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REPORT TITLE

TENSILE AND STRESS RUPTURE TESTS OF S8DR HASTELLOY-N
HEATS - ORNL VERIFICATION TESTS

AUTHOR

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NAA-SR-MEMO 12550

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		STATEMENT OF PROBLEM To determine the effect of test condition on tensile and stress-rupture data of Hastelloy-N.															
		ABSTRACT: In connection with the ORR Hastelloy-N irradiation experiments, a limited number of tensile tests and uniaxial and biaxial stress-rupture tests on S8DR Hastelloy-N heats were conducted at AI to determine the effect of some of the ORNL test conditions. The tests performed at AI were in parallel to the ORNL control tests. The results showed that the effect of the test condition variations between the two tests were generally insignificant. The effect of the test conditions is discussed.															

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I. INTRODUCTION

The ORR-S-1, -2, and -3 experiments were conducted to determine the effect of irradiation on the mechanical properties of Hastelloy-N under the SNAP-8 reactor operating conditions. The irradiation effect was derived by comparing test results of identical specimens in the irradiated and un-irradiated conditions. Due to simulating the in-pile test conditions and other equipment limitations, standard test procedures and methods were not uniformly followed. Past experience shows that results of mechanical tests are sensitive to test conditions and equipment systems. In order for AI to better interpret the ORNL results and correlate them to available Hastelloy-N data, it was deemed necessary that a limited number of tests parallel to the ORNL control tests be performed at AI. The tests include tensile tests and uniaxial and biaxial stress rupture tests and were designated as "ORNL Verification Tests."

II. RESULTS AND DISCUSSIONS

A. Biaxial Stress-Rupture Tests

The tube specimens for the biaxial stress-rupture tests were produced by AI. They were fabricated of three S8DS Hastelloy-N candidate heats. The specimens were chromized and coated internally. Construction of the specimen is shown in Figure 1. Dimensionally, they were 0.56" in diameter, 0.010" in wall thickness, and 4" in length. In these verification tests, three specimens of each heat were tested at three stress levels at 1400°F. The stresses were selected to obtain stress rupture life to cover the span between 100 to 1000 hours. The results of the tests are given in Table I in comparison with ORNL data. Although stress-rupture lives of the tests are in good agreement (Figure 2), the strains measured in the ORNL tests were consistently higher. Diametral strains in the ORNL data varied from 6.2 to 11.2%, while the AI results ranged only from 3.9 to 6.1%. To determine the discrepancy in ductility between the ORNL and AI data, the effects of some of the known variations in test conditions were investigated.

1. Temperature Distribution

In the ORNL control tests, heating was accomplished by sheathed nichrome wires wrapped around the specimens. This produced an axial temperature gradient between the center and ends of the specimens. As a result, failure of the specimens was confined to the central sections of the specimens. Rupture strains of the specimens consequently were free from the effect of end cap and weld restrictions. The AI tests were conducted in long resistance wound furnaces. Under these isothermal conditions, all of the specimens either failed at the welds or near the ends. To ascertain the effect of the temperature distribution on rupture strain, one specimen (No. 5053) which did not fail (because of a fitting leak) was reinserted in the same test rig and tested with an axial temperature gradient of 50°F between the central section and the ends. The result was that the specimen failed in the central section and the diametral strain at rupture was found to be higher (7%) than in any of the other AI biaxial stress-rupture tests.

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Typical distributions of diametrical strain under different heating conditions are shown in Figures 3 to 6.

2. Strain Measurement

Another factor that might have biased the strain results was the diametral strain measurement technique. The ORNL strains were obtained with a micrometer. In the AI tests, a precision profilometer was used. In order to determine the effect of the measuring techniques, the ruptured ORNL unirradiated specimens were returned to AI and subjected to profilometer measurement. The results are compared in Table II. The effect due to measurement technique appears to be negligible.

3. Test Atmosphere

Although He was the in-pile test atmosphere, the ORNL biaxial stress-rupture tests were conducted in air with argon as the pressurizing medium with the assumption that the effect of oxidation would be insignificant for chromized and coated Hastelloy-N under the test conditions. Since rupture strains of the specimens tested in air were higher, no investigation was made except to indicate that a discrepancy in atmosphere existed.

The results of the above investigation suggests the discrepancy in ductility was caused by end effect of the specimens rather than a difference in material property.

B. Uniaxial Stress-Rupture Test

The uniaxial stress-rupture tests were conducted with 1/8" diameter tensile bar specimens. The specimens for the tests were fabricated by ORNL and were not chromized. Dimensions and geometry of the specimens are shown in Figure 6. The only known discrepancy between ORNL and AI tests was the basis for which elongation was computed. The ORNL elongations were based on changes of the overall lengths of the specimens. In the AI tests, they were computed based on a one-inch gage length. The results of the verification tests are given in Table III. The rupture life appears to be in good agreement with the ORNL control data, as can be readily seen in Figure 7. No significant difference was apparent among the heats. The elongation values, however, indicates a significant difference in ductility between heat 6252AC and 5911 AW at 1400°F (Table III). The former heat varied from 34% to 65% (S/N 3911

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excepted; it failed in 10 hours due to overloading) and the range of the latter heat was 23% to 34% excluding those whose failures occurred on and outside the gage marks. The ORNL control data also showed the same behavior. The range of their elongation for 6252AC was 23% to 53% and for 5911 AW was 14% to 36%.

Vigorous analysis of the difference in rupture ductility is beyond the scope of this work. However, metallographic examination of the specimens with normal failures (excluding failures at and outside gage marks) revealed that it may be related to the degree of microsegregation banding of the specimens. The specimens from heat 6252AC had more pronounced segregation banding as shown in Figure 8.

The segregation banding appears to retard intergranular crack propagation. This retardation of crack propagation might have resulted in the redistribution of some of the stresses to the grain and caused distortion that contributed to the bulk of the deformation. Furthermore, chemical segregation would deplete the matrix material of alloying constituent and possibly make it more ductile. Other metallographic evidence indicated that there was some difference in the mode of fracture. Heat 6252 AC specimens failed with a limited amount of subcracking and the cracks were spheroidized. Heat 5911 AW, on the other hand, failed with profuse wedge shape subcracking. The difference in subcracking phenomena is shown in Figure 9.

C. Tensile Test

The tensile test specimens were identical to those used in the uniaxial stress-rupture test (see Figure 6). Deviations in the tensile tests between AI and ORNL was the method of deriving strain values. The ORNL tensile test elongation data were obtained by measuring the load-extension diagrams of the Instron universal testing machine. The extension corresponding to the maximum and the rupture loads were regarded as uniform and total elongations, respectively. In addition to obtaining similar data, one inch gage marks were placed on the verification test specimens to determine elongation. The results of the verification tensile tests are shown in Table IV and the ORNL results in Table V. At 1400°F, the data are in fair agreement. The ductility values are rather scattered and they were too few to denote any significant

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deviation. The 1200°F verification tests were affected by failure at the gage marks. It indicated the increase notch sensitivity of the material at the lower test temperature. The gage mark failure was also responsible for the lower values in some of verification test data. The verification tensile tests showed that the total elongation values obtained from the load diagrams were higher than those obtained by actual gage length measurements. This is probably due to the elastic strain and machine compliance which are included in the load diagram values.

It should also be noted in the data of both these verification tests and in the ORNL tests that the total elongations at 1200°F were primarily uniform and largely nonuniform at 1400°F according to the Instron load-extension diagrams.

III. CONCLUSIONS AND RECOMMENDATIONS

General agreement in the results of the AI verification tests and ORNL control tests indicates that the effect of test condition deviations are insignificant. The higher rupture strain range of the ORNL biaxial stress rupture tests should be accepted because the verification test strains were influenced by abnormal failures. However, the results should serve to indicate that diametral rupture strains are lower for end sections compared to central section of fuel cladding.

The verification tensile test results show that elongation values obtained from the Instron load diagram. Hence, for direct comparison of ductility data, the ORNL elongation should be reduced by 25%.

The results of AI verification uniaxial stress rupture tests generally agreed with those of the ORNL control tests. Both data showed that heat 6252 AC was more ductile than heat 5911 AW. It was not established whether this variation in ductility was caused by the difference in heat of the material or by their process conditions. The fact that the same stress range was covered by specimens from both heats indicates the effect was probably structural rather than caused by test conditions. Difference in the mode of failure between specimens failed with high and low strain may represent the structural influence on controlling creep mechanisms. It is recommended that the specimens be rigorously re-examined. Microprobe analysis and X-ray diffraction should be performed to determine the nature of the segregation banding and electron microscopy should be conducted to determine creep mechanisms. The structural effect, if verified, may be exploited to improve the mechanical properties of Hastelloy-N.

FIGURE 1. Construction of Biaxial Stress Rupture Specimen.

TABLE 1.
COMPARISON OF AI AND ORNL 1400°F UNIRRADIATED
BIAXIAL STRESS RUPTURE TEST RESULTS

Heat Number	Sample Number	Test Site	Hoop Stress (psi x 10 ³)	Rupture Life (hr)	Strain (%)	
					Average	Maximum
281-4-0143	5091 [*]	AI	16.3	174	4.9	5.2
	5070		13.2	335	2.3	3.9
	5041†		11.8	596	3.8	4.5
	5048	ORNL	18.6	64	-	8.9
	5072		14.9	153	-	8.2
	5062		12.4	789	-	11.2
5911	6022 [*]	AI	18.8	112	5.2	6.1
	6013		15.3	335	4.1	4.8
	6009†		12.8	586	3.3	3.9
	6019	ORNL	19.4	30	-	9.4
	6026		14.9	344	-	9.0
	6014		11.6	335	-	7.6
5911R	5056 [*]	AI	17.8	112	4.3	6.1
	5052 [§]		14.4	410	5.0	6.1
	5053†		10.7	(No rupture, fitting leak)		
	5049	ORNL	19.7	88	-	8.9
	5030		15.9	142	-	6.2
	5128		13.2	373	-	7.8

*Failure occurred at bottom weld

†Failure occurred at bottom section

§Failure occurred at top section

Figure 2. Comparison of ORNL and AI Biaxial Stress Rupture Test Results at 1400°F on SNAP 8 Cladding

FIGURE 3. Typical Diameter Profile of Biaxial Stress Rupture Specimens Before Test

FIGURE 4. Typical Diametric Strain Distribution of Biaxial Stress Rupture Specimens Heated in Marshall Furnace with Uniform Temperature

FIGURE 5. Diametric Strain Distribution of Biaxial Stress Rupture Specimen Heated in Marshall Furnace with Temperature Gradient of 50°F Between the Center and Ends of Specimen

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FIGURE 6. Typical Diametric Strain Distribution of ORNL Biaxial Stress Rupture Test Specimen Heated by Nichrome Wire and with Axial Temperature Gradient of 200° to 300°F Between the Center and Ends of Specimen

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TABLE II

COMPARISON OF RUPTURE STRAIN, MEASURED BY PROFILOMETER AND MICROMETER

<u>Specimen No.</u>	<u>Profilometer (%)</u>	<u>Micrometer (%)</u>
5069	17.2	17.2
5057	6.89	6.7
5097	8.07	7.7
5068	4.77	4.6
5098	9.69	9.6
5048	7.56	8.9
5072	8.17	8.2
5062	10.27	11.1
5078	10.75	10.6
6025	6.82	8.4
6029	3.35	3.9
6019	9.4	9.4
6018	6.73	6.4
6026	8.75	9.0
6014	8.78	7.6
6031	4.56	4.6
5127R	8.76	9.1
5126R	4.97	4.4
5057R	8.09	8.2
5050R	9.22	8.2
5049R	8.11	8.9
5038R	7.90	7.8
5130R	7.53	6.2
5128R	7.99	7.8
5123R	7.24	6.8
5054R	7.76	7.7

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TABLE III

VERIFICATION UNIAXIAL STRESS RUPTURE TEST RESULTS

Heat Number	Specimen Number	Test Temp. (°F)	Stress (psi)	Rupture Life (hr)	Total Elongation (%)	Reduction in Area (%)	Minimum Creep Rate (in./in./hr)
5911AW	3529	1400	20,400	138.9	23.0	22.7	1.2×10^{-3}
	3534*	1400	20,700	122.8	25.0	24.4	2.5×10^{-3}
	3536	1300	25,700	509	22.0	18.7	2.8×10^{-4}
	3541	1400	13,300	733	23	15.5	2.0×10^{-4}
	3542***	1400	13,700	349.3	3	0	8.2×10^{-5}
	3545**	1300	18,800	1664.8	18	6.5	5.3×10^{-5}
	3538****	1400	11,200	1222	16	11.0	7.7×10^{-5}
	3540**	1400	11,600	1596	20.0	19.0	9.1×10^{-5}
	4281	1200	50,100	45.6	17.0	15.3	9.9×10^{-4}
	4284	1200	35,000	448.2	11.0	13.9	9.1×10^{-5}
	4280**	1400	20,000	94.4	18.0	15.3	1.7×10^{-3}
	4287**	1400	13,000	857.6	24.0	19.7	1.7×10^{-4}
	4285	1400	11,600	1569.5	34.0	26.0	9.9×10^{-5}
	4286	1400	11,400	1829	35.0	28.5	1.6×10^{-4}
	4282**	1400	10,200	2104	19	12.5	9.0×10^{-5}
	4283	1400	10,000	2435	23	25.4	6.5×10^{-5}
6252AC	3912	1200	50,000	52.9	13.0	11.0	1.2×10^{-3}
	3915	1200	35,000	821.2	22	18.3	1.1×10^{-4}
	3911	1400	33,300	10.8	23	22.7	---
	3918	1400	13,000	941.8	65	46.0	2.5×10^{-4}
	3916	1400	11,600	1415	54	35.5	1.6×10^{-4}
	3917	1400	12,000	1572	63	36.0	2.2×10^{-4}
	3913	1400	10,000	2504	50	36.0	1.0×10^{-4}
	3914	1400	10,000	2135	34	41.0	1.0×10^{-4}

*Broke outside gage length

**Broke on gage mark

***Specimen damaged during loading

****Specimen failed due to equipment malfunction

FIGURE 7. Uniaxial Stress Rupture and Tensile Test Specimen

FIGURE 8

UNIAXIAL STRESS RUPTURE PROPERTIES OF HASTELLOY-N BAR AT 1400°F

Fracture Area of S/N 3916 Heat 6252 AC
Temperature - 1400°F Stress - 11,600
Rupture Life - 1415 hrs Elongation - 50%

Fracture Area of S/N 4283 Heat 5911 AW
Temperature - 1400°F Stress - 10,000
Rupture Life - 2435 Elongation - 23%

FIGURE 9. Comparison of Microsegregation Between
Heats 5252 AC and 5911 AW (40X)

Limited Intergranular Cracking Near Fracture Zone.
Cracks are spheroidized for Heat 6252 AC.

Profused Intergranular Cracking Near Fracture Zone.
Cracks are Wedge Shape for Heat 5911 AW.

FIGURE 10. Comparison of Stress Rupture Specimens
Between Heats 6252 AC and 5911 AW (40X).

TABLE IV
VERIFICATION TENSILE TEST RESULTS

Heat No.	Process Heat Treat	S/N	Test Lab	Test Temp. (°F)	Strength ₃ psi x 10 ³		Elongation (%)			Red. Area (%)
					Ultimate	Yield	Uniform	Total	Ga. Length	
5911 AW	1	3546	AI	1400	45.8	31.5	11.8	----	23	18.5
	1	3547*	AI	1400	47.8	34.5	10.5	26.0	19	23.1
	1 + 3	4288	AI	1400	45.5	29.8	10.0	41.1	32	29.6
	1 + 3	4289	AI	1400	46.0	29.8	10.3	36.9	32	32.3
6252 AC	2 + 3	3919	AI	1400	45.8	28.0	9.9	26.8	22	16.9
	2 + 3	3920	AI	1400	44.3	33.3	10.4	41.5	36	29.6
5911 AW	1	3548*	AI	1200	63.5	27.5	29.4	30.0	23	19.9
	1	3550*	AI	1200	63.0	27.8	25.6	25.8	19	19.9
	1 + 3	4290*	AI	1200	62.2	29.3	23.4	23.7	16	16.9
	1 + 3	4291	AI	1200	78.5	36.7	23.3	23.6	17	14.0
6252 AC	2 + 3	3921*	AI	1200	63.8	32.5	17.1	17.4	12	9.4
	2 + 3	3922*	AI	1200	63.8	33.2	16.3	16.5	12	11.0

(1) Annealed at 2150°F for 60 min.

(2) 50% reduction at 2100°F, Annealed 60 min. at 2150°F.

(3) Cold reduction of 8 1/3%, Annealed 30 min. at 1950°F three times.

Annealed 2 hrs @ 2000°F, Cold reduction of 4.5% and annealed for 10 min. at 2100°F.

*Fracture occurred at gage mark.

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TABLE V

ORNL CONTROL TENSILE TESTS RESULTS

Heat Number	Specimen Number	Heat Treat Process	Pre-Test Aging*	Test Temp. (°F)	Ultimate Strength (psi)	Yield Strength (psi)	Uniform Elongation (%)	Total Elongation (%)	Reduction in Area (%)
5911 AW ↓	3113	1	B	1020	87,800	32,600	57.1	58.2	41.6
	3117	1	A	1020	96,500	31,400	61.7	64.8	47.5
	3114	1	B	1110	65,200	35,400	22.5	23.5	23.2
	3119	1	A	1110					
	3108	1	A	1200	77,700	29,700	39.8	40.8	35.3
	3106	3A	A	1200	70,800	26,400	43.2	43.4	36.6
	2959	3	A	1200	76,600	34,300	29.6	30.3	25.7
5911 TH	3103	1	A	1200	74,300	29,200	41.1	42.7	33.5
5911 AW ↓	3121	1	A	1400	50,900	28,900	12.5	25.9	27.3
	3109	1	B	1400	47,700	32,200	8.0	13.4	14.4
	3115	1	B	1400	51,100	31,700	12.8	16.6	13.1
	2854	3A	B	1400	46,700	31,700	8.0	13.6	12.5
	2953	3	B	1400	45,800	32,200	8.2	22.9	22.1
5911 TH	3091	1	B	1400	47,800	32,400	7.7	16.2	13.9
6252 AC ↓	2919	2	A	1200	66,600	34,000	15.1	15.4	17.4
	2948	2 + 3	A	1200	73,500	37,500	21.6	21.9	19.1
	2921	2	B	1400	45,000	32,000	6.1	8.6	7.3
	3130	2A	B	1400	46,800	25,700	7.7	10.6	10.1
	2944	2 + 3	B	1400	44,700	33,500	8.7	20.2	17.6

*Pre-test aging treatments: A = 1080 hrs at 1200°F
B = 1080 hrs at 1400°F