CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Nickel Development Institute (NiDI) Workshop on the Fabrication and Welding of Nickel Alloys and Other Materials for Radioactive Waste Containers; Project Number 20.06002.01.081; AI 06002.081.301

DATE/PLACE: October 16–17, 2002
Las Vegas, Nevada

AUTHOR: D.S. Dunn

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PERSONS PRESENT: D.S. Dunn, Center for Nuclear Waste Regulatory Analyses (CNWRA), T. Bloomer, U.S. Nuclear Regulatory Commission (NRC) and approximately 60 representatives from various organizations including NiDI, the U.S. Department of Energy (DOE), Bechtel SAIC, Nuclear Waste Technical Review Board (NWTRB), Lawrence Livermore National Laboratory (LLNL), Idaho National Engineering and environmental Laboratory (INEEL) Clark County, Nevada alloy producers, and fabricators.

BACKGROUND AND PURPOSE OF TRIP:

The objective of the Nickel Development Institute Workshop was to discuss issues related to the design, materials selection, fabrication, welding, and degradation of the waste package (WP).

SUMMARY OF PERTINENT POINTS:

The workshop was composed of presentations by personnel from the Yucca Mountain Project M&O (LLNL), alloy producers, and various fabricators. Several open discussions were also held. Copies of the presentations will be sent to the workshop attendees at a later date.

The workshop was started with introductions by R. Moeller and G. Coates from NiDI. The role of NiDI was briefly explained. The NiDI promotes the use of nickel, and nickel containing alloys for a variety of applications.

Jerry Cogar (Bechtel SAIC) described the progress on the production and testing of WP mockups. The FY-00 mockup produced using an Alloy 22 outer barrier consistent with the site recommendation (SR) WP design is scheduled to be induction annealed at Ajax Magnothermic on November 7, 2002. There has been a lengthy delay in the schedule that was attributed to financial difficulties experienced by project subcontractors including Ajax Magnothermic. The induction annealing setup was described. The process will use a heating coil approximately 18 inches long traveling at 0.5 in/min. The coil will heat the extended outer closure lid to 1,125 °C [2,057 °F], and forced air will be used to cool the WP to below 500 °C [932 °F] in approximately 3 to 5 minutes.

The presentation also briefly described a weld flaw study recently completed by Senior Flexonics Pathway (New Braunfels, Texas). At present the report prepared by Senior Flexonics Pathway is under review and no details of the study were provided.

A study on the effect of alloy chemistry on processing, fabrication and thermal stability that is planned in the near future was also briefly described by J. Cogar and D. Smith (Bechtel SAIC LLC). The study will include variations in alloy chemistry including alloying and trace elements using 10 pound heats. It is anticipated that processing of some heats where concentration of the trace elements is maximized will not be possible. No additional details of the proposed study were provided.

J. Grubb (Allegheny Technologies, Allegheny Ludlum) presented information on processing of materials for the engineered barrier system. Currently there is only one 120 inch mill in the U.S.-owned by Bethlehem Steel. The 120-inch mill can produce Alloy 22 plate that is approximately 96 in wide. Production of plate with a width greater than 96 inches is not possible due to the physical limits of the mill. A 96 wide plate has some variation in cross-sectional thickness (thicker in the middle and thinner on the edges) typically referred to as crowning. Mills are typically limited to plate widths of 79 to 80 inches. Pickling, which is used to remove scale and chromium depleted layers after annealing typically has a length limitation of 380 inches. As a result of the width limitation of rolling mills, some WPs may require more than one circumferential weld in order to have sufficient length. For the proposed WP materials, there is adequate capacity and raw material availability to meet the projected demand. This does not appear to be the case for the titanium-palladium drip shield material however, and material constraint may be an issue. In subsequent discussion, D.C. Agarwal (Thyssen Krupp VDM) indicated that Krupp VDM can produce both Alloy 22 and Alloy 59 up to 118 in wide. The mill is limited to a 6000 pound maximum weight. Agarwal also raised the question on foreign versus domestic producers of material. At present there has not been any decision made to limit the supply of material to only American producers.

A. Ligenfelter (LLNL retired) provided information on the welding metallurgy of nickel alloys which included some historical information on alloys such as Alloy 600. Specific problems with welding were presented. Defects that must be considered include fusion zone cracking, contamination cracking, and lack of fusion. Fusion zone cracking of nickel base alloys can be attributed to chemical composition of the alloy, weld process and welding parameters, and weld joint restraint. Elements known to promote fusion zone cracking include boron (B), cerium (Ce), magnesium (Mg), calcium (Ca), phosphorus (P), and silicon (Si). Contamination cracking can be caused by a variety of elements including copper (Cu), zinc (Zn), and lead (Pb). Cases of lead as a source of contamination cracking have been noted when lead soft face hammers were used in fabrication shops to align components prior to fabrication. Another source of contaminants is temperature crayons that are often used to determine weld interpass temperature. Lack of fusion is perceived to be a likely type of weld defect based on the geometry of the weld joint and the viscous weld pool.

Marcos Herrera (Structural Integrity Associates) Presented some work on the finite element modeling of the WP outer closure weld during induction annealing. Much of the information presented on stress profiles was similar to the information published in analysis/model reports (AMRs). Temperature profiles during induction annealing were shown for the SR WP design. Future work will include bench marking the calculations using measurements obtained from the WP mockup.

T. Summers (LLNL) presented work on the phase stability studies for Alloy 22. Much of the material was previously presented in recent Material Research Society (MRS) Symposium Proceedings. The work was focused on characterizing the phase transformation after isothermal holds at temperatures up to approximately 750 °C [1,382 °F] for the purpose of extrapolating to repository temperatures. Consistent with previous papers and the aging and thermal stability AMR, the results presented suggest that Alloy 22 will not undergo significant phase transformation even after 10,000 years at temperatures of 300 °C [572 °F]. Because the WP will be limited to temperatures below 300 °C [572 °F] phase transformation after emplacement of the WPs is not expected to occur.

J. Crum (Special Metals) presented some information on the thermal stability of C-276 and Alloy 686. Alloy 686 is produced by Specialty Metals (formerly Inco Alloys) and designed to compete with Alloy 22, (i.e., C-22 from Haynes International), and Alloy 59 (Thyssen Krupp VDM). The information presented was limited to transformations that were expected at or below 500 °C [932 °F]. Long-range ordering was observed at temperatures in the range of 400 to 500 °C [752–932 °F] and it was suggested that a fully ordered material may be representative of the material after extended periods in the proposed repository. This suggestion was not well supported by calculations of expected WP temperatures in the proposed repository.

R. Mizia (INEEL) presented the results of work to develop a Ni-Cr-Mo-Gd alloy for neutron absorption. The results presented suggest that the alloy has adequate neutron absorption characteristics. However the Ni-Cr-Mo-Gd alloy cannot meet the minimum impact strength requirements of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code. After the presentation D. Stall (Framatome ANP) asked about the selection of gadolinium as a neutron absorber and inquired if other elements had been considered. R. Mizia responded that alloys with other elements were not produced and that the selection of gadolinium was based on the neutron absorption.

D.C. Agarwal (Thyssen Krupp VDM) presented material comparing Alloy 59 to Alloy 22. Alloy 59, which is under patent by Krupp VDM, is a nickel-chromium-molybdenum alloy designed to compete with Alloy 22 and is described as a pure ternary alloy that is produced with low concentrations of tungsten, iron, and cobalt to enhance corrosion resistance and thermal stability. Much of the presentation material was recycled from previous NiDI workshop presentations from Krupp VDM as well as Krupp VDM Alloy 59 marketing material. Tests conducted at Krupp VDM to compare the long term thermal stability of Alloys 22 and 59 indicate that Alloy 59 has better thermal stability. Similarly, corrosion testing of welded material using a variety of standardized tests with aggressive solutions (i.e., boiling HCl, boiling H_2SO_4 + $Fe_2(SO_4)_3$, and boiling oxidizing-acid-chloride solutions) suggests that the performance of Alloy 59 is better than Alloy 22. Krupp VDM can produce both alloys. During the post presentation discussion several apparent inconsistencies in the data were noted. In addition, the time temperature stability diagram, which is a staple of the Krupp VDM marketing literature, suggests that the thermal stability of Alloy 59 is only marginally better than Alloy 22.

G. Gordon (Framatome ANP) presented an update to the stress corrosion cracking testing utilizing constant load, U-bend, and slow strain rate tests (SSRT). Constant load tests were conducted using reduced section tensile specimens that contained both base metal and weld metal. Three notches were machined in the reduced cross-section that increased the stress intensity by a factor of 3.4. No stress corrosion cracking was observed after testing in basic saturated water (BSW), simulated concentrated water (SCW), simulated acidified water (SAW), simulated saturated water (SSW), concentrated $CaCl_2$, NaCl, or 1 percent $PbCl_2$ solutions. Crack growth rate tests using compact tension (CT) specimens indicate that cracks can be initiated in Alloy 22 under low frequency cyclic loading; however, the crack propagation rates are slow and crack propagation tends to stop under static loading conditions. The effect of lead on crack growth rates was evaluated by adding $Pb(NO_3)_2$ to BSW. No effect of lead was observed. In the subsequent discussion, a concern was raised about the validity of evaluating the effect of lead on stress corrosion cracking in this type of tests. Because BSW contains carbonates, it is likely that most of the lead added to the BSW solution was precipitated as lead carbonate. While such a test may demonstrate that the solubility of lead in carbonate containing solutions is insufficient to cause stress corrosion cracking of Alloy 22, it does not demonstrate that lead does not promote stress corrosion cracking.

G. Gordon (Framatome ANP) also presented information on stress mitigation methods to impart compressive stresses to the WP closure welds. Limited additional information was presented on the use of laser peening. Another method described was low plasticity burnishing. The method uses a hard sphere such as tungsten carbide that is hydraulically suspended and translated across the surface to be modified. After multiple passes, compressive residual stresses can be imparted to surface. To date tests of the modified surfaces have not been conducted.

R. Payne (Framatome ANP) provided information about the closure weld cell for the SR WP design. The cell would be designed to minimize the amount of equipment in the closure cell. The proposed cell will include 2 gas metal arc welding (GMAW) stations for the Type 316 nuclear grade (NG) stainless steel (SS) inner container closure, 6 gas tungsten arc welding (GTAW) stations for welding Alloy 22 and 2 post weld heat treatment stations. No turntable will be used in the welding operations to rotate the WP because of inadequate precision of such a method as well as accident concerns. The total time to weld, inspect, and post weld heat treat the SR WP design is projected to be 69 hours. Limited information was presented on proposed non destructive evaluation (NDE) of the closure lid welds. For the inner Type 316NG SS lid, visual inspection is proposed. The closure lid for the Type 316 NG SS container is proposed to be held in place using shear rings rather than a full penetration weld. Welds would be used as a seal and to hold the shear rings in place, however, it is claimed that the structural integrity of the inner Type 316 NG SS container closure would not be dependent on the integrity of the seal welds. The inner Alloy 22 WP closure weld is proposed to be a fillet weld that will be inspected using visual inspection. Alternative inner Alloy 22 closure lid designs were shown that incorporate a full lid thickness penetration weld. It was noted that such alternative designs have increased complexity and need to be evaluated. Several outer lid closure weld NDE methods were discussed including dye penetrant and eddy current methods.

R. Payne (Framatome ANP) also presented some information on the laser peening stress mitigation method. Stress distribution profiles were presented for materials of varying thickness. No metallurgical changes are claimed using this method. However, no corrosion rate, localized corrosion susceptibility, mechanical property or other material characterization information was presented. During the subsequent discussion, the means to monitor any potential stress mitigation method was questioned. At present, it is proposed that the process would not be monitored but would be qualified by testing. In addition the method to mitigate anomalies discovered during fit-up was questioned by A. Ligenfelter (LLNL retired). R. Payne indicated that minor problems such as cleaning could be performed in the weld cell, but another cell would need to be available to handle major repairs.

J. Dorsch (CTC, United Defense) and Peter Fielding (TWI Ltd.) presented information about electron beam welding. Details of a low pressure differential pumped electron beam gun used to perform single pass welds of this section of C-276 at 4 mbar was described. The benefits of the electron beam technique were fast welding time, lower residual stress, and lower volume of weld metal. Beam deflection methods that precisely raster the beam across the components to be welded can be used to increase the width of the molten zone, if desired.

R. Swain (Euroweld) presented information on the use of multiple filler metal feeds to obtain a controlled weld metal composition. Application of the methods presented was not specific to WP fabrication and closure. Most of the information presented was focused on methods used for submerged arc welding.

D. Jones (University of Nevada–Reno) presented the results of passive current measurements and potentiodynamic polarization tests of Alloy 22 in 1 N H_2SO_4. The selection of the test solution was not intended to represent a possible repository environment but provide a well characterized environment for testing. The test system used consisted of an Alloy 22 specimen at open circuit in an air saturated solution and a specimen maintained under potentiostatic polarization in a deaerated solution. The applied potential of the specimen in the deaerated solution was set to match the open circuit potential of the specimen in the air saturated solution. Passive current density of Alloy 22 after 100 hours was measured to be 5×10^{-9} A/cm^2.

L. Kaufman (Massachusetts Institute of Technology) presented the results of Pourbaix (Eh-pH) diagrams for Ni base alloys including Alloys 22 and 59. The calculated Pourbaix diagrams for the alloys are quite complex. Additions of W and Fe in Alloy 22 appear to be beneficial to passive film stability. Verification of the Pourbaix diagrams has not been performed.

C. Orme (LLNL) presented the results of passive film and thermal oxide characterization on Alloy 22 specimens. Cross-sectional transmission electron microscopy (TEM) of the thermal oxide layer showed an inner chromium-rich region and an outer nickel-rich layer. A similar structure was observed for oxide films formed under passive conditions in solutions. Future work will include an evaluation of the chemistry of the oxide film as a function of time. Additional tests will be performed to verify the results of the calculated Pourbaix diagrams.

P. Turchi (LLNL) presented the results of phase stability calculations. The calculations use a thermodynamic database (THERMO-CALC) and a kinetic database (DICTRA). Using the databases the temperature stability diagrams for nickel-chromium-molybdenum alloys including Alloy 22 and Alloy 59 may be calculated. Verification of the thermodynamic database was performed by comparing the calculated to known phase diagrams for binary (i.e. nickel-chromium, nickel-molybdenum, chromium-molybdenum, chromium-tungsten, nickel-tungsten, and molybdenum-tungsten) and ternary (nickel-chromium-molybdenum) systems. For the time-temperature stability calculations for Alloys 22 and 59, μ and P-phases were assumed to be identical. The phase stability calculations predict more P-Phase formed in Alloy 59 compared to Alloy 22 because of the higher concentration of molybdenum. Both chromium and molybdenum stabilize the topologically close-packed (TCP) phases (also referred to as Frank-Kasper or tetrahedrally close-packed phases). Molybdenum also stabilized the long range ordered (Ni_2Mo) phases, whereas tungsten tends to destabilize the Ni_2Mo phase. Future work will require an investigation of non-isothermal conditions and the effects of weld solidification. During the subsequent discussion, it was revealed that the phase stability calculations are only useful for bulk precipitation and cannot be used to determine the precipitation at grain boundaries.

R. Rebak (LLNL) presented information on the uniform and localized corrosion of Alloy 22. Much of the information presented was similar to that presented at the Corrosion 2002 Conference. Concerns regarding the methods used have been previously identified, such as the use of linear polarization to determine corrosion rates. During the following discussion D. Bullen (NWTRB) asked about the assessment of radiolysis and cited the Climax results where the effects of radiolysis were found to be significant. Further, D. Bullen firmly suggested that simulation of radiolysis by addition of H_2O_2 to test solutions was not adequate because this would not duplicate the high local concentrations that may be achieved in an actual repository. He specifically stated that going forward to license application (LA) without this data would not be acceptable. R. Rebak indicated that tests would need to be performed in a hot cell to obtain actual radiolysis data.

The last presentation was by J. Horn (LLNL) who provided the results of microbial influenced corrosion (MIC) studies conducted at LLNL. As with many of the previous LLNL presentations, results had been previously presented or included in papers or AMRs. Testing has been conducted using a combination of organisms and individual organisms that have been isolated from Yucca Mountain tuff including a sulfate reducing bacteria that can survive in a high chloride environment. In tests utilizing flow-through systems where the effluent was monitored for metal ion concentrations, higher Mo concentrations were reported in the effluent from nonsterile cells compared to the effluent from sterile controls. Other interesting results suggest that the bacteria can consume NO_3^- and alter the NO_3^- to Cl^- ratio.

SUMMARY OF ACTIVITIES:

None.

CONCLUSIONS:

The workshop provided an opportunity to review updated information regarding the WP design and testing. In addition the format of the workshop allowed for extensive discussion where warranted. Although some of the information presented has been previously presented, reviewed, or discussed, the need to augment the existing data was well recognized. The information presented suggests that the design of the WP may be revised. Laser peening or low plasticity burnishing are being evaluated as methods to mitigate residual stresses. Induction annealing has not been ruled out but has been described as a possible backup method to mitigate residual stresses.

PROBLEMS ENCOUNTERED:

None.

PENDING ACTIONS:

None.

RECOMMENDATIONS:

The Nickel Development Institute workshop series on waste package fabrication is a means to obtain valuable information. Future attendance at the workshops is highly recommended.

SIGNATURES:

Darrell S. Dunn — 10/30/2002
Senior Research Engineer — Date

CONCURRENCE:

Vijay Jain, Manager — 10/31/02
Corrosion Science & Process Engineering, Element — Date

for B. Sagar
Budhi Sagar — 10/31/2002
Technical Director — Date

DD:jg