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Effects of Internal Helium on Mechanical Properties of NITRONIC 40 Stainless Steel (U)

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Austenitic stainless steels are used for construction of equipment that is exposed to tritium. Proper design of tritium-handling equipment requires an understanding of how mechanical properties of these stainless steels are affected by internal helium-3 produced by radioactive decay of absorbed tritium. Rapid heating tensile testing at temperatures up to 1100°C has been used to determine mechanical properties of tritium charged and aged specimens of solution-annealed INCOLOY™ alloy 903 and high-energy-rate-forged 316L stainless steel containing helium-3 concentrations from several tenths to several hundreds of atomic parts per million (appm).[1] The most pronounced effect of internal helium was severe reduction of ductility at temperatures above about 600°C. At these temperatures, specimens containing internal helium failed by mixed-mode shear or intergranular brittle fracture compared to ductile transgranular fractures, cup-and-cone failures and plastic attenuation exhibited by specimens with no internal helium. Internal helium restricts the necking process. Thus, embrittlement is thought to involve interactions between the internal helium and the complex triaxial stress state that arises when necking starts. Recent efforts have been directed at determining helium concentration thresholds for this effect in several austenitic stainless steels. This report describes results of tests on specimens of annealed NITRONIC 40 stainless steel containing 0.0, 0.26 and 2.6 appm of helium-3.

Round bar specimens of NITRONIC 40 stainless steel with gage diameters of 2.9 mm and gage lengths of 22 mm were prepared by Metal Samples Company from hot-rolled annealed plate. Composition was reported to be 19.21% chromium, 9.02% manganese, 7.16% nickel, 0.43% silicon, 0.27% nitrogen, 0.14% copper, 0.09% molybdenum, 0.06% cobalt, 0.033% carbon, 0.019% phosphorus and 0.001% sulfur. Tests were performed on as-received specimens and two sets of specimens charged with tritium by heating at 300°C for two weeks at pressures of 2 and 200 kPa. One month of aging between tritium charging and tensile testing produced calculated uniform tritium distributions of 44 and 438 appm with corresponding helium-3 concentrations of 0.26 and 2.6 appm, respectively.[2] (Samples have been submitted to Rockwell International for helium analyses to confirm calculations.)

Rapid heating tensile tests were performed on an Instron tensile testing machine equipped with an environmental chamber connected to an off-gas exhaust system to remove evolved tritium. A quartz lamp heater in the environmental chamber was used to heat the specimens. Temperatures were controlled and monitored with small platinum-rhodium thermocouples spot-welded to the specimens.

Specimens were heated in air to the desired test temperatures within about a minute and held at constant temperature (within 20°C) for testing. Tests were conducted at an extension rate of 0.21 mm/sec. Ultimate tensile strength (UTS), 0.2% offset yield strength (OYS), total elongation (TE), uniform elongation (UE) and nonuniform elongation (NE) were determined from load-time recordings. UE was considered to occur under uniaxial tension up to the point of maximum load where necking usually begins. Reduction-in-area (RA) values were determined from measurements of specimen diameters at the point of fracture made from scanning electron microscope (SEM) images.

Strength parameters for uncharged specimens are plotted as functions of test temperature in Figures 1. Values of 732±7 MPa for UTS and 417±7 MPa for OYS were determined for three samples tested at 25°C (Table 1). UTS and OYS values decrease with increasing test temperature. UTS values decrease more rapidly than OYS values at temperatures up to about 800°C. Above 800°C, UTS values are only slightly greater than OYS values and both decrease toward zero near 1200°C. Figures 2 shows ductility parameters for uncharged specimens plotted as functions of test temperature. Measurements at 25°C yielded TE = 50.6±0.2%, UE = 38.9±0.1%, NE = 11.6±0.4% and RA = 81.9% (Table 1). A minimum in the value of TE of about 25% occurs near 800°C. Below 800°C, elongation is controlled by UE and cup-and-cone fractures occur. NE is the predominant elongation component above 800°C and plastic attenuation occurs. RA values increase from 76.8-90.7% at 25-780°C to 95.8-97.3% at 800-1100°C.

Three specimens containing 0.26 appm of helium-3 were tested at 809, 816 and 825°C. Two specimens containing 2.6 appm of helium-3 were tested at 840 and 843°C. Average values of strength and ductility parameters are given in Table 1 and compared with interpolated values for uncharged specimens. These results are presented graphically in Figure 3. Low concentrations of 0.26 and 2.6 appm of internal helium have no effect on OYS. The apparent slight decrease in UTS is attributed to experimental variations.

The predominant effect of low concentrations of helium-3 is decreased ductility caused by inhibition of necking. NE, the principal contributor to TE above 800°C, is the ductility parameter most sensitive to the presence of internal helium. At 817°C and 842°C, NE was decreased to 16.4% and 2.8% of its normal value by 0.26 and 2.6 appm of helium-3, respectively. UE is least sensitive to internal helium with corresponding decreases of 69.8% and 41.1%. RA, which is influenced by both uniform elongation and necking, exhibits intermediate sensitivity with decreases of 34.4% and 25.0% for 0.26 and 2.6 appm of helium-3, respectively.

Annealed NITRONIC 40 stainless steel exhibited greater sensitivity to internal helium-3 than solution-annealed INCOLOY alloy 903 and high-energy-rate forged 316L stainless steel. UE, NE and RA all showed greater decreases with low concentrations of helium-3 for NITRONIC 40 stainless steel than for INCOLOY alloy 903 and 316L stainless steel.

ACKNOWLEDGEMENT

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REFERENCES

1. Mosley, W. C., Effects of Parts Per Million Concentrations of Internal Helium on Tensile Properties of Austenitic Stainless Steels, Presented at the 17th DOE Compatibility, Aging and Service Life Conference, Rocky Flats Plant, Golden, Colorado, October 1-3, 1991.

2. Kain, K. E., Finite-Difference Program for Hydrogen Diffusion, March 1987, DP-1738.

Table 1. Mechanical Properties of NITRONIC 40 Stainless Steel Specimens

Temperature °C	He-3 appm	OYS MPa	UTS MPa	TE %	UE %	NE %	RA %
25	0.0	417±7	732±7	50.6±0.2	38.9±0.1	11.6±0.4	81.9
817±8	0.26	136±14	196±37	9.3±1.5	6.7±1.8	2.6±0.4	31.7±8.4
817*	0.0	138	225	25.3	9.6	15.8	92.0
842±2	2.6	127±5	154±16	3.4±0.6	2.8±0.6	0.5±0.0	24.0±2.6
842*	0.0	128	180	24.4	6.8	17.6	95.9

* Interpolated values

Figure 1

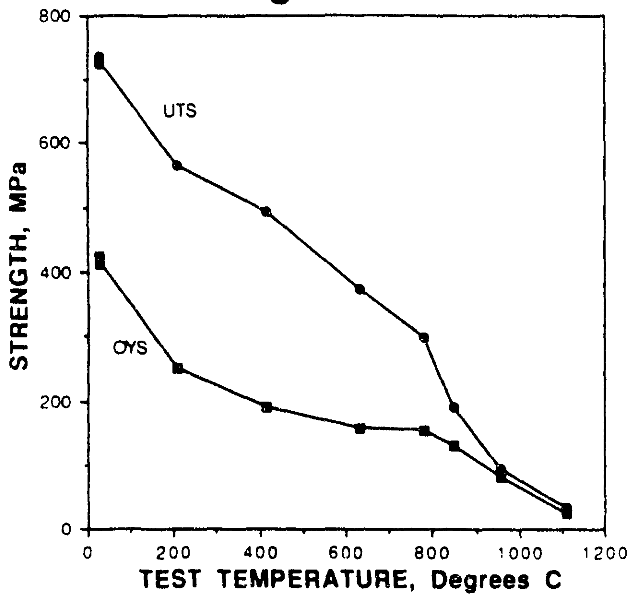


Figure 2

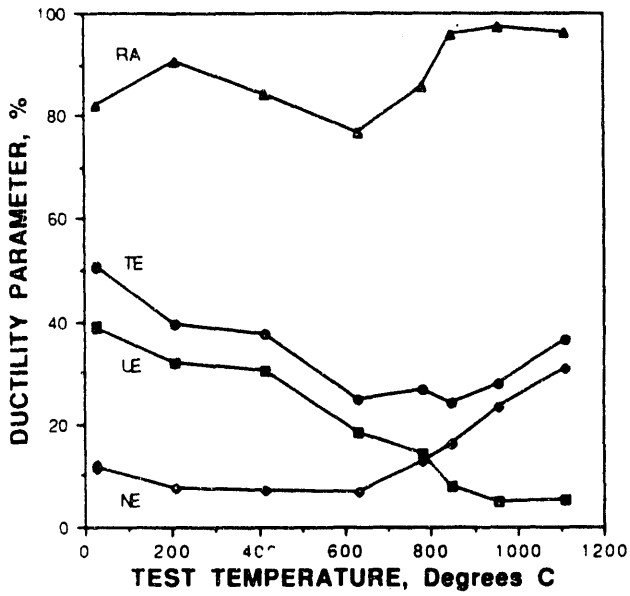
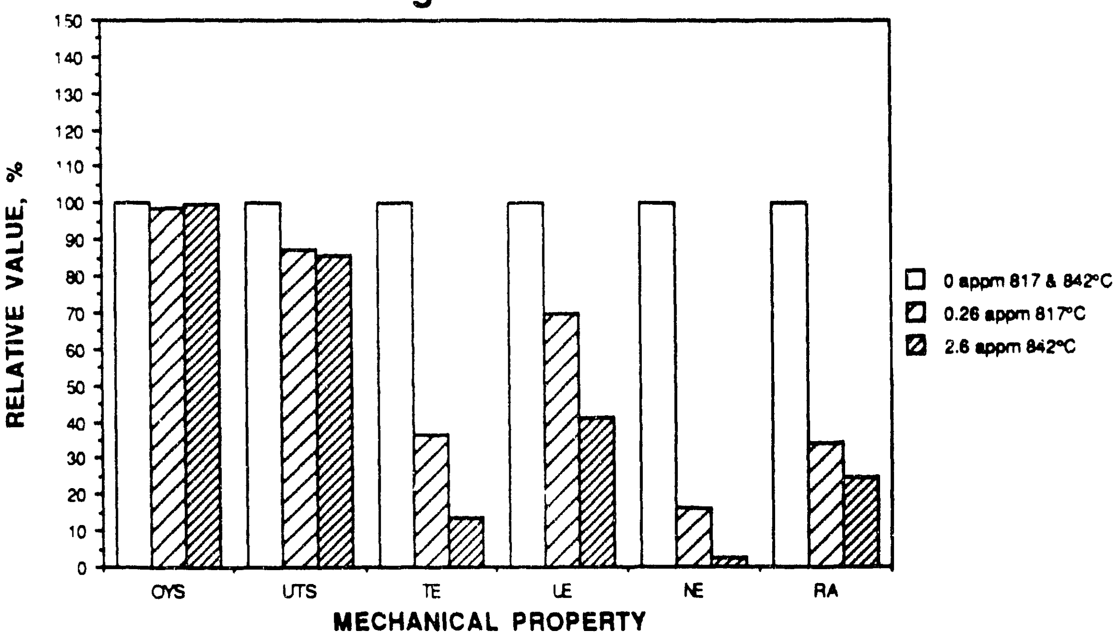


Figure 3



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