CONF-841105--31

ELEVATED TEMPERATURE CREEP BEHAVIOR OF INCONEL ALLOY 625*

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DE84 015836

July 1984

*Work supported by the U.S. Department of Energy.

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SUMMARY

Inconel alloy 625 in the solution-annealed condition has been selected as the clad material for the fuel and control rod housing assemblies of the Upgraded Transient Reactor Test Facility (TREAT Upgrade or TU). A general description of the expected clad temperature history has been described in reference (1). In brief, for the TU reactor, the clad is expected to be subjected to temperatures up to about 1100 °C - including the Design Basis Accident (DBA) event.

In this investigation, creep behavior for the temperature range of 800 - 1100 °C of Inconel alloy 625, in four distinct heat treated conditions, were experimentally evaluated.

The TU is an air-cooled reactor; its fuel consists of dispersed UO_2 in a graphite-carbon matrix. During the lifetime of the clad, oxidation/nitridation (outside surface) and carburization (inside surface) are expected to occur. Hence, for a proper design of the clad, the effect of these phenomena on the thermomechanical properties -- including creep strength -- had to be evaluated. The present work describes the creep experiments, the results obtained, and the analysis of data. No comparable study has been found in the technical literature.

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All the specimens were prepared from the Inconel 625 sheet material specified for the fabrication of the TU fuel assemblies (Huntington Alloys Heat #NX1626A). Nominal sheet thickness was 0.635 mm (0.025 in).

The specimen geometry is schematically shown in the inset of Figure 1. All tests were performed in the standard constant load test mode. The specimen gage temperature was controlled to an accuracy of ± 5 °C throughout the test duration (some lasting in excess of 11,000 hours). The specimen extension was measured using an LVDT attached to the loading arm. Pre- and post test measurements indicated that the deformation of the region outside-the gage length was negligibly small for 800 and 900 °C tests, while it was estimated to be less than 5% of the total deformation for temperatures of 1000 and 1100 °C. All data reported are based on the LVDT measurements. Thus, the actual creep rates for 1000 and 1100 °C are expected to be slightly lower than the reported value, the same is true for ductility values. In all, four types of specimens were tested during this work: 1) mill annealed (average grain diameter, 0.03 mm), 2) solution annealed at 1100°C (average grain diameter, 0.1 mm) 3) nitrided-solutionized (average grain diameter, 0.1 mm), and 4) solution-annealed at 1150 °C (average grain diameter, 0.3 mm).

Mill annealing was performed at 950 $\pm$ 25 °C by Huntington Alloys, Inc.; all the remaining heat treatments were done by Argonne National Laboratory. The solution-annealed condition was achieved by heating the specimens in an argon environment for one hour at 1100 or 1150 °C $\pm$ 10 °C. Nitriding-solutionizing was effected in an ammonia-rich atmosphere at 1100 $\pm$ 20 °C for 45 minutes. Nitrided layer thickness was measured as 7.6×10^{-2} mm. Time-to-rupture results for the solution-annealed material are depicted in Figure 1. The effect of stress and temperature is found to be as expected; increasing temperature or stress causes a reduction in rupture time. For ready comparison, the data from the 900 °C tests of the nitrided-solutionized specimens are also shown in Figure 1. These results indicate that the specific nitrided layer effected on these specimens has a strengthening effect. The rupture times of the nitrided specimen are found to be consistently greater than the solution-annealed specimens (of comparable grain size) by a factor of 20 to 30%.

Results pertaining to the minimum creep rate, primary creep rate, failure ductility and failure times for all tests - including the mill-annealed and 1150 °C solution-annealed materials - are summarized is Table 1. The interesting observation in regards to the mill-annealed material is that, that for a given temperature and stress value, the time to failure values are less than that for the solution-annealed material by about an order of magnitude. However, the solution-annealing appears to cause a reduction in the failure ductility, by a factor of about 2 for the 1100 °C anneal and factor of about 3 for 1150 °C anneal. Thus, - as others have observed on various super-alloys - increasing grain-size decreases the ductility and creep rates but results in an increase in the creep rupture time values.

Reference

1. Ankur Purohit, Ulrich Thiele and John E. O'Donnell, "Fatigue Strength and Evaluation of Creep Damage During Fatigue Cycling of Inconel Alloy 625", Trans. ANS, Vol. 45, November 1983, p. 288-289.

Table 1
Results of Creep Tests of Inconel Alloy 625

Test #	Test Temperature °C	Initial Stress ksi	Time of Failure, Hours	Minimum Creep Rate, %/1000 h	Primary Creep Rate, %/1000 h	Failure Ductility %	Material Condition*
1199	800	10.0	1955.1	7.45	38.14	35.78	2
1195	800	15.0	115.1	306	306	58.78	2
1213	800	15.0	117.7	350	350	57.83	2
1214	800	15.0	288.8	120.0	225.0	46.73	4
1216	800	15.0	31.8	970.0	970.0	75.35	1
1193	800	20.0	29.8	1380.0	1380.0	73.17	2
1219	900	5.0	28.7	1500.0	2166	93.6	1
1220	900	5.0	280.1	100.0	283	51.93	2
1202	900	5.0	258.76	137.0	137.0	52.99	2
1223	900	5.0	3128.9	25.19	81.82	62.99	3
1198	900	10.0	14.16	2566.66	2566.66	57.91	2
1206	900	3.0	11,182.8	14.0	112.5	67.70	2
1209	950	2.0	11,055.05	11.3	11.3	70.03	2
1204	950	3.0	539.19	139.0	139.0	72.28	2
1183**	950	1.5	(1000+)	9.63	9.63	(15.0+)	2
1208	1000	1.5	3904.18	48.0	185.2	44.8	2
1203	1000	2.0	337.06	301.45	301.45	71.55	2
1247	1000	2.0	5134.5	-	-	18.0	3
1234	1000	2.5	1990.71	20.15	69.6	72.76	4
1200	1100	1.5	91.42	1019.11	1019.11	92.95	2
1197	1100	2.0	15.3	2319.44	2319.44	57.36	2
1232	1100	2.0	60.64	660.5	1345.4	30.02	4
1262++	900	3.0	11,350+	-	-	20+	3
1259	900	5.0	702.5	-	-	49.0	3
1252	900	5.0	764.95	-	-	50.9	3
1253	900	7.1	95.35	-	-	35.16	3
1254	900	7.1	98.8	-	-	38.85	3
1250	900	10.2	21.1	-	-	53.6	3
1256	900	10.2	20.8	-	-	54.5	3
1257	900	15.3	2.4	-	-	77.01	3
1249	900	15.3	2.9	-	-	81.46	3

*1 = mill-annealed
2 = solution-annealed at 1100 °C
3 = nitrided-solutionized
4 = solution-annealed at 1150°C

**Test shut down before failure.
++Test in progress.

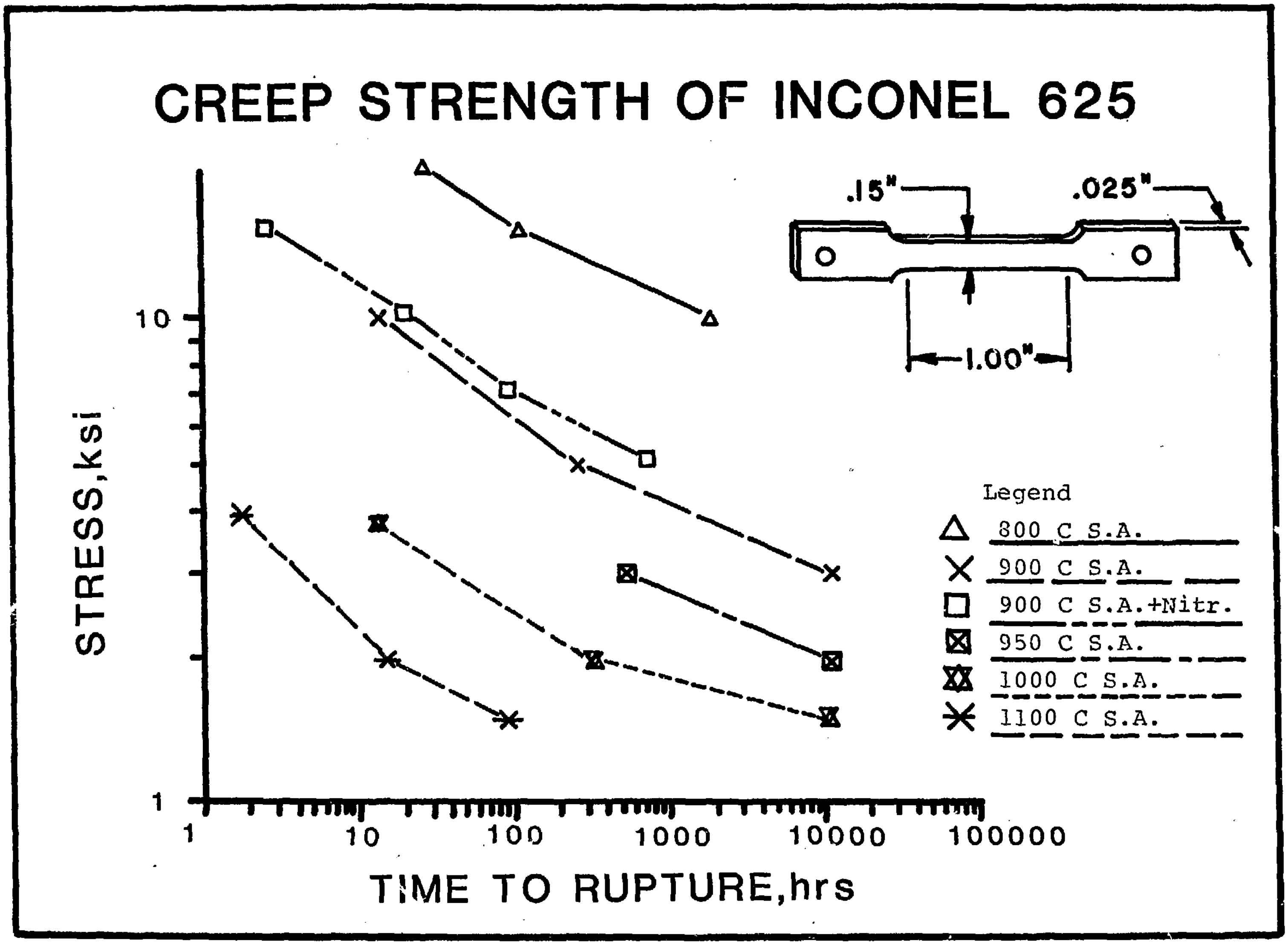

Figure 1. Creep rupture data for solution-annealed and nitrided-solutionized Inconel alloy 625