Cladding and Alloy 600 Repair Options in ASME Bruce Newton Manager, Welding Engineering



Cladding Repairs

- What is cladding?
 - From ASME IX, "Overlay, Corrosion-Resistant Weld Metal"
 - "Deposition of one or more layers of weld metal to the surface of a base material in an effort to improve the corrosion resistance properties of the surface. This would be applied at a level above the minimum design thickness as a nonstructural component of the overall wall thickness."
- Cladding provides a non-structural, protective barrier
- Since the deposit is non-structural:
 - Tensile testing of cladding PQR coupons is not required
 - The cladding HAZ is exempted from impact testing (NB-2121(f)) and IWA-4610(b)(1)(-e))
 - Procedure qualification focuses on deposit purity and integrity, rather than strength (QW-453)
 - ASME IX requires the following clad PQR coupon testing:
 - Liquid Penetrant Testing (PT) of the CRO deposit face
 - Four transverse side bend specimens
 - Chemical Analysis at minimum deposit thickness (when deposit chemistry is specified by the WPS)



Cladding Integrity

- Since cladding protects the underlying material from degradation:
 - Cladding integrity is important in maintaining component integrity
 - Cladding breach exposes underlying material to damage
 - Localized substrate exposure is undesirable
 - Can result in accelerated corrosion/damage in exposed area(s)
 - Detached cladding can cause damage as it travels through the system
- Cladding degradation has many causes:
 - Improper installation (lack of bond, lack of fusion, porosity, etc.)
 - Improper clad deposit chemistry (corrosion-susceptible)
 - Inservice damage (impact, high flow, thermal shock, erósion)
 Propagation of weld flaws/defects
- Clad damage is usually identified visually (via camera)
 - Upon initial detection, degradation is often considered 'new', but:
 - Industry experience has shown many newly identified areas of clad degradation are actually 'old,' but were previously undetected
 - In lieu of 'immediate' repair, Owners may defer repair for one or more operating cycles, so damage can be monitored and assessed



Cladding Repair Options

- Cladding repair in Class 1 vessels typically requires PWHT
 - PWHT is required for:
 - Welded repair of cladding on P3 vessels where:
 - Remaining clad thickness is 1/8" (3 mm) or less
 - PWHT of clad repairs is not desirable (often impossible)
- Temperbead welding avoids PWHT
 - Temperbead options in ASME Section III, 1999 Edition:
 - Prepare a WPS per NB-4622.10
 - Welding must use the SMAW process
 - Preheat to 350°F (177°C)
 - After welding, post-soak 2 hours at 450-550°F (232-288°C)
 - Temperbead options in ASME Section III, 2017 Edition:
 - Prepare a WPS per ASME IX, QW-290 (Ref. NB-4622.9(c))
 - Welding must use either the GTAW or SMAW process



Cladding Repair Options in ASME Section XI

- IWA-4640 addresses temperbead clad repair (2017 Ed.)
 - Prepare a WPS per IWA-4610
 - SMAW or Machine GTAW are permitted
 - Preheat to 350°F (177°C) for SMAW; 300°F (150°C) for GTAW
 - Preheat maintenance is required
 - After welding, post-soak 2 hours at 450-550°F (230-290°C)
- These rules were rarely used because:
 - Preheat and post-soak are impractical (or impossible)
 - IWA-4644 states that final NDE must include:
 - Surface exam (PT) and volumetric exam (UT or RT), however:
 - Volumetric exam of clad repairs is often impractical (or impossible)
- So, Code Cases were developed...



What is an ASME Code Case?

- An ASME Code Case provides alternatives to existing Code rules
 - Code Cases approval is usually faster than Code revision approval
 - Code cases can focus on specific applications and requirements
 - This focus simplifies their review and approval
 - So, a Code Case is an efficient and effective means to obtain ASME-approved solutions to specific issues
 - Code Cases are formally endorsed by ASME as approved alternatives to published Code rules
 - Representatives of the regulatory agency (NRC) and Authorized Inspection Agencies (ANII) participate in ASME Code Case review and approval
 - In the US, the regulator (NRC) typically considers ASME Code Cases to be legitimate, acceptable alternatives to published ASME Code rules (Reference USNRC Regulatory Guide 1.147)



Ambient Temperature Temperbead Welding Effective tempering without elevated temperature preheat and without PWHT



Code Cases for Ambient Temperature Temperbead Welding

- Machine GTAW is commonly used for temperbead welding
- Several Code Cases provide GTAW temperbead rules:
 - Code Case N-638: Ambient Temperature Temperbead welding
 - Contains 'generic' ambient temperature temperbead requirements
 - Was originally used for defect excavation and rewelding
 - N-638 does not specifically address structural weld overlays (SWO)
 - As PWSCC caused DMW cracking, N-638 was used in conjunction with N-504 (overlay of SS piping) to perform overlays
 - A relief request was used to combine the two Code Cases
 - This process was complex and confusing; a new Code Case was needed



Code Cases for Ambient Temperature Temperbead Welding

- Machine GTAW is commonly used for temperbead welding
- Several Code Cases provide GTAW temperbead rules:
 - Code Case N-740: Weld Overlay Repair of Class 1, 2, and 3 Items
 - N-740 was developed as 'stand alone' rules for SWO
 - N-740 is written exclusively for structural weld overlay
 - Includes both stainless steel and DMW overlays
 - Expands and adds details for SWO design
 - Adds NDE acceptance criteria restrictions
 - N-740 Appendix 1 contains the temperbead rules of N-638
- These and other Code Cases have been successfully used to mitigate Alloy 600 issues related to PWSCC
- Tempering is typically achieved as follows:



Code Cases for Ambient Temperature Temperbead Welding

- For Ambient Temperature Temperbead Welding:
 - Three tempering layers are required
 - Repair surface area is limited to 500 In² (325,000 mm²)
 - Maximum Repair Depth:
 - For excavation and repair (N-638): Maximum repair depth is 50% of the ferritic base material thickness
 - For overlays (N-740): Maximum repair depth is limited to 3/8 Inch (10 mm) in the ferritic base material
- Other Code Case requirements stipulate:
 - Qualification applies only to structural welds not cladding
 - Impact testing of PQR coupons is required
 - Surface and volumetric NDE (PDI-Ultrasonic Examination) is required for completed repair welds
- Many of these requirements are not well suited to nonstructural clad repairs, so application-specific Code Cases were needed



ASME Code Case N-829

Austenitic Stainless Steel Cladding and Nickel Base Cladding Using Ambient Temperature Temperbead Machine GTAW Temper Bead Technique



Code Case N-829 Cladding Repair using Machine GTAW

- N-829 is based on the practices and methods proven by application of N-638 and N-740
- N-829 applies only to stainless and nickel cladding
- Elevated temperature preheat and PWHT are eliminated
- Machine GTAW is used
- Three tempering layers are required
- Repair surface area is limited to 500 ln² (325,000 mm²)
- Since N-829 applies only to nonstructural cladding:
 - Maximum depth of a repair into the ferritic base material is limited to ¼ Inch (6 mm) or 10% of the base metal thickness, whichever is less
 - Completed welds are examined by PT
 - Volumetric examination of clad repairs is not required



Code Case N-829 Cladding Repair using Machine GTAW

- Welding procedure qualification is as follows:
 - The PQR coupon is:
 - A 6" by 6" by 2" (150 mm by 150 mm by 50 mm) plate
 - The same P-No and Group Number as the production base material
 - A cladding deposit is installed on the coupon face
 - Any welding process may be used to deposit the SS or Ni clad
 - After cladding, a repair cavity is prepared by excavating into the cladding
 - The excavation exposes the underlying base material
 - The excavation is 6" by 1.5" (150 mm by 40 mm)
 - The repair cavity is rewelded using three-layer GTAW machine temperbead welding
 - After temperbead repair, the coupon is tested as follows:
 - Liquid Penetrant testing is performed on the clad face
 - Four transverse side bend tests are performed
- N-829 was approved December 28, 2012 and was published with the 2013 Edition of ASME Section XI



ASME Code Case N-840

Cladding Repair by Underwater Electrochemical Deposition in Class 1 and Class 2 Applications



- N-840 establishes an innovative approach to clad repair:
 - It provides an alternative to welding, thereby avoiding preheat, post-soak, and temperbead requirements
 - It deposits a corrosion-resistant material using electrochemical deposition (ECD)
 - This non-structural nickel plating:
 - Effectively isolates the substrate from contact with process fluids
 - Protects the substrate from erosion and corrosion
- N-840 builds on knowledge and experience gained from prior Code Case N-569
 - N-569 is titled: "Alternative Rules for Repair by Electrochemical Deposition of Class 1 and Class 2 Steam Generator Tubing"



- N-569 was written in 1995, when:
 - Steam generator tube cracking and leakage was common
 - Effective, affordable mitigation options were badly needed
 - Steam Generator replacement was not desired
 - Some units faced decommissioning unless a repair option was approved
 - Repair options for SG tubes were limited
 - Tube Plugging (useful for only a limited number of tubes)
 - Tube Sleeving (repairs were considered temporary)
 - Each repair option had its own, unique limitations, so alternatives were urgently needed by the nuclear industry
 - A large task force of technical experts and industry representatives (approximately 30 people) was formed to develop Code Case rules and expedite ASME approval of this new process, called '*Electrosleeving*'



- Approved on August 9, 1996, N-569:
 - Established ECD as an ASME-endorsed repair process
 - Established ECD qualification and implementation rules:
 - Defined the essential variables governing ECD
 - Qualification, and;
 - Installation
 - Classified ECD deposits as structural and pressure-retaining
 - ECD is unique in that, unlike welding, the deposit material is actually fabricated in-place (a new ASME consideration)
 - Authorized ECD as a permanent, structural repair for throughwall SG tube cracks
 - Repairs were installed on the ID surface of defective tubes
 - These repairs were considered a structural replacement, so underlying SG tube cracks did not require removal
 - Established ECD methodology:



- The ECD process is accomplished by:
 - Placing an anode near the surface to be plated
 - Enclosing this anode and the repair surface in a sealed chamber
 - Circulating a chemical cleaning solution through the sealed chamber to clean the substrate surface
 - Flushing the cleaning solution from the chamber
 - Initiating an electrical current in the anode
 - Circulating an electrolyte solution (typically nickel chloride and boric acid) in the chamber to form an initial deposit layer (i.e., strike layer)
 - Circulating a nickel-bearing electrolyte through the chamber to form the ECD deposit



- Advantages of ECD repairs included:
 - Excellent corrosion resistance, based on laboratory tests of ECD deposits, which included:
 - Primary Water Testing (15,000 hours)
 - Pure Water Testing (4,000 hours)
 - Shutdown Condition Testing (1,000 hours)
 - C-Ring Testing in a caustic environment (3,000 hours)
 - High strength (tensile and burst testing)
 - High toughness
 - Excellent adhesion and ductility (ASTM E290 and B489)
 - High creep resistance (ASTM E139)
 - Minimal heat transfer loss



- N-569 testing confirmed ECD deposit strength
 - Burst testing was used to qualify ECD deposits as 'specially designed fittings' (ANSI B16.9)
 - Burst tests showed ECD strength was ≥ original SG tube materials
- N-569 demonstrated the acceptability of ECD for structural repair
 - N-569 was successfully implemented in production applications
- The methodology of N-569 provided a foundation on which to build N-840 for nonstructural clad repairs
 - Compared to SG tubes, however, clad repair poses some unique challenges...



- For cladding degradation, each repair is unique:
 - The chamber and seal must match the shape and contour of the repair location
 - The anode must be configured to match work piece contours
- N-840, therefore, addresses qualification as follows:
 - First, Process Qualification Testing is used to demonstrate, in a shop environment, that the ECD process itself produces acceptable deposit quality
 - Second, Process Demonstration Testing is performed on a mockup that simulates the actual repair, including:
 - Repair shape and configuration
 - ECD chamber configuration
 - Water depth
 - When Process Qualification Testing and Process Demonstration testing are complete, the ECD process is ready for production use



- N-840 deposit properties are acceptable for clad repairs:
 - Resistant to stress corrosion cracking and general corrosion
 - Low residual stresses, since ECD is a low-temperature process
 - Minimal heat transfer loss (relatively thin deposits that are intimately bonded to substrate surfaces)
 - Smooth, uniform deposit surfaces are generally suitable for service in the as-deposited condition
- Completed deposits are examined visually no volumetric exam
 - All indications greater than 0.044 In (1.1 mm) are relevant
 - Rounded indications greater than 1/16" (1.5 mm) are rejectable
- N-840 was approved January 23, 2014
 - Dr. Seong Hwang played a major role in the development and approval of N-840



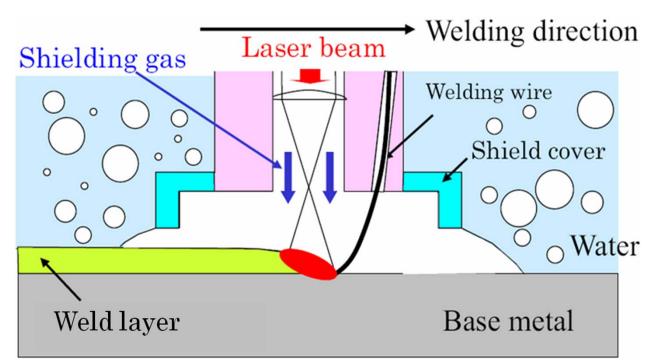
ASME Code Case N-876

Austenitic Stainless Steel Cladding and Nickel Base Cladding Using Ambient Temperature Automatic of Machine Dry Underwater Laser Beam Welding (ULBW) Temper Bead Technique



- ULBW is dry underwater welding, in that:
 - Welding is performed in a small chamber
 - Shielding gas is used to:
 - Create positive gas pressure in the chamber and thereby;
 - Displace water, to create a dry laser welding environment





- Laser Beam
 - Serves as welding heat source
 - Eliminates electric arc
 - Precise weld process controls



- Argon Gas
 - Displaces water under shield cover
 - Shields molten pool

- N-876 establishes an innovative approach to clad repair:
 - Enables welded clad repair in an underwater environment
 - Difficult-to-access areas may be repaired without draining
 - Mitigates radiation associated with primary vessel repair
- N-876 builds on knowledge and experience gained from prior Code Case N-803
 - N-803 is titled: "Similar and Dissimilar Metal Welding Using Ambient Temperature Automatic or Machine Dry Underwater Laser Beam Welding (ULBW) Temper Bead Technique"



- N-803 introduced ULBW to the ASME for the first time
- As a new welding process, ULBW:
 - Required extensive development and testing
 - The ASME "Task Group on ULBW" was formed:
 - Broad industry representation and participation
 - Two NRC representatives actively participated
 - Specific testing needs were dictated by the Task Group
 - Process essential variables and test requirements were the result of the ASME consensus process
 - Test results were documented in a white paper submitted to ASME with N-803



Test	Status	Results
Delta Ferrite Content	Acceptable	Results comparable to GTAW
All Weld Metal Tensile Test	Acceptable	Results comparable to GTAW
Entrained Diffusible Hydrogen	Acceptable	Certified as 'Extra Low Hydrogen' (<5mL/100g)
Molten Pool Cooling Rate	Acceptable	ULBW fully solidifies before contacting water
Side Bend Test	Acceptable	Side bend specimen PT results: White
ULBW Water Chemistry Effect	Acceptable	ULBW does not alter water chemistry
Weld and HAZ Metallography	Acceptable	No new or different microstructures
ULBW vs. GTAW	Acceptable	ULBW deposit is comparable to GTAW
Effect of Borated Water on ULBW	Acceptable	Borated water does not affect weld quality
Temper Bead Parameter Development	Acceptable	ULBW achieves effective HAZ tempering
Charpy Impact Testing	Acceptable	HAZ MLE significantly higher than base metal



- Clad repair Code Case N-876 was, therefore, based on two existing Code Cases:
 - N-803: ULBW Temperbead Welding
 - N-849: GTAW Temperbead Cladding Repair
- Essential variables for the ULBW process were taken from N-803, including:
 - Depth Limitations: A change of more than +\- 33 feet (10 m) requires requalification
 - Shield Cover Size: A decrease in the size of the shield cover requires requalification
 - Filler Material Transport: A change in the method of filler material transport (from dry to wetted) requires requalification



- Essential variables for Temperbead Cladding were taken from N-849, including:
 - A 6" by 6" by 2" (150 mm by 150 mm by 50 mm) PQR coupon is used
 - A clad deposit is installed on the coupon face
 - After cladding, a repair cavity is prepared by excavation
 - The excavation is 6" by 1.5" (150 mm by 40 mm)
 - This repair cavity is rewelded
 - Standard, three-layer GTAW machine temperbead welding is used
- After repair, the production ULBW clad repair is tested as follows:
 - Liquid Penetrant testing is performed on the clad face, when practical
 - When Liquid Penetrant testing is not practical, VT-1 is substituted
 - N-829 stipulates criteria for the VT-1 examination
- N-876 was approved June 12, 2017



Summary

- Cladding damage is an increasingly common issue in operating plants
- Recognizing the need for in-service repairs, ASME has issued three Code Cases to repair degraded cladding:
 - N-829, GTAW Temperbead Repair of Cladding
 - N-840, Underwater ECD Repair of Cladding
 - N-867, Underwater Laser Beam Welding Repair of Cladding
- These Code Cases provide targeted solutions to nonstructural cladding degradation, enabling:
 - Cost-effective repair options that are;
 - Targeted specifically toward cladding repairs:
 - Without elevated temperature preheat and PWHT
 - Without volumetric examination of repairs

