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# EFFECTS OF SOLIDIFICATION-INDUCED SEGREGATION ON ALLOY 22 PHASE STABILITY

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## BACKGROUND

- Alloy 22 (Ni-22Cr-13Mo-4Fe-3W in wt%) has been proposed by the U.S. Department of Energy as the outer container material of the waste package for containment of high-level radioactive waste in the potential geological repository at Yucca Mountain, Nevada.
- Fabrication processes, such as cold working, welding, and postweld heat treatments, may alter the microstructure and corrosion resistance of the Alloy 22 waste package outer containers.
- Solution annealing has been proposed (Plinski 2001) to mitigate the detrimental effects of phase instability and to remove residual stress created by forming and welding operations during the fabrication of the disposal containers.

## OBJECTIVES

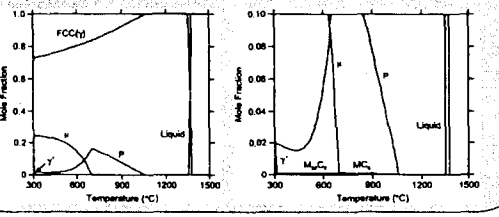
- Determine the phase stability of Alloy 22 affected by elemental segregation in the solidified weld microstructure using equilibrium and Scheil-Gulliver solidification simulations.
- Assess the effectiveness of the proposed solution-annealing treatments for Alloy 22 weldments based on experiments and thermodynamic calculations.

## SUMMARY


- The effects of solution annealing on Alloy 22 phase stability are related to the amount of the topologically close-packed phases (i.e., P, σ, and μ). All solution-annealing treatments of the welded materials at temperatures ranging from 1125 to 1300°C enhanced precipitation of the secondary phases. Contrary to the progressive homogenization of the fusion zone after solution annealing at 1125, 1200, and 1250°C, abnormal grain growth was observed at 1300°C.
- Solidification simulations predicted a high solvus temperature for the P phase in the Alloy 22 welds, especially in the interdendritic regions, as a result of Mo segregation during the solidification of the welded metal. These thermodynamic calculations suggest a solution-annealing temperature window in the range of 1265 and 1325°C, significantly higher than the currently proposed solution-annealing treatment of the Alloy 22 outer cylinders at 1150°C (Plinski 2001).
- Results obtained from both experiments and thermodynamic calculations indicate that longer solution-annealing treatment times at temperatures slightly higher than the calculated solvus temperature of 1265°C for the P phase may be required. Additional evaluation maybe necessary in assessing the solution-annealing treatments and the possible detrimental effects of fabrication processes on the localized corrosion performance of the waste packages.

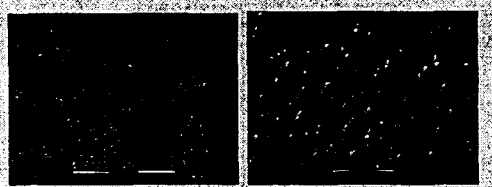

## EQUILIBRIUM PHASE DIAGRAM

Thermodynamic calculations were performed with the Thermo-Calc Version N software program and the Ni-Data Version 5 database. The calculated phase mole fraction versus temperature diagrams using the nominal Alloy 22 composition predicted that P phase is the stable topologically close-packed phase at higher temperatures up to its solvus temperature of 1062°C.




## AS-WELDED MICROSTRUCTURE

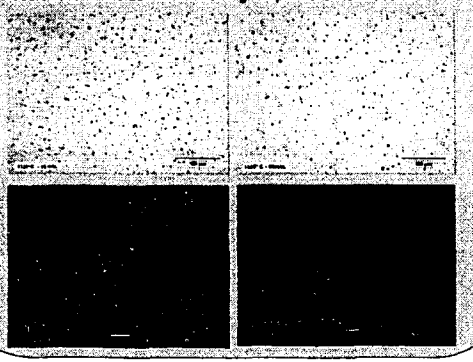
Gas-tungsten arc welded Alloy 22 shows formation of a dendritic structure and precipitation of topologically close-packed phases (white spots). Compositional analyses using energy-dispersive x-ray spectroscopy revealed segregation of Mo to the interdendritic regions due to alloying element partition in the solidified weld microstructure.



| Location | Chemical Content (wt%) | | | | |
|---|---|---|---|---|---|
| | Ni | Cr | Mo | Fe | W |
| Dendrite Core | 59.8 ± 1.3 | 21.6 ± 0.4 | 13.0 ± 1.1 | 2.75 ± 0.11 | 2.60 ± 0.09 |
| Interdendritic Region | 54.4 ± 1.6 | 22.8 ± 0.2 | 16.0 ± 1.6 | 2.48 ± 0.07 | 2.48 ± 0.06 |
| Alloy 22 Base Metal | 60.64 | 20.44 | 12.80 | 2.63 | 3.08 |
| Alloy 622 Filler | 59.89 | 20.41 | 13.99 | 2.46 | 2.96 |

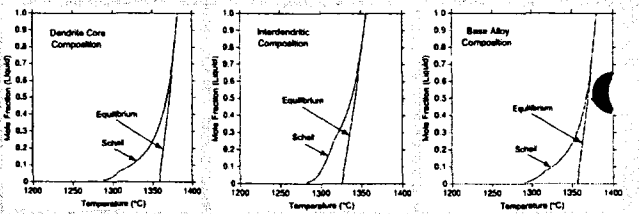
## SOLUTION-ANNEALED WELDS

Residual precipitates were observed in solution-annealed Alloy 22 welds after 15 and 60 minute heat treatments at 1125°C (top row). Solution annealing at higher temperatures (bottom row) results in homogenization of the fusion zone at 1200°C and abnormal grain growth at 1300°C. The amount of precipitates per unit area decreases as the solution-annealing temperature increases.



## SOLIDIFICATION SIMULATIONS

Equilibrium and Scheil-Gulliver solidification simulations were performed for the base alloy composition, as well as the measured compositions for the dendrite cores and the interdendritic regions under a 5°C cooling step. The Scheil-Gulliver simulations assume no back diffusion in solidified alloy whereas equilibrium is reached at each cooling step in the equilibrium simulations. Thus the equilibrium simulations predicted an accurate solidus temperature. The equilibrium simulations also predicted a solvus temperature of 1265°C for the P phase in the interdendritic region due to Mo segregation, which can be used as a lower temperature bound for dissolving the secondary phases. Based on the calculated P phase solvus temperatures and solidus temperatures, a solution-annealing temperature window ranging from 1265 to 1325°C is suggested.




Calculated Liquidus, Solidus, and P-Solvus Temperatures (°C)

| Location | Equilibrium Simulation | | | Scheil Simulation | | |
|---|---|---|---|---|---|---|
| | Liquidus | Solidus | P-Solvus | Liquidus | Solidus | P-Solvus |
| Dendrite Core | 1382 | 1358 | 1018 | 1382 | 1292 | 1310 |
| Interdendritic Region | 1357 | 1325 | 1265 | 1357 | 1287 | 1316 |
| Base Alloy | 1380 | 1356 | 1062 | 1380 | 1291 | 1314 |

REFERENCE Plinski, M.J. 2001. TDR-EBS-ND-000003 REV02. Las Vegas, Nevada: Bechtel SAIC Company.

## ACKNOWLEDGMENTS

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