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A Division of Southwest Research Institute®
6220 Culebra Road • San Antonio, Texas, U.S.A. 78228-5166
(210) 522-5160 • Fax (210) 522-5155

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Contract No. NRC–02–02–012
Account No. 20.06002.01.332

U.S. Nuclear Regulatory Commission
ATTN: Mr. Timothy J. Kobetz
Division of High-Level Waste Repository Safety
Two White Flint North
11545 Rockville Pike
Mail Stop 6–C11
Washington, DC 20555

Subject: Repository Design and Thermal-Mechanical Effects Key Technical Issue Revised Intermediate Milestone No. 20.06002.01.102.420, Microstructural Analyses and Mechanical Properties of Alloy 22

Dear Mr. Kobetz:

Enclosed is the revised intermediate milestone on the Microstructural Analyses and Mechanical Properties of Alloy 22. The report was revised to address U.S. Nuclear Regulatory Commission (NRC) comments. In addition to the revisions to the report, detailed responses to the NRC comments and questions are attached.

Fabrication processes such as welding and postweld heat treatments will alter the microstructure of the waste package materials. Microstructural changes that occur as a result of fabrication processes include segregation of alloying elements during solidification and formation of secondary phases that can alter the mechanical properties of Alloy 22. Formation of topologically close-packed phases as a result of welding and postweld heat treatments increases strength, but decrease ductility, impact strength, and fracture toughness. Based on the results of microstructural analyses and mechanical testing, it can be concluded that alteration of the mechanical properties of Alloy 22 will occur during fabrication and closure of the waste package; yet the outer container material is expected to remain ductile and resistant to fracture. The results of this study will directly support prelicensing interactions with the U.S. Department of Energy.

Washington Office • Twinbrook Metro Plaza #210
12300 Twinbrook Parkway • Rockville, Maryland 20852-1606

If you have any questions regarding this report, please contact me at 210-522-5151 or Darrell Dunn at 210-522-6090.

Sincerely yours,

Asadul H. Chowdhury, Manager
Mining, Geotechnical, and Facility Engineering

Attachment

cc:
D. DeMarco
B. Meehan
E. Whitt
W. Reamer
E. Collins
L. Kokajko
M. Bailey
K. Stablein
J. Guttmann
A. Campbell
F. Brown
R. Codell
T. McCartin
T. Ahn
A. Csontos
R. Johnson
D. Dancer
D. Galvin
D. Rom
Y. Kim
J. Pohle
B. Jagannath
M. Nataraja
W. Patrick
B. Sagar
D. Dunn
Yi-Ming Pan
D. Gute
G. Ofoegbu
K. Chiang
R. Benke
B. Dasgupta
S. Hsiung
A. Ghosh
V. Jain
P. Maldonado
Record Copy B, IQS

<u>Letter Only</u>
L. Gutierrez
CNWRA Directors
CNWRA Element Mgrs

Review Comments on Microstructural Analyses and Mechanical Properties of Alloy 22

1. Despite the conclusion in the last sentence (p. 4-1) "Considering the data presented in this report, a significant reduction in the fracture toughness of the waste packages as a result of welding and postweld heat treatment, including an improper postweld treatment, seems unlikely," the data show quite a bit reduction from 261 MPa $m^{1/2}$ to 63 MPa $m^{1/2}$ under weld and anneal conditions; elongation to 19 percent from 60 percent in Table 3-5 and to 17 percent from 71 percent in Table 3-3 on aging. This needs some explanation.

Response:

Chapter 4 has been revised to address this comment and Comment 11. The previous analyses using Charpy impact test specimens conservatively predicted significant reduction in fracture toughness of Alloy 22 in the welded + thermally aged condition. Additional data obtained and included in the revised report suggests that large reductions in fracture toughness are not expected unless the welds are exposed to a temperature of 870 °C [1,598 °F] for a period of more than 10 hours. Solution annealing conducted at the recommended temperature of 1,125 °C [2,057 °F] does not result in meaningful reduction in fracture toughness. The reduction in ductility after thermal aging and after solution annealing for the GMAW specimens is noted.

2. What would be the Implications of the different values between K_{JIc} and K_{Ic} (CVN)? How do we apply these different values to practical failure criteria?

Response:

As indicated in the response to comment 1, the K_{Ic} values obtained from Charpy V-notch specimens using the empirical correlation developed for pressure vessel steels can significantly underestimate the actual fracture toughness (K_{JIc}). The actual fracture toughness values should be used when available. These values may be used to construct failure assessment diagrams described in Dunn et al. (2004). The high values of fracture toughness for the mill annealed, as-welded and welded + solution annealed condition suggest that the failure mode will be plastic collapse (ductile failure) rather than fracture or mixed mode failure.

3. Will the welds of the waste package incorporate a mixture of welding procedure, i.e. GTAW welds are usually through the first two thirds of the plate with GMAW welds for the last third?

Response:

DOE has not provided detailed design information on the waste package design, however, a combination of GTAW and GMAW welding methods have been successfully used with Alloy 22 and similar Ni-Cr-Mo alloys. Suppliers of such alloys have recommended welding parameters for these methods.

4. NDE was not addressed, hence, what acceptance criteria if any were used to determine the integrity of the samples used in these tests.

Response:

As indicated on page 2-2 “All welded materials used in tests of mechanical properties were inspected using radiographic testing performed by IHI Southwest Technologies. (San Antonio, Texas)”. Additional information on the NDE has been provided on page 2-2.

5. Supplier qualification: Was the CNWRA supplier performing the work on making and testing these samples a qualified supplier?

Response:

There is no approved supplier for welded material on the Southwest Research Institute approved suppliers list. The vendor of the Alloy 22 material, Haynes International, recommended Roben Manufacturing as a supplier for welding. Because Roben Manufacturing did not have existing weld procedure specifications for 1 inch thick Alloy 22, these procedures were developed and are listed on page 2-2 of the report. Roben Manufacturing was supplied with qualified material and, all welds were inspected using radiographic testing performed by IHI Southwest Technologies. All suppliers performing testing including confirmatory chemical analyses of materials, radiographic testing, tensile testing, fracture toughness testing, and Charpy V-notch testing are on the Southwest Research Institute approved suppliers list.

6. The use of ERNiCrMo-10 filler metal for the weld has been justified. However, DOE has indicated that they may use a higher Mo content ERNiCrMo-14 filler metal for their welds on Alloy 22. Since the precipitation and growth of the Mo-rich TCP phases may be exacerbated with the use of this filler metal, what are the effects of them using this filler metal? Extrapolating extended aging kinetics for the ERNiCrMO-10 may be a possible solution, i.e. using ERNiCrMo-10 870 °C 1 hour data for the ERNiCrMo-14 870 °C 30 min data.

Response:

There is not sufficient information to estimate the performance of Alloy 22 welded with ERNiCrMo-14 using material welded with ERNiCrMo-10. Nevertheless, the revised report contains additional fracture toughness data on welded and thermally aged Alloy 22. The fracture toughness of welded and thermally aged material is quite high even after aging for 10 hours at 870 °C.

7. Section 3.2 page 3-4 3rd paragraph 4th sentence rearrange "few a" to "a few."

Response:

Text Corrected

8. Section 3.3, page 3-5, 1st paragraph 2nd sentence add ultimate before tensile strength.

Response:

Text Corrected.

9. Section 3.3, page 3-6, 2nd paragraph, 3rd sentence, add aging before "time increases" and change tense from present to past, i.e., decreases and increases to decreased and increased.

Response:

Text Corrected.

10. Section 3.3, Page 3-6, 3rd paragraph 4th sentence or section 3.3 page 3-7 5th paragraph, what is the valid thickness calculation for J_{Ic} of Alloy 22? Why not put it in here as a reference to determine how thick you need to be. Furthermore what about adding a statement mentioning that the thickness of Alloy 22 will be most likely 2 cm which is well below this J_{Ic} thickness criteria.

Response:

The thickness criteria for valid J_{Ic} measurements is included in ASTM 1820. This has been included in Section 3.3 of the revised report. In the mill annealed condition, the thickness criteria calculation included in ASTM 1820 indicated the material would need to be 7.24 cm (2.85 in) thick for valid J_{Ic} measurements. Such measurements would serve little purpose because it is established that the failure mode would be dominated by ductile failure rather than fracture.

11. Section 4, Page 4-1 This section could use some more analyses to demonstrate the effect of realistic fabrication effects on the mechanical/fracture performance of the waste package. For example, the last sentence is a good synopsis of the fracture data, however what effect will this have on the failure mode of Alloy 22. From the fracture toughness data and the papers presented by Dunn (TMS 2003) and Csontos (MRS 2004), enough background has been developed to say that the expected failure mode of Alloy 22 and GTAW welds is expected to remain in the ductile collapse regime for all credible fabrication processes known to date.

Response:

Agreed. The additional fracture toughness data included in the revised report also support this conclusion. Additional analyses has been added to Chapter 4.

12. Section 5, page 5-1, Is the 2nd sentence correctly stated? Is it the thermal stability or thermal aging? A rephrase would be good.

Response:

Text Corrected.