



Alloy Development for Irradiation Performance

Semiannual Progress Report
For Period Ending September 30, 1982

U.S. Department of Energy
Office of Fusion Energy

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<p><i>A fourth publication package of data pages has been released to handbook holders and a fifth package should be released during January. During the last 6 months approximately 100 data sheets have been received from HEDL, WAC, and NBS. These data sheets are currently out for review and will be released, assuming approval, during the next 6 months.</i></p>	
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2.3 HFIR/FFTF Irradiation Experiment — Final Design Phase
 (Westinghouse Hanford Company and Oak Ridge National
 Laboratory) 21 ✓

The combined HFIR/FFTF experiment on the Path A Prime Candidate Alloy and the Path D Long-Range Ordered Alloys is in the final design stage. A sodium-filled test assembly to be used for the HFIR irradiations has been designed, the main features of which are described. The updated proposed test matrix is also presented.

2.4 Neutronics Calculations in Support of the ORR-MFE-4
 Spectral Tailoring Experiments (Oak Ridge National
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The calculated fluences from the ongoing three-dimensional neutronics calculations are being scaled to agree with experimental data. As of October 11, 1982, this treatment yields 46.25 at. ppm He (not including 2.0 at. ppm He from ¹⁰B) and 4.97 dpa for type 316 stainless steel in ORR-MFE-4A and 40.18 at. ppm He and 4.55 dpa in ORR-MFE-4B.

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Pressurized tubes have been irradiated to 4.8 dpa at 330 and 400°C in the ORR-MFE-4A spectral tailoring experiment. At 330°C, 20%-cold-worked type 316 stainless steel (CW 316) and path A PCA demonstrated irradiation creep similar to predictions of the irradiation creep equation developed in the Fast Breeder Reactor Program. The creep rate for path A PCA was approximately 25% higher than that of type 316 stainless steel.

3.2 Swelling and Microstructural Development in Path A PCA and
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- 3.3 The Tensile Properties of Unirradiated Path A PCA
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- The tensile properties of PCA in the A1 (solution annealed), A3 (25%-cold worked), and B2 (aged, cold worked, and reaged) conditions were determined from room temperature to 600°C. The tensile behavior of PCA-A1 and -A3 was generally similar to that of titanium-modified type 316 stainless steel with similar microstructures. The PCA-B2 was weaker than PCA-A3, especially above 500°C, but demonstrated slightly better ductility.*
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- 3.5 Microstructural Development of 20%-Cold-Worked Type 316
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Microstructural studies indicated several possible causes for the low ductility observed in the Path B alloys. Precipitation of helium bubbles at grain boundaries was observed for all alloy conditions. Helium bubbles at grain boundaries could cause a reduction of the grain boundary cohesive energy and could also serve as potential crack nucleation sites during deformation. Other precipitates, which are known to cause a reduction in grain boundary strength were also observed. For example, cavities formed at precipitate/grain-boundary interfaces in cold worked and aged alloy B1; a layer of γ' completely coated grain boundaries in cold worked alloy B1; and η -phase plates were aligned in the grain boundary region in cold worked and aged alloy B4. These features weaken the grain boundaries and diminish their ability to deform. Relative to the weakened boundary, the matrix is quite strong, being strengthened by the formation of γ' or γ'/γ'' precipitates, radiation-induced faulted loops, and a high density of helium bubbles. Due to the limited deformation tolerance of the grain boundaries, failure will be initiated there before matrix deformation can relax local stress concentrations at high temperatures. A single principal mechanism to explain the low ductility phenomena observed cannot be selected on the basis of the results of the microstructural studies.

Path B alloys in their current form will not provide adequate ductility for first wall application at high temperatures.

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postweld heat treatment increased the hardness of both zones by reordering the structure and produced additional hardening in the fusion zone due to precipitation of small VC particles on grain boundaries and matrix dislocations.

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7.2 Fractographic Examination of HT-9 and 9Cr-1Mo Charpy Specimens Irradiated in the AD-2 Test (Westinghouse Hanford Company) 178

Fracture surface topologies have been examined using scanning electron microscopy for 20 selected half sized Charpy impact specimens of HT-9 and Modified 9Cr-1Mo in order to provide improved understanding of fracture toughness degradation as a result of irradiation for Path E alloys. The specimens matrix included unirradiated specimens and specimens irradiated in ERR-11 in the AD-2 experiment. Also, hardness measurements have been made on selected irradiated Charpy specimens. The results of examinations indicate that irradiation hardening due to G-phase formation at 390°C is responsible for the large shift in ductile-to-brittle transition temperature found in HT-9. Toughness degradation in HT-9 observed following higher temperature irradiations is attributed to precipitation at delta ferrite stringers. Reductions in toughness

as a consequence of irradiation in Modified 9Cr-1Mo are attributed to in-reactor precipitation of (V,Nb)C and M₂₃C₆. It is shown that crack propagatia mtes for ductile and brittle failure modes can he measured, that they differ by over an order of magnitude and that unexpected multiple shifts in fmcture mode from ductile to brittle failure can be attributed to the effect of delta ferrite stringers on crack propagation mtes.

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To be reported in the next semiannual report.

7.4 Fracture Toughness of Unirradiated HT-9 and Modified 9Cr-1Mo Welds (Westinghouse Hanford Company) 221

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7.5 The Toughness of Simulated Heat Affected Zone Micro-structure in HT-9 (ESR Melt Practice) (Sandia National Laboratories) 230

To be reported in the next semiannual report.

7.6 The Effect of Melt Practice (ESR vs. AOD) on the Toughness of HT-9 Laser Welds (Sandia National Laboratories)

The toughness behavior of laser welded AOD- and ESR-processed material from the Rational Fusion Heat was evaluated. In general, the fusion zone toughness was equivalent, if not superior, to that of the base metal. The microstructural refinement which results from weld solidification is probably responsible for the improvement in properties. The chemical inhomogeneity due to partitioning during solidification appears to exert only a small effect a the properties. The fmcture mode is analogous to that of the base material; lower shelf failure exhibits a cleavage mode while upper shelf failure occurs by ductile rupture.

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HT-9 contains about 9 volume percent retained austenite when air cooled after austenitizing. To reduce the retained austenite content of HT-9 from that of the air cooled (AC) condition, two other treatments after austenitizing were employed: oil quenching (OQ) and oil quenching followed by refrigeration in liquid nitrogen (OQLN). The OQ structure contained 6% retained austenite and the OQLN structure had only 4% retained austenite. Preliminary Charpy impact data indicate some beneficial effect of these treatments. The Charpy impact values of specimens tempered at 750°C were 78, 80 and 97 ft-lbs for the AC, OQ and OQLN structures respectively.

7.8 Preparation of ESR Alloy HT-9 and Modified 9Cr-1Mo Alloy for UBR Irradiation Experiments (Naval Research Laboratory) 252

Alloy HT-9 and Alloy 9Cr-1Mo (Mod.) are being evaluated for potential application as first wall materials in magnetic fusion reactors. Objectives of the current studies are the assessment of material notch ductility and fracture toughness in the pre- and postirradiation conditions and the correlation of miniature test specimens required for high flux reactor experiments with standard size specimens.

Planning and preparations for two irradiation experiments involving Alloy HT-9 and Alloy 9Cr-1Mo (Mod.) have been completed. The experiments are designed to attain specific research objectives recommended by the OFE Working Group on Irradiation Effects in Martensitic Stainless Steels.

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9.1 Corrosion of Path A PCA, Type 316 Stainless Steel and Fe-12 Cr-MoVW Steel in Flowing Lithium (Oak Ridge National Laboratory) 290

Results from lithium thermal-convection loop (TCL) experiments with the path A prime candidate alloy (PCA), type 316 stainless steel, and Fe-12 Cr-1 MoVW are presented. In short-term (<3050 h) weight losses of PCA in flowing lithium were just slightly higher than those of type 316 stainless steel and may be attributable to the higher nickel concentration of PCA. The corrosion response of PCA specimens was not affected by cold work. A surface analysis of type 316 stainless steel specimens exposed in the hot leg of a TCL for over 7000 h confirmed earlier observations regarding preferential leaching of nickel and chromium and deposition of pure chromium. These analyses also showed that exposure temperature strongly affects surface porosity and that molybdenum enrichment occurs on surfaces undergoing dissolution. Weight loss data as a function of time for Fe-12 Cr-1 MoVW steel exposed to lithium at 500°C yielded the same dissolution rate as the "steady-state" value for nickel-depleted type 316 stainless steel. Significant weight losses were measured in the cold leg of this loop, and they appeared to be related to chromium depletion (possibly as a result of impurity reactions).

9.2 Environmental Effects on Properties of Structural Alloys (Argonne National Laboratory) 304

Compatibility tests were wnducted with several ferritic and austenitic steels at 700 and 755 K to study the corrosion behavior in flowing lithium, and fatigue tests were performed with Type 316 stainless steel in lithium at 755 K. The results indicate that an increase in the nitrogen content in lithium increases the dissolution rate, whereas the depth of internal penetration is not affected significantly. The dissolution rate of ferritic steels is an order of magnitude lower than for the austenitic stainless steel. The austenitic steels develop a very porous ferrite layer, whereas the ferritic steels exhibit little or no penetration. For the austenitic stainless steels, depth of internal penetration increases with time and the penetration mtes at 755 K mnge from 50 to 180 $\mu\text{m}/\text{year}$. Preliminary data on Type 316 stainless steel yield similar penetration mtes at 700 and 755 K. The fatigue life of annealed Type 316 stainless steel in lithium at 755 K is a factor of 3 to 8 greater than in air.

9.3 Corrosion of Ferrous Alloys in Static Pb and Pt-17 at. % Li (Oak Ridge National Laboratory) 314

Specimens of type 316 stainless steel were exposed to static pure lead for 1000 and 3000 h at 400, 500, and 600°C, respectively. Weight tosses measured in these tests were compared with those measured in similar tests with Pb-17 at. % Li. The data showed that the addition of 17 at. % Li to lead has some effect on its dissolution behavior relative to type 316 stainless steel; however, the weight losses in both the lead-lithium and pure lead melts were much larger than in pure lithium. Preliminary results from compositional analyses of type 316 stainless steel exposed to static Pb-17 at. % Li showed surface depletion of nickel at 500°C.

9.4 Compatibility Studies of Structural Alloys with Solid Breeder Materials (Argonne National Laboratory) 323

The compatibility of ferritic and austenitic steels with Li_2O pellets has been investigated at 823 K (550°C) in flowing helium containing 93 ppm H_2O and 1 ppm H_2 . The results indicate that both steels develop an iron-rich outer scale and a chromium-rich subscale. The reaction rates for ferritic and austenitic steels are comparable and yield a value of $\sim 85 \mu\text{m}/\text{year}$ for penetration rate. The Li_2O pellets exposed with the various alloys lose weight. The weight loss follows a parabolic law, predicting a value of $\sim 4.8\%/\text{year}$.