations of the codes, and potential future uses and efforts to minimize unnecessary but currently required PWHT, are discussed. The best-practice approach to the development, qualification, and implementation of the temperbead welding technique is discussed and an outline of the steps needed is provided.

## Challenges and Objectives

The objective of this project is to develop a single source document usable by both by new and experienced engineering staff involved in the development and implementation of temperbead welding for nuclear site applications. The guide provides detailed information on temperbead welding, how it works, the technical objectives, the use of power ratios, the consistent layer approach, the importance of process controls, and so on. The guide addresses appropriate codes and regulatory issues; qualification requirements based on applications; the development of welding procedures; craft training; testing and nondestructive evaluation; the selection and use of filler metals, and other key topics.

## Application, Value, and Use

Welding and Repair Technology Center members and key ASME code experts are actively engaged in initiatives to address the welding requirements (particularly the PWHT rules and requirements) in the various ASME codes used in the power generation industry. The results and data in this report will be used to support these initiatives as the temperbead alternative to PWHT becomes more accepted.

## Approach

The intent of this project is to provide the guidance needed by the industry to enable a consistent approach to the application of temperbead welding techniques. EPRI—particularly through the Welding and Repair Technology Center—is in a unique position to work with utility representatives and industry experts to identify and promote techniques such as temperbead welding and provide a foundation of technical support.


## Keywords

Post-weld heat treatment (PWHT)
Temperbead
Welding
Carbon steel
Low-alloy steels

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# Section 1: Introduction

## 1.1 Background

The EPRI Welding Repair Technology Center (formerly known as the Repair and Replacement Applications Center) has promoted the use of the temperbead welding techniques as an alternative to PWHTs for nuclear repair for a number of years. Welding and Repair Technology Center members and key ASME Code experts are intimately involved in the ASME Codes supporting this effort. There have been numerous sponsorships of Technical Reports supporting ASME Code Cases and Code revisions permitting this application. They have also sponsored a revision to ASME Section IX, *Welding and Brazing Qualification*, which is now being used widely to support the qualification of welding procedure specifications (WPS) used for the temperbead welding techniques.

## 1.2 Application

This guidance provides a source document for the use of temperbead welding technique as an alternative to PWHT. It may be used whenever temperbead welding techniques are being considered by EPRI members or by construction or repair/replacement organizations. The intent is to provide consistency in how the technique is to be implemented, including the justification for use, limitations needed, process qualification, implementation, and inspection.

# Section 2: Use in Applicable Codes and Standards

## 2.1 ASME Code Applications

The ASME Codes currently permit application of the temperbead welding techniques within several Codes applicable to power plants, particularly as the need occurs for repair applications in nuclear plants. This is more prevalent in nuclear plants due to repair applications where PWHT is difficult or impossible due to restrictions in operation or access. However, there are also many applications in fossil power plants permitted for repair after PWHT. With the exception of the repair or replacement applications of ASME Section XI, these applications are targeted at new construction welds.

A number of EPRI reports have been issued to justify ASME Code changes and Code Cases needed to allow the temperbead technique (including other similar controlled deposition techniques). There are also reports that have been sponsored by the ASME to determine a potential detrimental effect of PWHT on carbon and low alloy steels. This information is discussed in Section 4. The ASME Codes, including the Boiler & Pressure Vessel Codes and the B31 Pressure Piping Codes, are therefore evolving toward the acceptance of the temperbead techniques as an alternative to PWHT.

### *2.1.1 ASME Section I, Power Boilers*

The 2010 edition of ASME Section I, Power Boilers, allows minor repair to tube-to-header of tube-to-drum joints of materials included in P Nos. 1, 3 (Groups 1 & 2), 4, and 5A. This does not require the use of the temperbead techniques but is instead limited to the tube size (4 in. (100 mm) OD except for P No. 1 which allows up to 6⅝ in.(170 mm) OD) and the depth of the repair (10% of the drum or header or 50% of the tube). However, Section I does also allow the repair after a PWHT of any joint between P No. 3 (Groups 1 & 2) materials or to these materials using a controlled deposition process and elevated preheat. The depth of the repair is limited to 10% of the thickness of the material. No specific mention is made of requiring qualification in accordance with ASME Section IX, QW-290 where the half bead technique is covered within the temperbead qualification requirements. A hydrogen bakeout heat treatment is specified after the weld is complete for materials greater than 1 in. thickness.

### 2.1.2 ASME Section III, Nuclear Power Plant Components

The 2010 edition of ASME Section III, Subsection NB and Subsections NC and ND have different requirements regarding the use of special welding techniques which allow exemption of PWHT.

Subsection NB Para. NB-4622.9 allows the exemption of PWHT to P Nos. 1 & 3 materials and welds provided the temperbead qualification is done per the requirements of ASME Section IX, QW-290. However this is limited to repairs after the final PWHT, an area not exceeding 500 $in.^2$(3230 $cm^2$), and a depth of the repair not exceeding ⅓ of the base material thickness. The impact testing option is required.

Subsection NC & ND (Paras. NX-4622) are basically identical in content. These subsections do not specifically reference temperbead techniques although some of the requirements are related to the achievement of tempering caused by multiple beads. No specific mention is made of requiring the welding qualification per ASME Section IX, QW-290. Only P No. 3 materials are covered and only for repair on vessel welds or vessel materials. (It should be noted that the normal PWHT requirements would automatically exempt PWHT on P No. 1 materials for a material thickness $\leq$ 1½ in. (38 mm) or a weld thickness < ¾ in. (≤ 19 mm) when the base material is > 1½ in. (38 mm)) The size and depth of the repair is also limited to not more than 10 $in.^2$(6500 $mm^2$) or ½ in. (13 mm) weld thickness.

### 2.1.3 ASME Section VIII, Pressure Vessels

The 2010 edition of ASME Section VIII, Div. 1, allows some exemption of PWHT following repairs done after the final PWHT for P Nos. 1 & 3, Groups 1, 2, & 3. UCS-56(f) permits these exemptions provided the repair depth is not more than 1½ in. (38 mm) on P No. 1 materials and not more than ⅝ in. (16 mm) on P No. 3 materials. There are additional specific requirements on the weld electrode and the preheat (200˚F for P No. 1 materials and 350˚F for P No. 3 materials). Other than the control on the electrodes, no specific mention is made of the temperbead technique for the P No. 1 materials. For P No. 3 materials however, the requirement is to use the half bead repair technique followed by the temperbead technique for the final pass. No specific mention is made of requiring the welding qualification per ASME Section IX, QW-290.

### 2.1.4 ASME Section IX, Welding and Brazing Qualifications

The 2010 edition of ASME Section IX gives specific rules for the welding qualification of the temperbead welding technique in QW-290. However, this qualification is not mandatory unless it is a requirement of the construction Codes by specific reference to QW-290.

Assuming the construction Code requires it, ASME Section IX, QW-290, covers the additional qualification requirements for temperbead welding beyond the basic requirements for welding procedure qualification. Once the basic welding procedure is qualified, it is only necessary to run the additional qualification specified in QW-290. Variations of temperbead welding, including the half bead technique specified in some construction Codes, are included since they are addressed within the temperbead variables.

QW-290.2 limits temperbead welding to SMAW, GTAW, SAW, GMAW (including FCAW), and PAW although the use of manual and semiautomatic GTAW and PAW is prohibited except for root passes and repairs (additional requirements are imposed). Additional essential and nonessential variables are listed in Table QW-290.4 and detailed in QW-400. If impact testing is required by the construction Code, the additional supplementary essential variables also apply for the process, as specified by the basic qualification requirements.

For repairs made with the GTAW or PAW manual or semiautomatic processes, an additional requirement of a proficiency demonstration for welders to follow these requirements are included which provide for assurance that the temperbead results will be comparable to those that are achieved using machine or automatic welding processes.

Two approaches are used for the basis of acceptance of the temperbead qualification, hardness testing or impact testing. Hardness testing is the default basis; however, there are no stated acceptance criteria for hardness. If impact testing is required by the construction Code, the acceptance is the same toughness required of the basic qualification. Although most of the applications are based on construction Codes that include impact testing acceptance criteria, consideration is in progress for some that do not. If no hardness acceptance is available, measurements are required to be recorded but no further action is required. This may require additional acceptance criteria to be established by the construction Codes that do not have impact testing criteria (such as Section I and B31.1) should they allow qualification in accordance with QW-290.

Should hardness testing be required, the test method is the Vickers test method using a load of 10 kg. This load essentially makes this a macrohardness test (rather than microhardness). The current rules in the 2010 edition cause a problem in that the required separation of 0.010 in. (0.25 mm) would often be a violation of the required minimum separation between the indentations. This is in the progress of being corrected with changes to Section IX.

Recommendations for the qualifications required are contained in Section 5.

### *2.1.5 ASME Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components*

The 2010 edition of ASME Section XI is the most comprehensive of the ASME Codes that permit the exemption of PWHT using the alternative of the temperbead welding techniques. There has been and are many Section IX Code Cases addressing this approach in order to deal with different applications. The current Code addresses the temperbead welding technique as an alternative to PWHT as follows:  (Code Cases which are not currently incorporated are addressed in item 2.1.5.1.)

ASME Section XI, IWA-4600 covers Alternative Welding Methods including the requirements for several applications of temperbead welding. These methods are specifically targeted at repairs or replacements done on safety related nuclear plants components. This is particularly important since the ability to accomplish PWHT is difficult in some safety related or radiation environment situations.

ASME Section XI – 2010 addresses temperbead welding alternatives to PWHT with general requirements (IWA-4610) and four methods (IWA-4620, IWA-4630, IWA-4640, and IWA-4650). The 2010 Edition does not specifically require the temperbead qualification to be done using the ASME Section IX, QW-290 rules. Instead, Section IX is only referenced for normal qualification. (See additional discussion in Section 5.1 as a change is in progress.)Additional welding qualification requirements are imposed in Para. IWA-4610, General Requirements for Temper Bead Welding. The significant additional requirements for procedure qualification include an increased preheat temperature, control over the interpass temperature, an equivalent PWHT on the weld coupon prior to the temperbead qualification, weld joint direction, and weld joint included angles. There is also an additional requirement for performance qualification to require demonstration of the welder's capability to make the weld when the production weld is physically obstructed.

ASME Section XI – 2010, IAW-4620 covers "Temper Bead Welding of Similar Materials". This method is somewhat restrictive since it is limited to P Nos. 1, 3, 12A, 12B, and 12C materials, a finished surface area of not more than 100 $in.^2$(6500 $mm^2$) and a depth of not more than ½ the base metal thickness. Note that P Nos. 12A, 12B, and 12C were assigned to base metals by ASME Section III and Section IX but have now been reclassified within P Nos. 1, 3, 9A, 9B, and 10A by ASME Section IX. The reassignments noted in Section XI and in several of the Code Cases indicate the reassignment in footnotes incorrectly. Table 2-1 shows the original Section IX assignment and the current Section IX assignment for these materials.

*Table 2-1*
*P No. Reassignment of P Nos. 12A, 12B, and 12C Materials*

| Material – 1971 Designation | Material – 2010 Equivalent (2) | Tensile Strength ksi (MPa) | Sec IX-1971 P No. | Sec IX-1974 P No. | Sec IX-2010 P No. Group No. |
|---|---|---|---|---|---|
| SA-352 Grade LCB | Same | 65 (450) | 12A | P No. 1 Group 1 | P No. 1 Group 1 |
| SA-508 Class 1 | Same | 70 (485) | 12A | P No. 1 Group 2 | P No. 1 Group 2 |
| SA-541 Class 1 | Same | 70 (485) | 12A | P No. 1 Group 2 | P No. 1 Group 2 |
| SA-352 Grade LC1 | Same | 65(450) | 12A | P No. 3 Group 1 | P No. 3 Group 1 |
| SA-352 Grade LC2 | Same | 65 (450) (1) | 12A | P No. 9A Group 1 | P No. 9A Group 1 |
| SA-352 Grade LC3 | Same | 65(450) (1) | 12A | P No. 9B Group 1 | P No. 9B Group 1 |
| SA-508 Class 2 | Grade 2 Class 1 (Changed A94) | 80 (550) | 12B | P No. 3 Group 3 | P No. 3 Group 3 |
| SA-508 Class 3 | Grade 3 Class 1 (Changed A94) | 80 (550) | 12B | P No. 3 Group 3 | P No. 3 Group 3 |
| SA-533 Class1 Grade A | Type A Class 1 (Changed W72) | 80 (550) | 12B | P No. 3 Group 3 | P No. 3 Group 3 |
| SA-533 Class 1 Grade B | Type B Class 1 (Changed W72) | 80(550) | 12B | P No. 3 Group 3 | P No. 3 Group 3 |
| SA-533 Class 1 Grade C | Type C Class 1 (Changed W72) | 80 (550) | 12B | P No. 3 Group 3 | P No. 3 Group 3 |
| SA-541 Class 2 | Grade 2 Class 1 (Changed A94) | 80 (550) | 12B | P No. 3 Group 3 | P No. 3 Group 3 |
| SA541 Class 3 | Grade 3 Class 1 (Changed A94) | 80 (550) | 12B | P No. 3 Group 3 | P No. 3 Group 3 |
| SA-537 Grade B | Class 2 (Changed W72) | 80 (550) | 12B | P No. 1 Group 3 | P No. 1 Group 3 |
| SA-487 Grade 1Q | Grade 1 Class B (Changed A87) | 90 (620) | 12C (Added W71) | P No. 10A Group 1 | P No. 10A Group 1 |
| SA-533 Class 2 Grade A | Type A Class 2 (Changed W72) | 90 (620) | 12C | P No. 3 Group 3 | P No. 3 Group 3 |
| SA-533 Class 2 Grade B | Type B Class 2 (Changed W72) | 90 (620) | 12C | P No. 3 Group 3 | P No. 3 Group 3 |
| SA-533 Class 2 Grade C | Type C Class 2 (Changed W72) | 90 (620) | 12C | P No. 3 Group 3 | P No. 3 Group 3 |
| SA-487 Grade 2Q | Grade 2 Class B (Changed A87) | 90 (620) | 12C (Added W71) | P No. 10F Group 6 | P No. 3 Group 3 (changed A98) |

Notes:
(1) Listed tensile strength now 70 ksi (485 MPa)
(2) Information provided by R.Swayne, Reedy Associates [1]

### 2.1.6 ASME Code Cases Related to Temperbead Welding Techniques

The use of temperbead welding techniques to eliminate the requirements to perform Code PWHTs is largely supported for nuclear repair and replacement activities in accordance with the rules of ASME Section XI, *Rules for Inservice Inspection of Nuclear Power Plant Components*. The approach used to implement these techniques is to support the development of Section XI Code Cases, often supported by EPRI research activities. Although some related Code Cases have subsequently been incorporated into the Section XI Code, there are many which may still be used to support repair or replacement welding on carbon or limited low alloy materials without the PWHT that would be otherwise required by the applicable construction Code. These Code Cases therefore represent Code acceptance of the temperbead welding techniques (as described in the Code Cases) which then may be used (if approved by the NRC or regulatory body) as an alternative to PWHT.

Code Cases which support Code acceptance for variation from existing construction Code (e.g., ASME Section XI) rules apply until they are annulled by the Code Committee. The annulment usually occurs when the variation has been incorporated into the Code. Code Cases which support variations to Code rules may remain applicable to editions of the Code from the original date of approval until the variation is incorporated or until subsequent revisions of the Code Case are approved. However, Code Cases applicable to ASME Section XI provide for the applicability of the Code Cases to Code editions prior to the date of the approval in accordance with the *Applicability Index for Section XI Cases*. As a result, multiple revisions of the Code Cases supporting Section XI may remain applicable. This is important because plant Inservice Inspection and Repair and Replacement programs are only updated periodically so earlier Section XI editions may be the applicable. The acceptability of ASME Code cases for nuclear applications is also subject to NRC approval as the primary regulatory authority. Approval may be gained through generic acceptance via Regulatory Guide 1.147 for Section XI or Regulatory Guide 1.84 for Section III or a Relief Request may be submitted to the NRC requesting approval to use the Code Case or variations of them. Following is a list of Code Cases which are applicable to the use of the temperbead welding techniques as an alternative to construction Code required PWHT through Code Case Supplement 4 of the 2010 edition. Table 2-2 provides the ASME applicability status and the status of the approval via the NRC Regulatory Guides (RG 1.147 Rev 16 and RG 1.84 Rev 35, both dated October, 2010).

1. N-236 Repair and Replacement of Class MC Vessels – This Code Case covers the repair and replacement of Class MC vessels and Class CC vessels when not backed by concrete. Welding requirements were by reference to specified editions and paragraphs of Section XI, Subsection IWB.
2. N-236-1 Repair and Replacement of Class MC Vessels – Same as N-236 except the welding requirements are contained within the Code Case. The Code Case has been incorporated into Section XI (originally in Section XI -

1992, IWA-4540 but IWA-4650 in 2010 edition). The SMAW process was required and the materials were limited to P No. 1, Groups 1 & 2.

3. N-432 Repair Welding Using Automatic or Machine Gas Tungsten-Arc Welding (GTAW) Temperbead Technique – This Code Case covers the use of automatic or machine GTAW for temperbead repair welding instead of SMAW.
4. N-432-1 Repair Welding Using Automatic or Machine Gas Tungsten-Arc Welding (GTAW) Temperbead Technique – Same as N-432. Note that the current rules for temperbead repairs or replacements in Section XI, IWA-4620 through IWA-4640 already address the use of the automatic or machine GTAW process. However, IWA-4650 still only addresses SMAW.
5. N-561 Alternative Requirements for Wall Thickness Restoration of Class 2 and High Energy Class 3 Carbon Steel Piping – The temperbead techniques are required if the piping contains steam or water by reference to the Section XI requirements. The restoration may include using low-alloy steel overlays.
6. N-561-1 Alternative Requirements for Wall Thickness Restoration of Class 2 and High Energy Class 3 Carbon Steel Piping – Same as N-561 except with updated Section XI Code references.
7. N-561-2 Alternative Requirements for Wall Thickness Restoration of Class 2 and High Energy Class 3 Carbon Steel Piping - Same as N-561 and N-561-1 except with updated Section XI Code references.
8. N-562 Alternative Requirements for Wall Thickness Restoration of Class 3 Moderate Energy Carbon Steel Piping - The temperbead techniques are required if the piping contains water by reference to the Section XI requirements. The restoration may include using low-alloy steel overlays.
9. N-562-1 Alternative Requirements for Wall Thickness Restoration of Class 3 Moderate Energy Carbon Steel Piping - Same as N-562 except with updated Section XI Code references.
10. N-562-2 Alternative Requirements for Wall Thickness Restoration of Class 3 Moderate Energy Carbon Steel Piping - Same as N-562 and N-562-1 except with updated Section XI Code references.
11. N-594 Repairs to P-4 and P-5A Materials for Pumps and Valves Without Postweld Heat Treatment (Note: this is a Section III Code Case) – While this Code Case is not included as a Section XI repair or replacement method, it is unusual in that it applies to Cr-Mo materials (P Nos. 4 and 5A) and allows the use of manual GTAW in addition to SMAW. It applies only for repairs when the material selection was based on erosion resistance. Specific temperbead techniques are not utilized but the requirements include basic temperbead placements.

12. N-606 Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique – This Code Case applies to BWR CRD housing or stub tube repairs using automatic or machine GTAW temperbead techniques. It is limited to ½ of the ferritic base metal thickness and the maximum area is 100 $in.^2$(6500 $mm^2$) and is applicable to P Nos. 1, 3, 12A, 12B, and 12C.
13. N-606-1 Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique for BWR CRD Housing/Stub Tube Repairs – Same as N-606 with some editorial changes and updated Section XI Code references.
14. N-638 Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique – This Code Case is similar to the N-606 Code Cases except not restricted to BWR CRD housing or stub tube repairs. It is similarly restricted to automatic or machine GTAW temperbead welding and a maximum area of 100 $in.^2$(6500 $mm^2$) and is applicable to P Nos. 1, 3, 12A, 12B, and 12C except SA-302 Grade B. Draining the component may not be required.
15. N-638-1 Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique – Same as N-638 except modified slightly to allow use of method to relieve radiological concerns not related to draining the component.
16. N-638-2 Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique – Same as N-638-1 with the following changes:

    (1) Revise limitation of SA-302, Grade B to allow welding of SA-302, Grade B modified that include from 0.4% to 1.0% nickel, quenching and tempering, and application of a fine grain practice
    (2) Clarify impact testing acceptance criteria and add provisions for an Adjustment Temperature.
    (3) Change NDE requirements and acceptance criteria to comply with Construction Code.
    (4) Include provisions to perform a VT-1 visual examination when surface examinations are impractical.
    (5) Add requirement to monitor process temperatures during the welding process.
    (6) Clarified existing interpass temperature provision.
    (7) Miscellaneous changes and clarifications were also made to update code case.
17. N-638-3 Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique – Same as N-638-2 except that the area limitation of 100 square inches is increased to 500 $in.^2$(3230 $cm^2$).

18. N-638-4 Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique – Same as N-638-3 except the requirement for a 48 hr. hold after welding before NDE can be performed is modified to start the 48 hr. hold after completion of the 1st three layers of weld when austenitic materials are used.
19. N-638-5 Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique – Same as N-638-4 except the welding qualification requirement is changed to ASME Section IX rather than being detailed within the Code Case.
20. N-651 Ferritic and Dissimilar Metal Welding Using SMAW Temper Bead Technique Without Removing the Weld Bead Crown for the First Layer – This Code Case allows the final weld deposit on the cap of the weld to remain provided the weld is done with a "nonferritic" filler metal. It is limited to a repair area not exceeding 100 in.$^2$ (6500 mm$^2$) with a repair depth not exceeding ½ of the base metal thickness.
21. N-661 Alternative Requirements for Wall Thickness Restoration of Classes 2 and 3 Carbon Steel Piping for Raw Water Service - This Code Case allows the overlay restoration of localized thinned areas of carbon steel piping resulting from erosion, corrosion, cavitation, or pitting. It does not directly require temperbead welding but rather references IWA-4000 rules if the construction Code requirements for the welding procedure cannot be followed.
22. N-661-1 Alternative Requirements for Wall Thickness Restoration of Classes 2 and 3 Carbon Steel Piping for Raw Water Service - Same as N-661 except additional limitations on the service life, repeated applications, and the examination requirements were added.
23. N-661-2 Alternative Requirements for Wall Thickness Restoration of Classes 2 and 3 Carbon Steel Piping for Raw Water Service - Same as N-661-1 except additional requirements were added to address examination of the area of the overlay, the limitation to depressurize thin section materials was changed to cautionary, a reconciliation of any flexibility analysis was added, and the requirement to do volumetric examination of Class 3 applications was relaxed.
24. N-740 Dissimilar Metal Weld Overlay for Repair of Class 1, 2, and 3 Items – This Code Case allows the use of overlays to mitigate the existence of a flaw in similar or dissimilar welds on ferritic and austenitic steels and nickel alloys. Ambient temperature temperbead welding techniques may be used as an alternative to PWHT requirements in the Construction Code. The temperbead overlay is limited to a surface area of 500 Square inches.
25. N-740-1 Dissimilar Metal Weld Overlay for Repair or Mitigation of Class 1, 2, and 3 Items – Same as N-740 except the mitigation of SCC flaws may be addressed.
26. N-740-2 Full Structural Dissimilar Metal Weld Overlay for Repair or Mitigation of Class 1, 2, and 3 Items – Same as N-740-1 except the overlay may be applied to additional material combinations.

27. N-762 Temper Bead Procedure Qualification Requirements for Repair/Replacement Activities Without Postweld Heat Treatment – This Code Case provides for the use of ASME Section IX, Para. QW-290 rules for the welding qualification for the temperbead technique in lieu of PWHT. Additional limitations are applied, including the limitation to permit only GTAW or SMAW processes.

28. N-766 Nickel Alloy7 Reactor Coolant Inlay and Onlay for Mitigation of PWR Full Penetration Circumferential Nickel Alloy Dissimilar Metal Welds in Class 1 Items Section XI, Division 1 – This Code Case addresses the use of inlays and onlays to mitigate flaws in nozzle or pipe welds. When performed on ferritic materials, temperbead welding techniques may be applied in lieu of PWHT. The welding qualifications are required to be in accordance with ASME Section IX with additional limitations.

*Table 2-2*
*Nuclear Code Case Applicability and Acceptability*

| Code Case No. | ASME Section XI Edition Applicability | NRC Regulatory Guide Acceptability |
|---|---|---|
| N-236 | 1974 through 1983 w/ W84A | Superseded Code Case by Revision per RG1.147 Rev 16, Table 5 |
| N-236-1 | 1974 through 1989 w/ 90A | Previously Unconditionally Acceptable per RG1.147 Rev 16, Table 3 – Annulled 8/5/97 |
| N-432 | 1971 w/ S73A through 1989 w/ 90A | Superseded Code Case by Revision per RG1.147 Rev 16, Table 5 |
| N-432-1 | 1971 w/ S73A through 2007 w/ 08A | Acceptable per RG1.147 Rev 16, Table 1 |
| N-561 | 1977 through 2004 | Superseded Code Case by Revision per RG1.147 Rev 16, Table 5. Unacceptable per RG1.193 Rev 3 Table 2 |
| N-561-1 | 1977 through 2004 w/ 05A | Unacceptable per RG1.193 Rev 3 Table 2 |
| N-561-2 | 1977 through 2007 w/ 08A | Not Addressed in Current Regulatory Guide Revisions |
| N-562 | 1977 through 2004 | Superseded Code Case by Revision per RG1.147 Rev 16, Table 5. Unacceptable per RG1.193 Rev 3 Table 2 |
| N-562-1 | 1977 through 2004 w/ 05A | Unacceptable per RG1.193 Rev 3 Table 2 |
| N-562-2 | 1977 through 2007 w/ 08A | Not Addressed in Current Regulatory Guide Revisions |
| N-594 (1) | NA | Acceptable Section III Code Case per RG1.84 Rev 35, Table 1 |

*Table 2-2 (continued)*
*Nuclear Code Case Applicability and Acceptability*

| Code Case No. | ASME Section XI Edition Applicability | NRC Regulatory Guide Acceptability |
|---|---|---|
| N-606 | 1977 w/ S78A through 2004 | Superseded Code Case by Revision per RG1.147 Rev 16, Table 5 |
| N-606-1 | 1977 w/ S78A through 2007 w/ 08A | Conditionally Acceptable per RG1.147 Rev 16, Table 2 |
| N-638 | 1977 w/ S78A through 2004 | Superseded Code Case by Revision per RG1.147 Rev 16, Table 5 |
| N-638-1 | 1977 w/ S78A through 2007 w/ 08A | Superseded Code Case by Revision per RG1.147 Rev 16, Table 5 |
| N-638-2 | 1980 w/ W81A through 2004 | Superseded Code Case by Revision per RG1.147 Rev 16, Table 5 |
| N-638-3 | 1980 w/ W81A through 2004 | Superseded Code Case by Revision per RG1.147 Rev 16, Table 5 |
| N-638-4 | 1980 w/ W81A through 2004 | Conditionally Acceptable per RG1.147 Rev 16, Table 2 |
| N-638-5 | 1980 w/ W81A through 2004 | Not Addressed in Current Regulatory Guide Revisions |
| N-651 | 1977 w/ S78A through 2007 w/ 08A | Acceptable per RG1.147 Rev 16, Table 1 |
| N-661 | 1977 through 2004 w/ 05A | Superseded Code Case by Revision per RG1.147 Rev 16, Table 5 |
| N-661-1 | 1977 through 2004 w/ 05A | Conditionally Acceptable per RG1.147 Rev 16, Table 2 |
| N-661-2 | 1977 through 2007 w/ 08A | Not Addressed in Current Regulatory Guide Revisions |
| N-740 | 1980 w/ W81A through 2004 w/ 06A | Unacceptable per RG1.193 Rev 3 Table 2 |
| N-740-1 | 1980 w/ W81A through 2004 w/ 06A | Not Specifically Addressed in Current Regulatory Guide Revisions although N-740-1 was determined to be inadequate for acceptance in RG1.193 Rev 3 Table 2 within discussion of N-740 |
| N-740-2 | 1986 w/ 88A through 2007 w/ 08A | Not Addressed in Current Regulatory Guide Revisions |
| N-762 | 1995 w/ 95A through 2007 w/ 08A | Not Addressed in Current Regulatory Guide Revisions |
| N-766 | 1986 w/ 88A through 2010 | Not Addressed in Current Regulatory Guide Revisions |

Note (1) N-594 is a Section III Code Case

## 2.2 Other Applications

### *2.2.1 National Board Inspection Code*

The National Board Inspection Code (ANSI/NB-23), 2007 edition with addenda through 2009, contains three parts, Installation, Inspection, and Repairs & Alterations, labeled Parts 1 through 3, respectively. Part 3 Repairs and Alterations, Section 2, covers Welding and Heat Treatment. Paragraph 2.5.3 covers several alternative welding methods without PWHT, including 4 applications of temperbead welding techniques. The welding procedure qualification rules of ASME Section IX, QW-290 are applied. Also, when ferritic filler metal is used, electrodes with a diffusible hydrogen content of H8 or lower and a hydrogen bakeout are required. The hydrogen bakeout may be omitted when the electrode diffusible hydrogen content is H4. The surface temper reinforcing bead is required to be removed.

Each of the methods which prescribe temperbead welding techniques are briefly described as follows:

#### 2.2.1.1 Welding Method 2 (NBIC Para. 2.5.3.2)

This method may be used under the rules of the NBIC when the original Code of Construction required notch toughness testing or when notch toughness is verified. There are very few limitations regarding the carbon and low alloy steels to which this method may apply, including P Nos. 1 Groups 1-3, 3 Groups 1-3, 4, 5A, 9A, 10A, 10B, 10C, 11A, and 11B. The welding processes may be SMAW, GMAW, FCAW, or GTAW (there is no specific limit on the use of manual GTAW other than the reference to ASME Section IX, QW-290 which provides some such limitation. An elevated preheat and a limit on the interpass temperature is required for P Nos. 1, 3, 4, and 5A. The material thickness and the repair depth is only controlled by the Section IX qualification.

#### 2.2.1.2 Welding Method 3 (NBIC Para. 2.5.3.3)

This method may apply when the original Code of Construction did not require notch toughness testing. However, it is limited to P Nos. 1 or 3 and the SMAW, FCAW, and GTAW processes. It is otherwise similar to Welding Method 2.

#### 2.2.1.3 Welding Method 4 (NBIC Para. 2.5.3.4)

This method is limited to repair welds less than full thickness where the original Code of Construction did not require notch toughness testing, materials of P Nos. 4 Groups 1-2, and 5A, and the SMAW, FCAW, GMAW, or GTAW processes. Again, it is otherwise similar to Welding Method 2.

#### 2.2.1.4 Welding Method 5 (NBIC Para. 2.5.3.5)

This method is limited to dissimilar materials welds between the materials designated in Welding Method 2 to P Nos. 8, 42, 43, or 45. Some of the remaining rules are somewhat inconsistent in that similar limitations are addressed differently. For instance, only machine or automatic GTAW is allowed instead of unlimited GTAW. The welding qualification when P Nos. 1 or 3 is the ferritic material (not requiring notch toughness testing)may also be confuse since both the temperbead welding qualification of Section IX, QW-290 and the non-temperbead qualification of Welding Method 1 (not a temperbead technique) is specified.

### 2.2.2 Related French Code Rules

While there was no attempt to gain access to global applications, some information was available on requirements within France as described in the following. This information was provided for general discussion only. Any applications in other countries would require compliance with the applicable regulatory and Code requirements.

#### 2.2.2.1 RCC-M – Design and Construction Rules for Mechanical Components of PWR Nuclear Islands– French Association for Design, Construction and In-Service Inspection Rules for Nuclear Island Components

Item S7600 within this document covers "Repair by Welding". Item S7620 "Special Case of Repairs by Welding Exempted from Subsequent Heat Treatment" specifically provides direction for temperbead welding qualification when approved by the Contractor.

#### 2.2.2.2 RSE-M – In-Service Inspection Rules for the Mechanical Components of PWR Nuclear Islands - French Society for Design, Construction and In-Service Inspection Rules for Nuclear Island Components

Binder I, Item I.1.2.2 of this document provides for welding qualifications (both welding procedures and the welders) in accordance with the qualification requirements of RCC-M (see item 2.2.2.1). Additional requirements for the weld repairs themselves are contained in Items I.2 and I.3. SMAW and automatic GTAW are specifically permitted.

## 2.3 Potential Applications

### *2.3.1 B31.1 Power Piping Code*

The 2010 edition of ASME B31.1 does not currently allow the use of the temperbead welding techniques as an alternative to PWHT. However, there is an item on the B31.1 agenda intended to provide a proposal to allow this alternative. As the item has not yet been approved, it is preliminary to determine exactly how or if this will be addressed. However, the B31.1 Committee has in the past interpreted the acceptance of the modification of fabrication rules by a designer (as accepted by the Owner) to be a valid approach to meeting the Code. A specific interpretation involving exceptions to the PWHT rules has not been approached.

While this has been awarded but no results are currently available, it should be noted that there is an ASME ST-LLC research proposal that relates to the potential use of the temperbead welding techniques in B31.1 (and possibly ASME Section I). This proposal intends to determine acceptable hardness values for the temperbead welding qualification, particularly on P Nos. 4 and 5A materials.

### *2.3.2 B31.3 Process Piping Code*

The 2010 edition of ASME B31.3 does not currently allow the use of the temperbead welding techniques as an alternative to PWHT. However, there is an item on the B31.3 agenda intended to provide a proposal to provide consistency between B31.3 and B31.1 with regard to preheat and PWHT. As the item has not yet been approved, it is preliminary to determine exactly how or if this will be addressed.

# Section 3: Metallurgy

## 3.1 Basic Welding Metallurgy of Hardenable Alloys

Many ferrous materials used within power plant applications are capable of being heat treated, potentially modifying the properties of the material. There are many factors which determine the properties as a result of the heat treatment but critical factors include the alloying elements, the alloying element content, the heat treatment temperature, the time at the heat treatment temperature, and the rate of cooling from the heat treatment temperature. The material specifications generally control the heat treatment done on base materials, but the fabrication processes used during fabrication, construction, repairs, and maintenance may alter the properties achieved during the material manufacturing and heat treatment. This is particularly true of most welding operations since the process of welding generally subjects the material or component to a radical thermal cycle. The result of this radical thermal cycle is the creation of a heat affected zone (HAZ) and weld metal which may have significantly different properties than the original base material. Both toughness and hardness (corresponds with tensile strength) can be affected. Figure 3-1 shows a simplified description of the development of the HAZ as related to the iron-iron carbide phase diagram.

The welding thermal cycle can have a significant effect on the properties of the weld metal and the HAZ where the material had reached temperatures from slightly subcritical to melting. Figure 3-2 shows the potential resulting microstructure which may be the result of a weld on hardenable carbon steel or low alloy materials. This is an extreme example which was the result of a very high heat input weld but it shows the potential grain structure changes that may result from welding.

For carbon and low alloy steels (taken to be materials which belong to P Nos. 1 through 5A), the area of concern is often the HAZ immediately adjacent to the fusion zone. This is described in Figure 3-1 as the coarse grain region since this material was heated during the welding process to the upper region of the austenitic microstructure where grain growth is known to occur. This area is also typically the highest hardness since it goes through a very rapid cooling rate during the phase transformation from austenite, resulting in a potentially martensitic, partially martensitic, or a bainitic microstructure. This of course depends on the composition of the material and the cooling rate during this phase transformation.

One parameter which is often used to describe the composition which is related to the hardenability of the material is the term carbon equivalent (CE). Although there are several CE formulas that are used in the industry, the formula to be used in this guidance is as follows:

$$CE = \%C + \%Mn/6 + (\%Cr + \%Mo + \%V)/5 + (\%Ni + \%Cu)/15$$

As can be seen from the formula, the carbon content is the most significant of the elements which contribute to the hardenability of the material and in fact controls the maximum hardness achievable in any particular material.

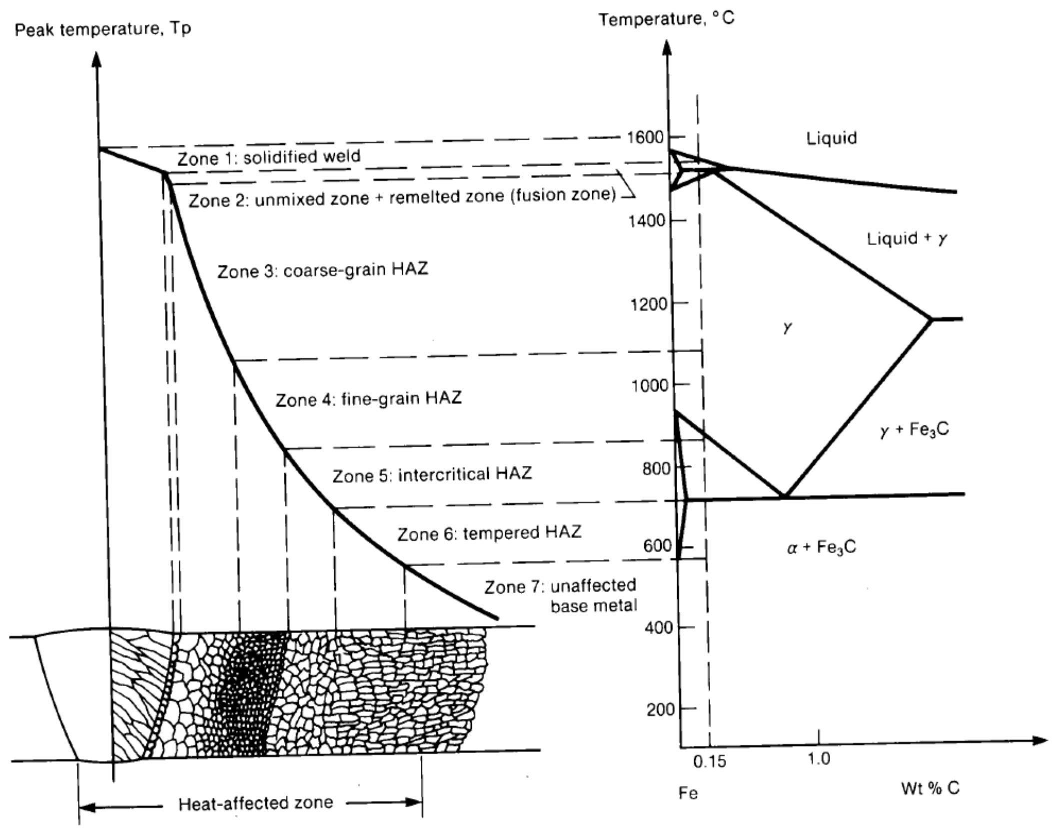


*Figure 3-1*
*Relationship Between Peak Metal Temperatures of a Weld and the Correlation to the Iron-Iron Carbide Phase Diagram.*

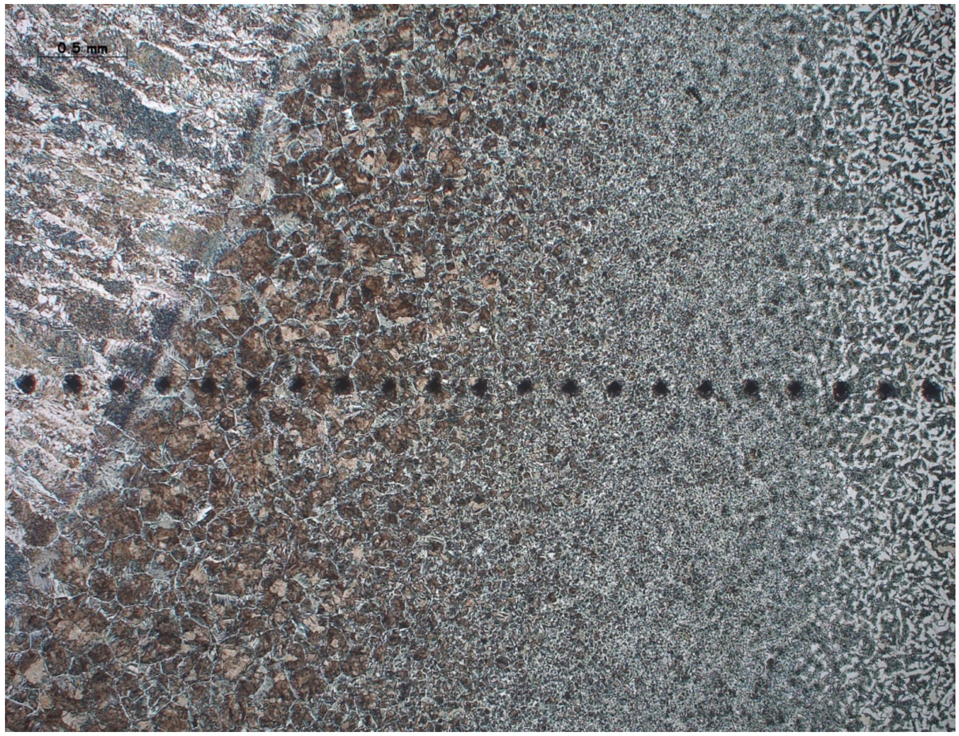


*Figure 3-2*
*Microstructure of a Carbon Steel Weld HAZ Showing Large Grain Region and Fine Grain Region (Note: The straight line indications are hardness indentations.)*

The area of the microstructure immediately adjacent to the fusion zone may be significant for several reasons. This is where the highest hardness may occur within the base metal of a weldment. In an un-tempered state this area may exhibit low toughness and a susceptibility to cracking as a result of a coarse grain structure. When toughness is a requirement of the construction code, this is a location which is subjected to toughness testing (Charpy V-notch) as part of a welding procedure qualification. ASME Codes typically address the issue of HAZ hardness and toughness through the use of PWHT. Temperbead welding techniques provide an alternative to PWHT.

## 3.2 Metallurgy of Temperbead Welding

Toughness is typically most critical in the large grain region of the HAZ, immediately adjacent to the fusion zone. This may also be the location of the highest hardness in a weldment, although hardness and toughness are not directly related. The toughness is typically better in the fine grain region of the HAZ. The temperbead welding technique is to place weld passes over previous weld passes with the heat input and the bead placement such that the properties of toughness and hardness are improved from a conventionally welded HAZ.

The ASME Codes have typically required post weld heat treatment (PWHT) for the materials and conditions where high hardness or high residual stresses could be expected. This results in a requirement to temper materials with high hardenability using subcritical PWHT. High residual stresses are not necessarily addressed directly but in some cases the weld thickness (which is related to the residual stress) is used as a control parameter. As described in Section 2, the requirement to perform a PWHT may be replaced with the alternative of temperbead welding techniques for certain applications.

The basic concept of temperbead welding has been known for decades. As described in Item 3.1, the welding process has a significant effect on the microstructure of ferritic hardenable alloys due to the rapid thermal cycle. This process however is not a single event in most welds where PWHT would normally be required since a typical weld in any materials greater than ⅛ in. thickness would likely be made with multiple passes. Each pass then would have its own thermal cycle and would therefore individually cause microstructural changes in the resulting HAZ of previous passes. The mechanical properties of tensile strength, yield strength, ductility, hardness, toughness, and creep strength can be affected within the weld and the HAZ. Fortunately this can be a very positive result. The basis of the temperbead welding technique is this positive effect which may result, rendering a PWHT unnecessary. An excellent description of the temperbead welding technique is given in Appendix A (abridged presentation of presentation to Section IX Code Committee for Code Revision item 01-242) [2].

As described in Appendix A, the temperbead welding technique uses specific positioning and relative heat input of each weld bead to effectively create a pass by pass PWHT during welding. However rather than a subcritical PWHT typically required by the ASME Codes, the temperbead technique actually creates a zone of austenitizing PWHT in the localized HAZ area which may otherwise have an unfavorable microstructure.

# Section 4: Industry Experience

## 4.1 EPRI Research

As stated previously, EPRI has been an industry leader in investigation and implementation of the use of the temperbead welding techniques as a method of providing an alternative to post weld heat treatment (PWHT). The emphasis has largely been in nuclear power plant repair and replacement activities where PWHT is impractical or impossible although the application of this technique is not limited to such applications. It should be noted that additional earlier EPRI reports were published which supported some of the earlier work justifying the temperbead welding technique as a viable alternative to PWHT. These reports also provide a rich source of background information on the temperbead welding techniques. The following is a list of related EPRI reports with a brief description of the issues being addressed:

### *4.1.1 P-No. 4 and P-No.5A Temperbead Repair Using the Flux-Cored Arc Welding (FCAW) Process*

Report No. 1001271 [3] provides data supporting the use of the FCAW process for temperbead repair welding on Cr-Mo materials. The basic need was to support changes to NBIC Welding Method 4 to allow the additional process of FCAW to this method which allowed only the SMAW process on P Nos. 4 and 5A materials. This was needed since a higher production process was needed. The test results provided additional support for the ability of the temperbead welding techniques to provide adequate and possibly superior weldment properties, even on the Cr-Mo materials. NBIC Welding Method 4 now allows the use of the FCAW process.

### *4.1.2 Elimination for 48 Hour Hold for SMAW of P3 Materials*

Report No. 1003163 [4] supports the development of related data to support a "Position Paper" which was used to report the results and background information to ASME Section XI on why a 48-hour hold is unnecessary for SMAW of P3, Group 3 materials.

### *4.1.3 Temperbead Qualification - Joint P3 Weld Qualification*

Report No. 1003292 [5]outlines the joint procedure qualification per Code Case N-573 for a temperbead weld repair on P3 Group 3 materials.

### 4.1.4 Evaluation of Large Area Temperbead Repair for Pressure Vessels

Report No. 1003541 [6] supports an increase in the allowable surface area for repairs from 100 $in^2$(65000 $mm^2$) to 500 $in^2$(3230 $cm^2$) using finite element analysis. The original limitation of 100 $in^2$(65000 $mm^2$) was reported to be arbitrary to protect against excessive repairs. This report provides a more comprehensive analysis of the effect of the repair surface area.

### 4.1.5 Review of Temperbead Welding Heat Input Ratios for ASME Code Applications

Report No. 1006806 [7] evaluated the range of suitable heat input parameters necessary to accomplish the desired HAZ properties. The use of heat input ratios as the control approach was developed under this study. This approach was used for the basis of the temperbead welding qualification requirements in Section IX.

### 4.1.6 Ambient Temperature Preheat for Machine GTAW Temperbead Applications

Report No. GC-111050 [8] addresses the elevated preheat and post hydrogen bakeout that the Codes require for temperbead welding of ferritic materials, specifically P Nos. 1 and 3 materials. When the temperbead techniques are used, the concern for high restraint weld cracking due to high hardness is mitigated so the concern was primarily for the possibility of hydrogen weld cracking. The machine or automatic GTAW process provides very little diffusible hydrogen so the need for preheat and the post weld hydrogen bakeout was determined to be unnecessary.

### 4.1.7 P-No. 4 and P-No. 5 Valve Body Temperbead Repair Guideline for Nuclear Applications

Report No. TR-108138 [9] provides an approach and information for the qualification and implementation of weld repairs to P Nos. 4 and 5 valve bodies using the temperbead welding techniques as an alternative to PWHT. Specific parameters were developed for this repair approach.

### 4.1.8 Hydrogen Evaluations for Shielded Metal Arc Welding

Report No. 1015158 [10] provides technical justification to relax the 48 hour hold requirement before performing the final NDE on ambient temperature temperbead applications with SMAW. A test matrix of materials (welding consumables and base materials), and hydrogen and induced stress conditions was used to validate that low hydrogen practices are acceptable for temperbead welding of P1 andP3 materials with SMAW.

### 4.1.9 Acceptable CVN Results for Procedure Qualification

Report No. 1015161 [11] investigates alternative toughness testing methods for qualification of temperbead welding procedures. ASME test protocol required a drop weight test be used to establish a nil-ductility transition temperature. The test criteria investigated provided that a series of CVN tests over a range of temperatures would be an adequate method of provided assurance of acceptable toughness.

### 4.1.10 Justification for Extension of Temper Bead Limit to 1000 Square Inches for WOL of P1 and P3 Materials

Report No.1021073 [12] provides justification for larger temperbead repair areas than had been acceptable in many Code Cases for weld overlay (WOL) repairs. The previous limit of 500 in.$^2$(3230 cm$^2$) was inadequate for large diameter, heavier wall piping and nozzles. This report supports increasing the limit to 1000 in.$^2$ (6500 cm$^2$).

### 4.1.11 Shielded Metal Arc Welding Temperbead Welding of P3 Material

Report No. 1021076 [13] provides test results which support that the use of low hydrogen SMAW electrodes (H4R diffusible hydrogen designation) for temperbead welding on P3 materials. Deposits made with these electrodes do not contain sufficient diffusible hydrogen levels which would support hydrogen delayed cracking in these materials.

### 4.1.12 Investigation of Manual Temperbead Repairs to Existing Automatic GTAW Temperbead Welds

Report No. 1011870 [14] provides the results of investigations on manual SMAW and GMAW repairs to automatic GTAW temperbead repairs. The intent was to address concerns for variations in the effects of manual repairs versus automatic repairs to temperbead weld repairs.

### 4.1.13 RRAC Temperbead Rule Section IX

Report No. 1013559 [15] provides support for the adoption of the Section IX QW-290 temperbead welding qualification rules into construction Codes that currently address the temperbead qualifications independently. This would then permit the use of a single qualified temperbead qualified welding procedure across a broad range of Code applications.

### 4.1.14 RRAC TB Rules in NBIC

Report No. 1013560 [16] discusses the efforts to gain approval by the National Board of Boiler and Pressure Vessel Inspectors for inclusion in NB-23, the National Board Inspection Code (NBIC).

#### 4.1.15 SMAW Temperbead Welding of P3 Materials

Report No. 1016715 [17] extends the justification for the relaxation of the 48 hour hold prior to conducting nondestructive examination after temperbead welding repairs to P3 materials as described in EPRI Report 1013558 (see 4.1.21). The justification in Report 1013558 applied mainly to GTAW temperbead welding while this report addresses the use of low diffusible hydrogen electrodes and the SMAW process on materials at ambient temperatures.

#### 4.1.16 ASME Code Rules for Application of Temperbead Welding

Report No. 1002943 [18] provides a broad based approach to additional Code rules for temperbead welding approaches, including the reduction of the inspection hold time, temperbead qualification rules, and the expansion of repair limits.

#### 4.1.17 RRAC Code Justification for the Removal of the 100 Square Inch Temper Bead Weld Repair Limitation

Report No. 1011898 [19] provides technical justification for increasing the temperbead repair area beyond the 100 in.$^2$(6500 mm$^2$) which was a limitation when this report was issued. Several configurations were addressed and compared to approaches currently within Code limits (such as multiple repair areas).

#### 4.1.18 SMAW Temperbead Weld Repair Without Grinding

Report No. TE-113416 [20] is a dated (1999) report that justified the modification of the half bead repair techniques to the current approaches which do not require the grinding removal of part of the weld bead. The approach establishes that the proper placement of the weld beads and the control of the heat input during welding is sufficient to provide the properties desired during temperbead welding repairs. Testing was done on P Nos. 1, 3, 4, and 5 materials and on service aged P Nos 4 and 5 materials.

#### 4.1.19 Temperbead Welding of P-Nos. 4 and 5 Materials

Report No. TR-111757 [21] provides an overview discussion of the development of the present day temperbead welding techniques, from the original half bead techniques to temperbead controlled deposition techniques.

#### 4.1.20 Justification for the Removal of the 100 Square Inch Limitation on P3 Material

Report No.1006066 [22] provides initial justification for the removal of the 100 in.$^2$(6500 mm$^2$) limitation for GTAW temperbead welds on P3 materials.

### *4.1.21 48-Hour Hold Requirements for Ambient Temperature Temperbead Welding*

Report No. 1013558 [23] provides technical justification to allow the 48-hour delay to begin following completion of the third temperbead weld overlay weld layer applied to P3 low alloy steel pressure vessel components. This is an alternative to starting the 48-hour hold after the entire weld has been completed and cooled to ambient temperatures.

## 4.2 Industry Research

Welding Research Council (WRC) Bulletin 412 [24] provided a number of industry research reports related to the use of the temperbead techniques. A brief discussion on each of the related reports follows:

### *4.2.1 History and Need Behind the New NBIC Rules on Weld Repair Without PWHT, Doty, W.D.*

This paper provides support data from major research programs which provided support for the original Welding Methods in the NBIC which use temperbead techniques as an alternative to PWHT (see 2.2.1).

### *4.2.2 Position Paper Covering New NBIC Rules on Weld Repair Without PWHT, Lemire, J., Quinn, G.*

This provided concerns with the alternatives to PWHT using the temperbead repair welding techniques as an alternate to PWHT. It was pointed out that the NBIC rules stated in 1992 that, "These alternative methods should not be used in highly stressed areas or if service conditions are conducive to stress corrosion cracking or, in some cases for materials subject to hydrogen induced cracking."

### *4.2.3 Weld Repairs Without PWHT in the Petroleum Industry, Ibarra, S.J.*

Particular concerns were expressed for using the temperbead techniques in cases where sulfide stress cracking (due to sour service environments) was a potential. The temperbead techniques had been used successfully in other services.

### *4.2.4 Overview of Results from PVRC Programs on Half-Bead/Temper-Bead/Controlled Deposition Techniques for Improvement of Fabricationand Service Performance of Cr-Mo Steels, Lundin, C.D.*

This paper described the testing and results of using controlled deposition welding techniques (temperbead) on carbon and low alloy Cr-Mo materials. The use of the temperbead techniques did not have a great effect on the carbon steel when compared to welding using conventional techniques although improved toughness in the HAZ fusion line area was noted. However, the use of temperbead on the P No. 4 material (Grade 11) showed significant improvement in toughness, hardness, creep strength, and the absence of reheat cracking. The results on the P No. 5A material (Grade 22) showed an increase in HAZ toughness but was not as successful with the hardness traverses.

### 4.2.5 EWI/TWI Controlled Deposition Repair Welding Procedure for 1¼Cr-½Mo and 2¼Cr-1Mo Steels, Friedman, L.M.

This paper reported the results of research on P No. 4 and P No. 5A materials welded using controlled deposition techniques (temperbead) and the SMAW process. Discussion of the techniques required to effectively achieve the optimum benefits was given. Significant increases in the toughness of the HAZ was achieved.

### 4.2.6 Development of Controlled Deposition Repair Welding Procedures at Ontario Hydro, Lau, T.W., Lau, M.L., Poon, G.C.

Ontario Hydro reported extensive experience in applying temperbead welding techniques to achieve desired results. This included both grain refining techniques and tempering techniques which are explained in the paper. Recommendations for qualifying both the welding procedures and the training and qualification of welders, electrode care, preheating, postweld bake outs, distortion control, quality control and technical support were all addressed as important issues to properly control the use of temperbead welding techniques.

### 4.2.7 Performance of Weld Repairs on Service-Aged 2¼Cr-1Mo Girth Weldments Utilizing Conventional Postweld Heat Treatment and Temper-bead Repair Techniques, Gandy, D.W., Viswanathan, R., Findlan, S.J.

This paper reported the results of temperbead and conventional (with PWHT) repairson service aged hot reheat piping. Both methods showed similar results regarding estimated remaining life but the temperbead repair improved the toughness while the conventional repair severely lowered the HAZ toughness.

### 4.2.8 Utility Guidelines for Controlled Deposition Repair Welding, Neary, C.M.

High temperature service aged material was repair welded with the temperbead techniques. Several issues were reported. The filler metal had significantly higher creep rupture properties unless it had a low carbon content. Subsequent high temperature operation resulted in relaxation of both hardness and residual stress. The paper recommended several guidelines for repairs using the temperbead techniques. Included was a close evaluation of the failure mechanism, procedure qualification, welder training on a mock-up, and NDE.

### *4.2.9 Petrochemical Industry Guidelines for Controlled Deposition Repair Welding of Chrome-Moly Components, Hammond, J., Dennis, R.A.*

This paper covers the repair welding of Cr-Mo components in a petrochemical service. While this may bring in additional issues such as wet $H_2S$ conditions, there were common issues that were applied to all such repairs. Included were material composition, service history, metallurgical condition, service stresses (including residual stress), and the environment. Also discussed was the inconsistency of the weld groove in many repairs which may make bead placement more difficult.

### *4.2.10 Weld Repair of Carbon-Moly Coke Drums Without Postweld Heat Treatment, Moore, D.E.*

The repair to C-½Modrums using SMAW was discussed. The process used was the half-bead technique and an elevated preheat of 300°F. Some additional applications of GMAW were used. Charpy, tensile, and low cycle fatigue tests were accomplished. The results reported were that the use of the temperbead welding techniques were acceptable for this application.

### *4.2.11 Development of Temper-Bead Technique Applied to Dissimilar Welded Joints of Nuclear Pressure Vessels, Higuchi, M., Umemoto, T., Matsusita, A., Shiraiwa, T.*

This report outlines the testing done to address the use of temperbead welding techniques for a P No. 3, Group 3 alloy such as used in nuclear pressure vessels to austenitic stainless steel piping. Inconel 82 filler was used for the buttering interface welds. Hardness tests, Charpy V-Notch tests, tensile tests, bend tests, residual stress measurements, and NDE was performed. Relatively little difference was found in the level of residual stress from the test specimen with a PWHT. All other tests were acceptable with the toughness being improved in the HAZ compared to the test specimen with PWHT.

### *4.2.12 Welding Procedures to Mitigate Reheat-PWHT Cracking in A710/A736 Type Steels, Lundin, C.D., Upitis, E.*

This research involved temperbead welding techniques used to reduce or eliminate the course grain HAZ with buttering techniques so a subsequent repair PWHT could be done with minimized risk for reheat cracking. The materials were very sensitive to reheat cracking so the temperbead technique was used to assist in mitigating the cracking problem.

### 4.2.13 Weld Repair of a 2¼Cr-1Mo Petrochemical Reactor, Baker, K., Sloan, J.R., Upitis, E.

A repair was required on a 2¼Cr-1Mo vessel clad with a stainless steel overlay which was embrittled by sigma. The cracking had extended into the Cr-Mo material. A controlled deposition technique was used to build up the excavated area to avoid further cracking. The final repair weld was then subjected to PWHT.

### 4.2.14 Investigation of Aged Materials for Feasibility of Repair Welding of Refinery Equipment, Japan Welding Engineering Society; Tahara, T., Kohno, T., Mukai, Y.

A number of materials were tested, including some P Nos. 3, 4, and 5A materials. It did not appear that the properties of the aged material were significantly affected by the repair welds which were not true temperbead welds but were rather high restraint bead on plate welds with multiple passes, simulating repair welds.

## 4.3 Industry Experience

Other than the reports of industry experience in item 4.2, a brief survey of nuclear plants that have utilized temperbead repair techniques was made. Seven responses were received. All of the responses except two had applied temperbead using the existing Section XI Code Cases. The two which did not use the Code Cases were for a French utility (different regulatory rules applied) and for a pump casing repair (where the WPS was qualified using IWA-4440 and a PQR from another utility).

Several materials were involved in the repairs reported. Included were carbon steels, martensitic stainless steel, carbon-moly steel, austenitic stainless castings, and dissimilar material combinations. The filler metals used included alloy 52/52M, austenitic stainless, and carbon steel. The processes used included GMAW-SC, GMAW pulsed, GTAW Machine, and SMAW.

Basically, relatively few problems were reported. One utility reported that the vendor welders did not understand the requirements for the welding parameters for the 1st two layers. Another utility reported problems with the GMAW process which resulted in numerous NDE indications. Both problems were resolved – one by additional training and the other by switching to SMAW but with a loss of time.

# Section 5: Temperbead Welding Qualification

## 5.1 General

The qualification of the Welding Procedures and the Welders/Welding Operators can be complicated by inconsistent rules originating from the Code or Code Case addressing the use of the temperbead technique as an alternative to PWHT. The temperbead qualification requirements are only implemented in Section IX if the construction Code specifically references Para. QW-290. Some resolution of consistency is progressing by references to these rules in the construction Codes. However, until the references are complete, caution is needed that the requirements of the Code or Code Case must be addressed instead of or in addition to the requirements of ASME Section IX.

ASME Section XI has recognized the need to reference the qualification rules of Section IX for temperbead welding. Code Case N-762 (approved by ASME on January 21, 2007) specifically refers to the use of Section IX, Para. QW-290 as an acceptable procedure qualification approach in lieu of the requirement contained in Section XI (IWA-4600). In addition, a change has been processed and accepted (but not yet published) in Section XI which references the requirements of QW-290. This change allows the use of previously qualified WPSs in accordance with the IWA-4600 requirements to be used. It is strongly recommended that any qualification of temperbead WPSs address the rules of QW-290 whether or not they are written to cover Section XI IWA-4600 rules or any Section XI Code Cases. This will ease their use in future activities after the effective date of these changes or when other Codes are used for the welding activity.

Other Codes currently reference ASME Section IX, Para. QW-290 as the standard for temperbead WPS qualification. Included are Section III, (NB-4622.9) and NBIC Part 3 (Section 2 Welding Methods alternatives without PWHT). There are also other Codes that are considering the use of the temperbead techniques or to a greater extent than are currently allowed with the stipulation of qualification using the temperbead qualification rules of QW-290.

This may be further complicated by the testing required by the applicable Code or Code Case. The nuclear Codes and Code Cases and Section VIII typically require impact toughness testing as the test required. Section I and B31.1 (although B31.1 does not presently address temperbead welding) would require hardness testing since they do not have impact toughness testing criteria. Many organizations do both toughness testing and hardness testing although there appears to be evidence that the hardness testing done was also inconsistent (Vickers with different loads, Brinell, Rockwell).

ASME Section IX states that the WPS to be used on a temperbead production weld needs to be qualified with all of the essential variables of the basic welding process as well as the essential variables of the temperbead qualification process. The basic WPS qualification variables for each process therefore apply although the temperbead technique may address the PWHT variables as no PWHT being used. See ASME Section IX, Para. QW-290.1 for guidance.

### *5.1.1 Consistency Issues*

Following is a brief description of some of the issues which should be addressed during qualification of temperbead welding as a result of the inconsistency of the existing rules. These issues should be reviewed and addressed if necessary prior to qualification in accordance with ASME Section IX, Para. QW-290.

1. The rules for qualification may differ between source documents (as mentioned in 5.1).
2. The materials to which temperbead welding may be used vary between the source documents. In some cases, materials belonging to P Nos. 1, 3, 4, and 5A may be temperbead welded, in other cases, a more severe limitation may be applied.
3. The temperbead process may be referenced as a controlled deposition process, a half-bead process, or the temperbead process. All are similar in their intent but specific requirements (such as the removal of part of the weld beads in the half-bead technique) may be applied.
4. Requirements for preheat (or allowance to use ambient temperature welding) may be different between the source documents.
5. The welding processes which may be used may be different between the source documents.
6. The application to repair, replacement, or new construction may be different between the source documents. Most of the current rules apply only to repair and also only to repair on welds that have previously been subjected to PWHT.

7. ASME Section XI Code Cases may require prior authorization from the NRC if not currently accepted in the applicable Regulatory Guide (see Table 2-2). There may also be partial acceptance with additional conditions.
8. Some essential variables for welding procedure qualification may change dependent on the qualification testing (i.e., impact toughness or hardness) applied.

## 5.2 Materials Needed

### *5.2.1 Base Materials*

As with all WPS qualifications, materials for temperbead WPS qualification are required to be similar to the materials being welded. However, the product form is not as critical; therefore plate may be used for WPS qualification instead of pipe even if the material to be welded is a pipe. The selection of materials and product form is critical to the qualification both from the standpoint of meeting the qualification requirements and providing for efficiency so excessive testing is avoided.

Other than the limitations of applicability per item 2 of 5.1.1, further limitations depend in part on the testing method being applied for the WPS qualification. If toughness testing is required, the materials need to be of the same P No. and Group No. of ASME Section IX, Table QW/QB-422. Each material category shall be tested as required for temperbead toughness testing in the applicable construction Code. However, when the Construction Code is Section III or Section XI, the ferritic base materials selected for the temperbead qualification have additional requirements. Section III, Para.NB-4334.2(a) and Paras. 4622.9(a)(2) and (a)(3) states:

> **NB-4334 Preparation of Test Coupons and Specimens**
>
> **NB-4334.2 Coupons Representing the Heat Affected Zone.**
>
> (a) If the qualification test material is in the form of a plate or a forging, the axis of the weld shall be oriented in the direction parallel to the principal direction of rolling or forging.
>
> **NB-4622.9 Temper Bead Weld Repair.**
>
> (a) General Requirements.
>
> *(2) Welding Procedure Qualification Test Plate.* The test assembly materials for the welding procedure qualification shall be subjected to heat treatment that is a least equivalent to the time and temperature applied to the materials being repaired.
>
> *(3) Neutron Fluence.* If the repair area is to be subjected to a significant fast neutron fluence greater than $10^{19}$nvt $E^0$> 1 MeV, the weld metal Cu content shall not exceed 0.10%.

Similarly, Section XI, Paras. IWA-4610(b)(1)(a) and (b)(1)(b) states:

> **IWA-4610 General Requirements for Temper Bead Welding.**
>
> *(b)(1) Procedure Qualification*
>
> *(a)* The test assembly material for the welding procedure qualification test shall be of the same P-Number and Group Number, including a postweld heat treatment that is at least equivalent to the time and temperature already applied to the material being welded.
>
> *(b)* If the qualification test assembly material is a plate or a forging, the axis of the weld shall be parallel to the principal direction of rolling or forging.

The concern for neutron fluence is unlikely for operational plants but may apply in the core region of the reactor pressure vessel. If this is the case, close further review of the requirements for welds in this region is required (e.g., surveillance specimens, etc.).

The requirement to subject the qualification coupon to a PWHT at least equivalent to the time and temperature already applied to the area requiring temperbead repair may in some cases be difficult to determine. If this time cannot be ascertained, it may be worthwhile to subject the test material to the PWHT time and temperature limits applicable to the original construction weld procedure if known. If not known, a best effort to determine the expected PWHT time and temperature may be the only alternative.

The rolling direction can be determined by the supplier or by metallurgical means. This is needed to develop the correct weld axis per the above requirements.

Both ASME Section I (Power Boilers) and ASME Section VIII (Pressure Vessels) allow the use of temperbead techniques with limitations. However, they do not require the use of welding qualification per QW-290. They still require the WPS qualification of course and offer specific direction when repairs after PWHT are required. In ASME Section VIII, the directions are given in Para. UCS-56(f) for P Nos. 1 and 3. Toughness testing could be required if required for the original application. Somewhat more restrictive requirements for ASME Section I repair after PWHT applications are given in Para. PW-40.3.4. There is an additional material requirement in that the P No. and the Group No. of the materials are required for the procedure qualification. Testing to ensure that the technique is effective is required but not delineated within Sections I and VIII.

If hardness is the testing method being applied, the material for qualification shall be selected such that the material carbon equivalent (CE) exceeds or equals the carbon equivalent of the material being welded. This can be an issue if the material intended to be welded has a high carbon equivalent in which case it may be difficult to find a material that would adequately address this variable. Since the material is not limited by Group No. when the test criterion is hardness, it may be possible to go to a higher Group No. which may have higher alloy content (unless there are other requirements that prevent this approach. The carbon equivalent (CE) formula to be used is the IIW formula, as follows:

$$CE = C + Mn/6 + (Cr+Mo+V)/5 + (Ni+Cu)/15$$

The requirement to determine the CE when hardness is an acceptance criteria for the temperbead qualification therefore requires the chemical composition (at least the elements noted above) to be known. These are actual composition requirements, not composition requirements noted by the material specifications.

#### *5.2.2 Filler Materials*

The filler metal selection is typically a composition and alloy similar to that used for the original weld if addressing a repair, similar to the base metal if an original weld, or an austenitic material if it is being used as a buttering layer or overlay. The latter applications may require specific dissimilar alloys for the purpose of corrosion resistance and/or strength. If the temperbead technique is being used in a joining application or to fill a repair cavity, the selection of the filler may be to select a filler strength at the lower level of the base material strengths. This is due to the fact that the absence of a typical PWHT may result in a higher than expected strength in the weld even though the HAZ would not be similarly affected.

### 5.3 Welding Procedure Specification (WPS)

The WPS to be used on a temperbead production weld needs to be qualified with all of the essential variables of the basic welding process as well as the essential variables of the temperbead qualification process. The basic WPS qualification variables for each process therefore apply although the temperbead technique may address the PWHT variables as no PWHT being used. See ASME Section IX, Para. QW-290.1 for guidance.

#### *5.3.1 Welding Process Restrictions*

Each governing document (Code, Code Case, regulatory restrictions) must be reviewed since only specific welding processes may be permitted. ASME Section IX addresses the range of processes that are allowed in other documents (QW-290.2 Welding Process Restrictions). The temperbead welding processes permitted by ASME Section IX, Para. QW-290 rules are SMAW, SAW, GMAW (including FCAW), GTAW, and PAW. GTAW and PAW are further limited to exclude manual or semiautomatic application except for the root pass of groove welds made from one side and repairs to temperbead welds. This limitation is due to the relative lack of control of the heat input when the filler is typically added manually and disassociated with the arc.

Specific applications of the temperbead techniques as an alternate to PWHT further limit the processes which may be used beyond the typical requirement that only automatic or machine GTAW or PAW may be used. For example, ASME Section XI, IWA-4600, only references the SMAW and the GTAW automatic or machine processes. The Code Cases listed in item 2.1.6vary regarding the acceptable welding processes.

It should be noted that, although addressed in QW-290, no permitted application of temperbead welding using the SAW process was found in the referenced construction Codes.

## 5.4 Qualification of WPS

The qualification of any WPS is intended to prove that the procedure will result in acceptable properties in the weldment. This is no different for the qualification of temperbead welding techniques where the use of PWHT (and preheat in some applications) may be avoided but which will still result in acceptable mechanical properties. For temperbead WPS qualification, the resulting test weld must be shown to meet the basic property requirements of tensile strength and ductility and also the property of toughness if required by the construction Code (see item 5.3) or acceptable hardness if toughness is not required by the construction Code.

There may be occasions where impact toughness is specified for the temperbead qualification but where the original weld did not require impact toughness qualification (e.g., a safety related component where the original installation was done using B31.1). In either case, the ASME Section IX, QW-250 supplementary essential variables are required to be applied for the temperbead qualification as well as any additional variables required by the applicable implementing document (Code, Code Case, or regulatory). If the qualification is done in accordance with Section IX, QW-290, the additional Impact Test Essential Variables of Table QW-290.4 would apply. The nonessential variables of Table QW-290.4 would also be required to be addressed in the WPS.

In some cases not yet specifically identified (potential applications within B31.1 and Section I) where toughness is not a requirement, the WPS qualification may be accepted on the basis of hardness tests rather than impact toughness. However, there is no current hardness test acceptance criterion so the required hardness test results need only be recorded. There is some current research in progress which deals with developing hardness test acceptance criterion so this may be available in the future.

Since the Codes that permit temperbead welding techniques as an alternative to PWHT are increasingly specifying the WPS qualification in accordance with the Section IX, QW-290 rules, it would be advisable to use those rules as a basis for the requirements. Additional requirements may be imposed by the document authorizing the temperbead usage, but the use of the standard Section IX requirements increases the opportunity that further qualification will not be necessary for other applications. While there is no current application which requires hardness tests per QW-290, it may also be worthwhile to take the required hardness readings and to record them for applications that may be accepted in the future.

### *5.4.1 General Temperbead WPS Qualification Requirements Per QW-290 Rules*

As stated previously, the basic Section IX WPS qualification requirements for the process being used still apply and may provide further limitations than stated for the temperbead qualification variables. In addition, there are several essential and nonessential variables that are required for temperbead welding qualification regardless of the test method (toughness or hardness) being used for verification of the process. These are found in Table QW-290.4in Section IX. The common essential variables are mostly technique variables but include bead placement and bead overlap which are critical to the proper temperbead application. Another common and very important essential variable is the heat input ratio which requires control of the bead size and heat relationship between temperbead passes. EPRI Report 1006806[7] was used as the basis for this variable approach.

The nonessential variables that were added by the rules of QW-290 are all common variables irrespective of the test method. These cover issues such as preheat soak, postweld bakeout, and prevention of moisture intrusion (reduction of hydrogen cracking potential).

### *5.4.2 Temperbead WPS Qualification Requirements Per QW-290 Rules When Impact Toughness Testing Required*

Several temperbead WPS qualification essential variables apply only when impact toughness testing is the required verification test method. These specific variables include the thickness qualification when the material is cooled by backing fluids, the Group No. as well as the P No., and the maximum interpass temperature per layer.

### *5.4.3 Temperbead WPS Qualification Requirements Per QW-290 Rules When Hardness Testing Required*

Several temperbead WPS qualification essential variables apply only when hardness testing is the required verification test method. These specific variables include the thickness qualification when the material is cooled by backing fluids (different limits than when impact toughness is the required test), an increase in the carbon equivalent (see 5.2.1), additional limits on the material thickness, and a record of the preheat temperature for each layer.

### 5.4.4 Additional Application Specific Temperbead WPS Qualification Requirements

A number of temperbead applications are outlined in the documents which allow the technique. Even if the WPS qualification requirements of QW-290 are specifically referenced, additional qualification requirements for the specific application may be, and often are, required. Each application must be reviewed to determine the additional requirements, if any.

## 5.5 Qualification of Welders and Welding Operators

Welders and welding operators are required to be qualified in accordance with Section IX, QW-300 but additional qualification is not specifically required by QW-290. However, a proficiency demonstration is required when a manual or semiautomatic GTAW or PAW repair to a temperbead weld is required (QW-290.6(e)). In addition, Section III (NB-4622.9(a)(7)) and Section XI (IWA-4610(b)(2)) requires a demonstration of ability to deposit sound weld metal when a physical obstruction may impair the welder's ability. Similar demonstrations are also required in many of the temperbead welding Code Cases.

As stated in 5.4.4 for temperbead WPS qualification, there may be additional welder or welding operator qualification requirements imposed by the specific application. An extensive example of this is the production test required by Section XI, Para. IWA-4652.4 for Butter Bead-Temper Bead Welding for Class MC and for Class CC Metallic Liners (see IWA-4650). A number of variables are outlined for this production test that would be required in addition to the basic welder qualification requirements. This production test also requires additional examinations that are not required in most other applications. As with the WPS qualification for specific applications, the welder and welding operator performance qualification or proficiency demonstration requirements must also be reviewed for each specific application.

# Section 6: Training

## 6.1 Training of Welders and Welding Operators

While welders and welding operators are not required to be formally qualified for temperbead welding other than the basic qualification requirements of Section IX, QW-300 and possible additional demonstration of ability as stated in item 5.5, they need to be familiar with the bead placement and heat input requirements of the temperbead WPSs.The temperbead welding techniques require control beyond the requirements of conventional welding.

ASME Section IX, Para. QW-322.1(b) states:

> **QW-322 Expiration and Renewal of Qualification**
>
> **QW-322.1 Expiration of Qualification.** The performance qualification of a welder or welding operator shall be affected when one of the following occurs:
>
> (b.) When there is a specific reason to question his ability to make welds that meet the specification, the qualifications that support the welding he is doing shall be revoked. All other qualifications not questioned remain in effect.

This paragraph requires that the welder and welding operator have the necessary experience or can demonstrate their ability to provide confidence that the requirements of the WPS, in this case the temperbead WPS, can be performed by the individual. This is the essence of assuming the responsibility for the welding performed by individuals under the supervision of the organization. This confidence can be gained by a qualification test using the temperbead WPS, a performance demonstration of ability, or simply by having prior successful experience. However, note that the six-month rule for continuity of qualification is applied by Section IX, Para. QW-290.6(e)(4) when repairs to temperbead welds are done using manual or semiautomatic GTAW or PAW. This applies to the proficiency demonstration required.

### *6.1.1 Recommended Training for Welders and Welding Operators*

A presentation of the basic mechanics of temperbead welding and what effect a properly executed temperbead weld is intended to accomplish should be presented to personnel unfamiliar with the techniques. Appendix A [2] is a recommended handout or screen presentation. Examples of proper and improper bead placement should also be shown. Section IX (Figures QW-462.12 and QW-462.13) and Section XI (Figures IWA-4623.1-1, IWA-4623.2-1, IWA-4633.1-1, IWA-4633.2-1, IWA-4643.2-1, IWA-4652.4-1, IWA-4652.4-2, and IWA-4655-2) are good sources for sketches or drawings showing the temperbead techniques. Section XI also discusses improper temperbead spacing and potential corrections (IWA-4655 and Figure IWA-4655-1).

Emphasis is needed on the importance of the bead placement and the heat input ratio. However, all of the variable requirements of Section IX, QW-290 and of the specific application (which may be controlled or affected by the welding) should be reviewed prior to implementation.

This training should be presented prior to any performance qualification tests or proficiency demonstrations.

## 6.2 Training of Welding Supervision

Welding supervisors overseeing temperbead welding should receive the same training as the welders or welding operators but are not required to demonstrate proficiency or to pass performance qualification tests.

Supervisors who oversee proficiency demonstrations or performance qualifications should also receive training on all of the variables and test requirements for those activities.

## 6.3 Training of Inspectors

Quality control inspectors covering the temperbead welding activities should receive the same training as the welding supervision. In addition, they should receive training on the specific requirements of the WPS and for WPS qualification and testing. The tolerances for the applications expected by engineering regarding bead placement and heat input calculations should be discussed.

## 6.4 Training of Support Personnel

Support personnel include several job functions. This would include repair personnel who may be applying preheat (if required), grinding, or equipment operation and maintenance. It may also include schedulers and management responsible for providing adequate schedule time to correctly accomplish the required temperbead training, proficiency demonstration or qualification, and welding and the economic support for these functions. When Code Case relief requests are required, the Licensing personnel should also be familiar with the temperbead requirements. The efficient application of the temperbead welding techniques depends greatly on non-conventional techniques during welding. While support personnel are often familiar with the conventional techniques, they need to understand the additional requirements needed for temperbead welding.

If the training is not being offered by the technical personnel responsible for temperbead welding repairs, the trainer will need to conference with the technical personnel to ensure that all critical issues are covered.

# Section 7: Implementation of Temperbead Welding Techniques

## 7.1 General

Implementation of temperbead welding techniques as an alternate to PWHT can take a wide range of requirements. This is because standard applications are still be developed and accepted by the Codes. The large number of specific Code Cases in ASME Section XI and Section III for repair is an example of the applications. Section XI also allows temperbead welding to be used in specific repair and replacement applications. Temperbead welding is also permitted for repair of previously post weld heat treated welds that require subsequent repair within the construction Codes Section I, Section III, and Section VIII. Finally, the NBIC allows repairs to welds and materials using temperbead welding techniques.

Other Codes such as B31.1 are considering the addition of temperbead welding to avoid PWHT for some materials. The application of temperbead welding is seeing significant growth since increasing evidence is available which shows the properties which result are adequate and in many cases superior to welds that have been post weld heat treated.

However, due to the very wide range of applications and restrictions, it is very difficult to establish any routine approach to implementation of the temperbead welding process. A few suggestions are offered as follows to highlight some areas of concern when temperbead welding is being used to avoid a difficult, or costly, or impossible conventional PWHT.

### *7.1.1 Planning*

Some use of temperbead welding for repairs can be planned prior to recognition of a repair need. For instance, temperbead repair procedures could be developed for the repairs to previously post weld heat treated welds as is allowed by ASME Sections, I, III, and VIII or to repairs and replacement being performed under the requirements of the NBIC. This approach requires relatively little notice to implement since the necessary WPSs and qualification can be prepared in advance. This is an excellent opportunity to qualify a series of temperbead WPSs using the requirements of ASME Section IX, Para. QW-290 although some additional requirements may be needed when the qualification per QW-290 is supplemented by requirements of the applicable Code. Since welder and welding operator performance qualification is not generally required but may be desirable, this may also be preplanned by offering some training and proficiency demonstration.

Planning for unexpected repairs in operating nuclear plants can be an entirely different scenario. This can require advance identification of the application to determine if the situation would allow the application of currently approved Section XI methods or the use of Code Cases that have received regulatory approval through Regulatory Guide 1.147 (see Table 2-2). If this prior approval has not been issued, a relief request would be required and must be approved in order to apply the temperbead welding solution to the application. This can require a significant pre-planning period to gain that approval. Of course, this would always carry the risks that the relief request would not be approved or that unacceptable conditions would be applied for approval.

### 7.1.2 Acceptance of Method

As stated above, there may be different degrees of acceptance required. Some temperbead applications are pre-approved; others are not. If it is possible to use a pre-approved application, that is a more certain path to success. ASME Section XI Code Cases are often written to address a specific need that has not been pre-approved. This is often the first step in gaining approval within the operational nuclear facilities – get a Code Case approved by the applicable Code. Code Cases may or may not be accepted by the regulatory authority such as the NRC or a State regulatory authority. However, this may be the only route to gaining acceptance.

### 7.1.3 WPS Qualification

The addition of temperbead WPS qualification requirements in ASME Section IX, Para. QW-290, has been a significant step toward standard qualification for the temperbead WPS qualification. Section III, Section XI (in Code Case N-762 and an approved revision not yet published), and the NBIC has adopted QW-290 as the basic WPS qualification standard. However, for those applications that have not yet accepted the standard of QW-290 or which have additional requirements in addition to the requirements of QW-290, specific WPS qualification may be required. The qualification acceptance is typically impact toughness testing of the weld and HAZ but may be hardness testing or both. Specific attention is required for those applications where the temperbead welding technique is applied to repair previously post weld heat treated welds since the material for qualification may require heat treatment for time and temperature prior to the qualification. Where hardness is used as an acceptance criteria, the carbon equivalent of the material for qualification may not exceed the carbon equivalent of the material being welded.

### 7.1.4 Training of Personnel Involved

Since the temperbead welding techniques are not currently a recognized and conventional technique to avoid PWHT, training on the method is strongly recommended and part of the implementation needs. The training needs are addressed in Section 6.

### 7.1.5 Welder or Welding Operator Qualification or Proficiency Demonstration

Some applications require a proficiency demonstration by welders or welding operators but do not specifically require performance qualification. Either qualification or proficiency demonstration will address the need to have confidence in the welder's or welding operator's ability to properly apply the temperbead techniques. However this issue is not well addressed for those applications where neither the proficiency demonstration or performance qualification is required. It is recommended that testing or training be used to gain confidence in the welding being done.

### 7.1.6 Inspection

While inspection is covered in Section 8, the implementation of the temperbead process includes allowing for the inspection that will be performed. This includes inclusion of the inspectors in the training on the temperbead techniques.

### 7.1.7 Records

Records that need to be kept include not only the records required by the Quality Control/Quality Assurance Program, but also commentary on the issues that may need to be addressed in future applications. Certainly records such as WPSs, PQRs, Performance demonstrations, WPQs, Quality Control inspections, examination procedures and results, and nonconformance records are almost always required to be kept. Equally valuable are notes of issues which needed to be addressed to make the implementation more efficient.

# Section 8: Inspection of Temperbead Welding Activity

## 8.1 General

Inspection includes much more than just traditional Quality Control overview although that is certainly one part of inspection. The only individual that is familiar with every aspect of the temperbead welding as it is being applied is the welder or welding operator. The supervisor of the welder has responsibility to provide adequate direction and to make sure their instructions are followed but may not be present during the entire operation. The Quality Control inspector typically spot checks the operation with hold points or notification points to verify critical steps of the operation. The NDE technician typically provides required examinations during or after the temperbead welding operation. The engineer would typically establish the requirements to meet the requirements of the Code, Code Cases, or regulations. The Authorized Inspector (or Authorized Nuclear Inspector), the Owner's Inspector, or the Regulator provides verification that the entire operation met the requirements.

Following are some suggested activities that may be considered for these different functional positions during a temperbead welding operation. These suggestions should be considered while keeping in mind that different organizations may use different titles or assign multiple functions to individuals. In many cases contract organizations are utilized to perform the operation.

### *8.1.1 Role of Engineer (or Welding Program Owner)*

- Periodic progress checks
- Communication with management
- Resolution of problems and nonconformances

### *8.1.2 Role of Welder or Welding Operator*

- Follow the requirements of the WPS
- Verify machine settings to meet heat input requirements
- Verify bead placement
- Report problems with welding

### 8.1.3 Role of Supervisor

- Ensure that welder or welding operator has proper equipment and materials
- Periodic progress checks
- Report problems with welding or other operations
- Notify when next operation may be required

### 8.1.4 Role of Quality Control Inspector

- Verify that WPS has been properly qualified, including conventional requirements and additional requirements of temperbead applications
- Verify that welder or welding operator has been qualified as required by conventional requirements and additional requirements of temperbead applications
- Establish hold and notification points to verify critical operations
- Identify and communicate problems
- Verify bead placement
- Verify heat input ratio

### 8.1.5 Role of NDE Examiner

- Perform NDE as required
- Report results of NDE

### 8.1.6 Role of Authorized Inspector, Owner's Inspector, or Regulator

- Establish hold and notification points as desired
- Verify requirements for temperbead operation have been met
- Verify that problems have been adequately resolved
- Verify that results of NDE examination are acceptable
- Verify that any required pressure test has been completed

# Section 9: References


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24. *Challenges and Solutions in Repair Welding for Power and Process Plants*, WRC Bulletin 412, Welding Research Council, Inc., New York, NY: 1996.

# Appendix A: Temperbead Welding Technique [2]

Temper bead welding is defined as the placement of a weld bead at a specific location in or at the surface of a weld for the purpose of affecting the metallurgical properties of the heat-affected-zone or previously deposited weld metal.

Metallurgical properties of the heat-affected zone (HAZ) are affected by the temperature that is reached in the heat-affected zone as shown in Figure A-1. Portions of the heat-affected zone that exceed the lower transformation temperature (A1) are subject of formation of non-equilibrium-cooled microstructures upon cooling. Specifically, slow cooling produces ferrite and carbide (pearlite), rapid cooling produces martensite and, for some alloys, intermediate cooling rates produce bainite. See Figure A-2. Martensite is generally not a preferred microstructure since it is hard and brittle. Martensite can, however, be softened and its toughness increased by reheating the microstructure to just below the lower transformation temperature; this is known as tempering. Bainite is generally an acceptable microstructure that results in good mechanical properties.

In addition to possibly forming less-than-desirable microstructures upon cooling, the portion of the HAZ that exceeds approximately 1900°F (1040°C) will exhibit grain growth. See Figure A-3. As grains enlarge, the toughness of the steel tends to drop. The result is that there will be a variety of microstructures in the HAZ, including the “coarse-grain region” that exhibits reduced toughness. See Figure A-4.

The essence of temper bead welding is to control subsequent weld beads (both overlapping and subsequent layers) so that the appropriate level of overlap of HAZs improves the properties of the previously-deposited weld metal and HAZ. See Figures A-5, A-6, and A-7.

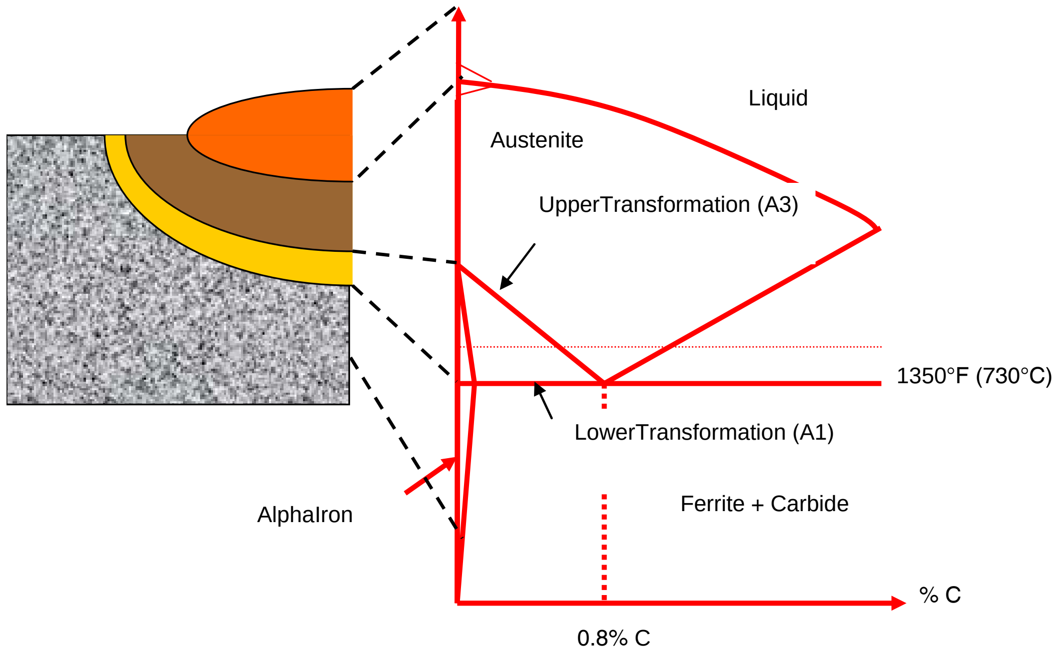


*Figure A-1*
*Bead on plate: This diagram shows various parts of the heat-affected zone related to the equilibrium phase diagram.*

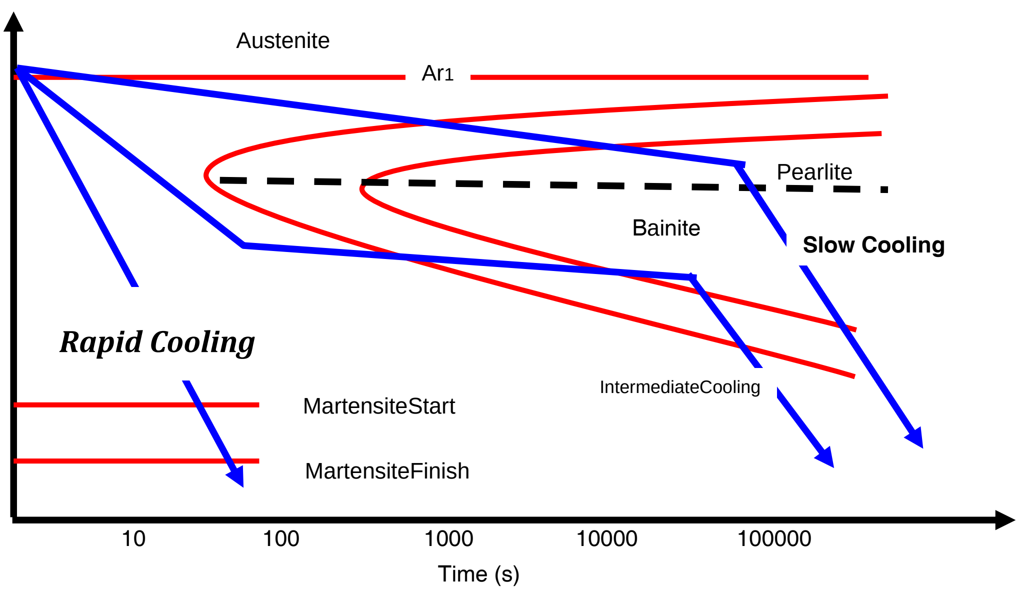


*Figure A-2*
*Time-Temperature-Transformation Diagram: This diagram shows the various microstructures that can result from different cooling rates. The microstructure produced depends on the chemical analysis of the material and the specific cooling rate. Different materials have different transformation curves; generally, the more highly-alloyed a material, the easier it is to transform it into martensite.*

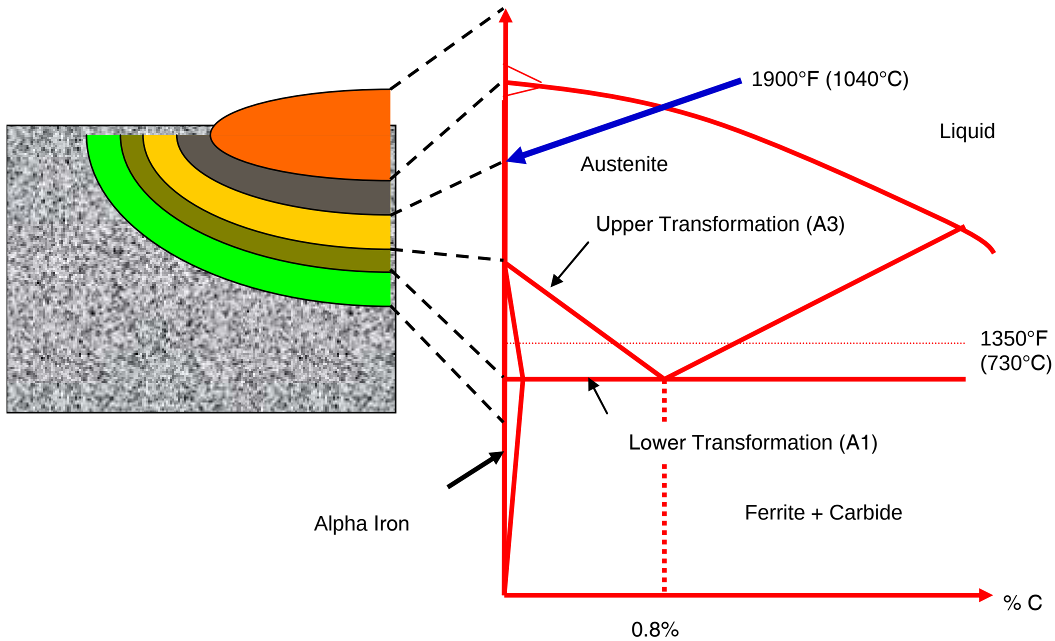


*Figure A-3*
*Rapid Grain Growth Occurs above About 1900°F (1040°C): Although phase changes occur above the A1 temperature, grain growth does not occur until the metal reaches about 1900°F(1040°C). Grain growth results in degradation of toughness.*

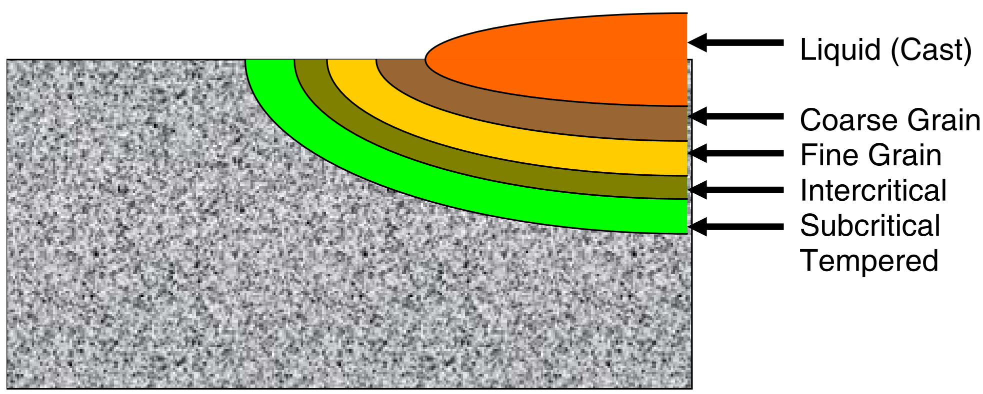


*Figure A-4*
*Nomenclature of various regions in the HAZ: Heat-affected zones are quite complex. Coarse grains are formed near the weld metal and this typically reduces toughness. Fine grain structure zones are frequently tougher than the original base metal.*

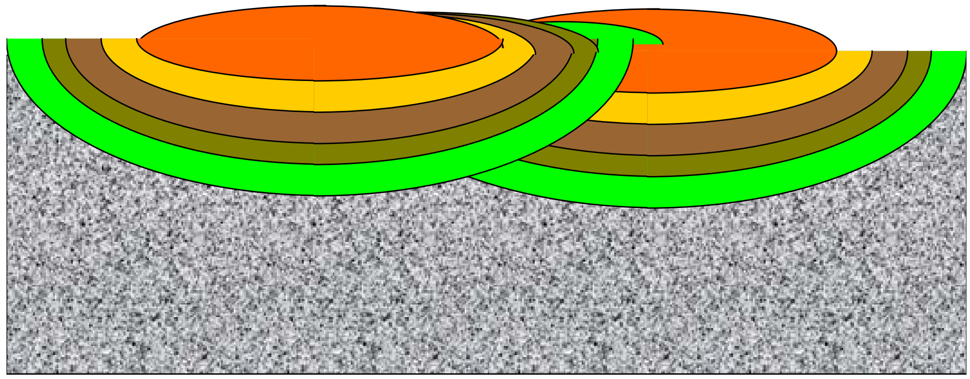

*Figure A-5*
*Weld Beads with Minimum HAZ Overlap: Overlap results in tempering and refinement the coarse-grain zone and previously deposited weld metal. This improves properties somewhat but leaves large amounts of the previous structure untempered.*

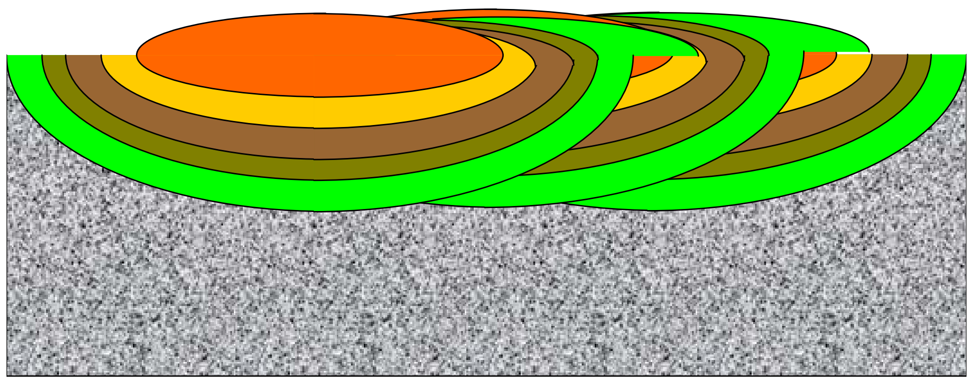

*Figure A-6*
*Weld Beads with Plenty of Overlap: An adequate amount of overlap results in significantly more tempering and refinement the coarse-grain zone and previously deposited weld metal than happened in Figure 5. A second layer of weld metal will result in further tempering and refinement coarse-grain zone. Control of overlap, thickness of the weld bead and the energy provided by subsequent layers can improve the properties of the heat-affected zone and previously deposited weld metal.*

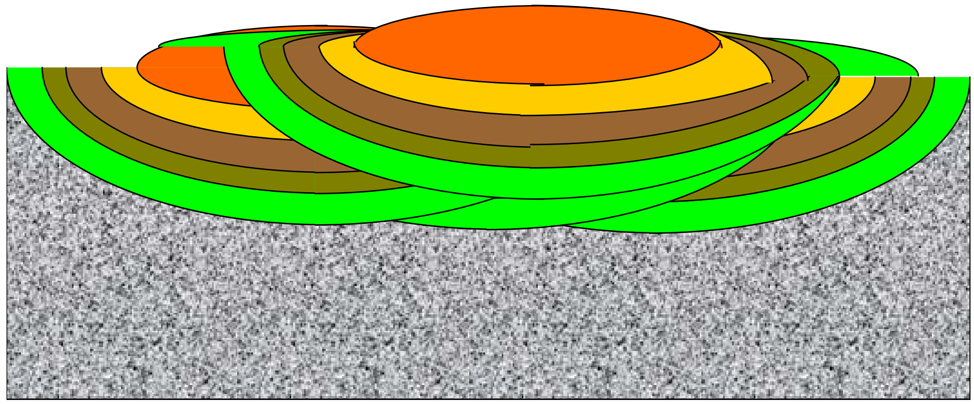

*Figure A-7*
*Weld Beads with Plenty of Overlap and a Second Layer:  A second layer of weld metal further modifies the microstructure of the previously deposited weld metal and heat-affected zones. If the weld beads are appropriately sized relative to each other, the properties of both the previously deposited weld metal and heat-affected zone are improved.*

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**Electric Power Research Institute**
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com