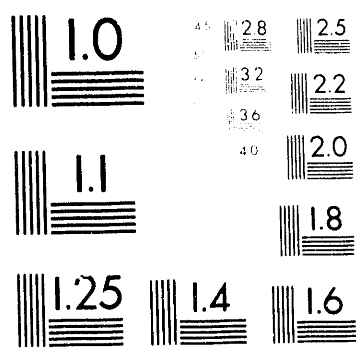
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2

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RAPID HEATING TENSILE TESTING UPDATE: 304L STAINLESS STEEL (U)

by

W. C. Mosley

Westinghouse Savannah River Company
Savannah River Site
Aiken, South Carolina 29808

A document prepared for:
presentation and publication at the 1993 Meeting of the IMOG-Subgroup on Mechanical Testing
at Livermore, CA
from 07/20/93 thru 07/22/93

DOE Contract No. **DE-AC09-89SR18035**

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Rapid Heating Tensile Testing Update:
304L Stainless Steel (U)

W. Clanton Mosley
Westinghouse Savannah River Company
Savannah River Technology Center
Aiken, SC 29802

To be presented at
1993 Meeting of the
IMOG Subgroup on Mechanical Testing
Sandia National Laboratories
Sandia/California
Livermore, CA
July 20-22, 1993

Rapid Heating Tensile Testing Update: 304L Stainless Steel

W. Clanton Mosley
Westinghouse Savannah River Company
Savannah River Technology Center
Aiken, SC 29802

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 uncharged, protium charged, and tritium charged and aged specimens of stainless steel containing helium-3 concentrations from several tenths to several hundreds of atomic parts per million (appm).[1,2] Protium charged specimens had properties similar to uncharged specimens but tritium charged and aged specimens exhibited 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 304L stainless steel containing low concentrations of helium-3.

Round bar specimens of 304L stainless steel with gage diameters of 3.2 mm and gage lengths of 12.7 mm were prepared by Metal Samples Company. The mill test showed this heat to contain 18.53% chromium, 1.28% manganese, 8.78% nickel, 0.49% silicon, 0.073% nitrogen, 0.32% copper, 0.29% molybdenum, 0.10% cobalt, 0.018% carbon, 0.027% phosphorus and 0.022% sulfur. Mechanical properties were reported as 772 MPa tensile strength, 565 MPa yield point, 46% elongation, 70% reduction in area, and a Brinell hardness number of 235. Tests were performed on uncharged specimens and two sets of specimens charged with tritium by heating at 300°C for two weeks at pressures of 2 and 200 kPa and aged for one month. Analyses by Rockwell International showed corresponding helium-3 concentrations of 0.47 and 4.1 appm.

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 fracture diameters made from scanning electron microscope (SEM) images.

Figure 1 shows strength parameters for uncharged specimens as functions of test temperature. Values of 753±5 MPa for UTS and 680±56 MPa for OYS were determined for three samples tested at 25°C (Table 1). UTS and OYS values decrease with increasing test temperature with UTS values being only slightly greater than OYS values. Figures 2 shows ductility parameters for uncharged specimens plotted as functions of test temperature. Measurements at 25°C yielded TE = 52.1±1.2%, UE = 33.7±1.6%, NE = 18.4±0.3% and RA = 76.8% (Table 1). A minimum value of TE of 18.4% at 610°C reflects decreasing values of UE and increasing values of NE with increasing temperature. The value of UE decreases sharply to 8.3% on heating to 195°C, decreases gradually to 4.3% on heating further to 800°C, and increases to 10.6-12.3% at 930-1040°C. In contrast, NE values decrease gradually to 12.6% on heating to 610°C and then increase sharply to 29% at 1040°C. NE is the predominant elongation component above about 130°C. RA values range between 64.2% and 76.7% at 25-1040°C. All specimens exhibited ductile cup-and-cone fractures with transgranular, dimpled rupture surfaces.

Elongation of 304L stainless steel differs from that of other tested austenitic stainless steels which must be heated above 700-800°C before NE becomes the predominant elongation component. 316L stainless steel and Incoloy 903 specimens containing hundreds of parts per million of internal helium exhibit little loss of ductility at 600°C but severe ductility loss at 800°C.[1,2] Therefore, a 304L stainless steel specimen containing 0.47 appm of helium-3 was tested at 615°C to see if the difference in elongation behavior might lead to ductility loss at this lower temperature. However, this specimen behaved in the same manner as an uncharged specimen tested at 610°C (Table 1 and Figure 3). Both specimens had cup-and-cone fractures and transgranular, dimpled rupture surfaces.

Specimens of 304L stainless steel containing 0.47 and 4.1 appm of helium-3 tested at 803-814°C exhibited significantly lower values for TE, NE and RA than uncharged specimens tested at 800-824°C (Table 1 and Figure 3). TE values decreased to 70.3% and 29.3% of those for uncharged specimens for 0.47 and 4.1 appm of helium-3, respectively. Similarly, NE values decreased to 66.0% and 17.4% and RA values decreased to 66.9% and 34.3%. These concentrations of internal helium had no significant effects on OYS, UTS and UE. Tritium charged specimens failed by brittle fracture with predominantly intergranular rupture surfaces.

Mechanical properties of 304L stainless steel were not affected by 0.47 appm at 615°C but ductility as determined by TE, NE and RA was severely decreased at 810°C. These effects must be considered when 304L stainless steel equipment exposed to tritium is heated above 600°C.

ACKNOWLEDGEMENT

This work was supported by the U. S. Department of Energy under contract number DE-AC09-89SR18035. Tensile tests were performed by A. T. Crumm and D. P. Healy. Examinations of fractured specimens were performed by C. L. Shelor, S. B. Rhodes and P. L. Morgan. S. M. Wood prepared samples for helium-3 analysis.

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2. Mosley, W. C., Rapid Heating Tensile Tests of Solution Annealed Incoloy™ 903 Charged with Hydrogen and Tritium, presented at the Sixth Meeting of the IMOG Subgroup on Mechanical Testing, Amarillo, TX, May 1-3, 1990, WSRC-MS-90-139.

Table 1. Mechanical Properties of 304L Stainless Steel Specimens

Temperature °C	He-3 appm	OYS MPa	UTS MPa	TE %	UE %	NE %	RA %
25	0.0	680±56	753±5	52.1±1.2	33.7±1.6	18.4±0.3	76.8
610	0.0	398	425	18.4	5.8	12.6	68.9
615	0.47	383	420	19.3	7.4	12.5	64.8
812±12	0.0	259±22	267±22	27.3±2.0	4.3±0.3	23.0±1.7	74.1
808±8	0.47	227±12	236±15	19.2±0.2	4.0±0.5	15.2±0.7	49.6
810±6	4.1	250±14	259±16	8.0±0.6	4.0±0.2	4.0±0.5	25.4±4.0

Figure 1

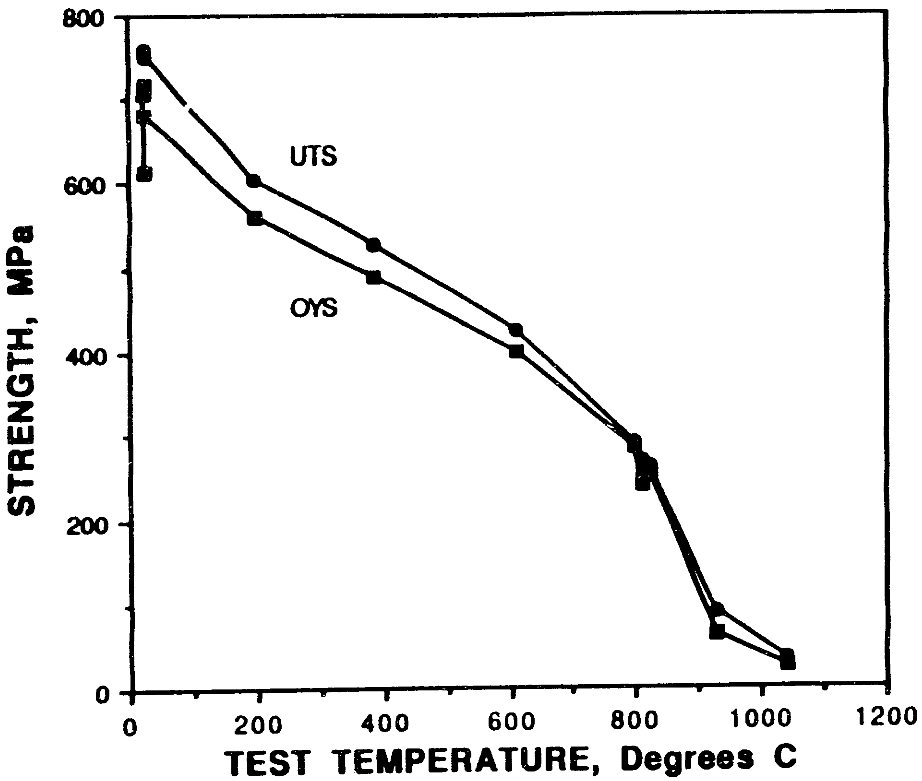


FIGURE 2

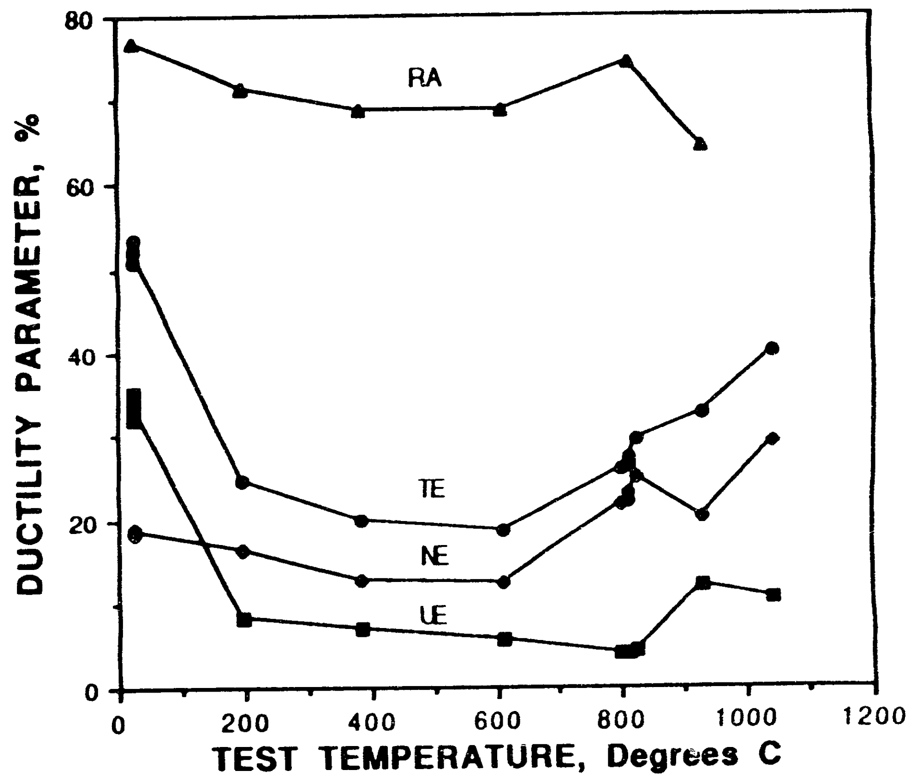
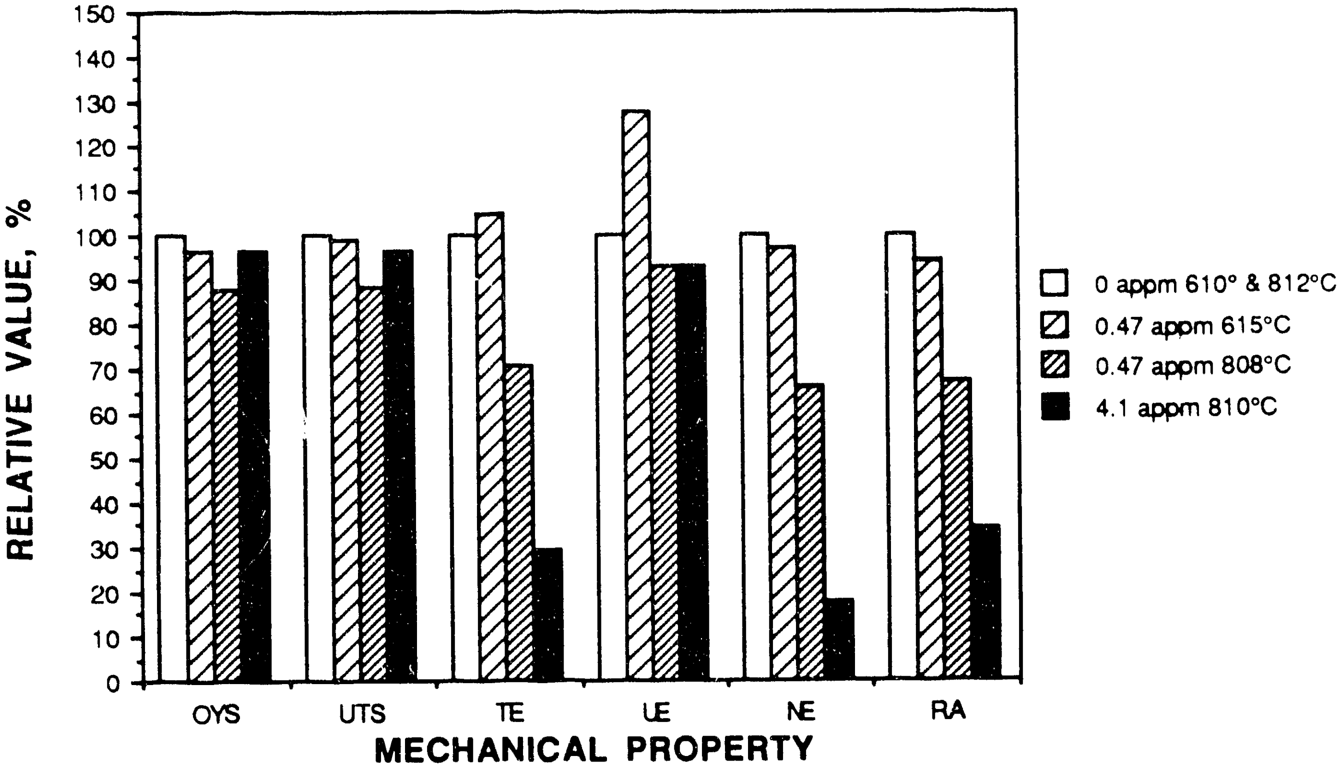


FIGURE 3



RELATIVE VALUE, %
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
OYS
UTS
TE
UE
NE
RA
MECHANICAL PROPERTY
0 appm 610° & 812°C
0.47 appm 615°C
0.47 appm 808°C
4.1 appm 810°C

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