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EG&G contribution to the "Mechanical
Properties Test Data for Structural
Materials Semiannual Progress Report
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MASTER

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SUMMARY

1. EG&G IDAHO, INC.

Mechanical property investigations of Alloy 718 given either the 954°C conventional or the INEL heat treatment are continuing. Current conventional heat-treat data include tests showing the effects of surface finish, product variability, and thermal exposure on the high-cycle fatigue properties; creep-fatigue tests at 538, 593, 649, and 704°C with 0.1 hour hold times at peak strain; and stress-rupture tests of notched and smooth specimens showing the effect of pretest thermal exposure. A few stress-rupture tests of weld and base metals given the INEL heat treatment are also reported.

High-cycle fatigue tests of Type 316 stainless steel at 593°C are reported and compared with previous data from other sources.

ORNL SEMI-ANNUAL PROGRESS REPORT

1. EG&G IDAHO, INC.

Dr. D. D. Keiser

1.1 INTRODUCTION

EG&G Idaho, Inc., is conducting mechanical properties investigations under a program sponsored by DOE, Division of Reactor Research and Technology.^a The Alloy 718 Mechanical Property Program has as its primary objective the acquisition of the necessary mechanical property data to permit safe, efficient use of this material in LMFBR service. Any reactor service applications which require high levels of mechanical properties at temperatures up to 649°C are also expected to make use of this material.

To provide an adequate data base for LMFBR design needs and qualify for ASME Code approval, additional data are being generated to complement existing data in the literature. Current tests are being conducted on material given both the 954°C conventional^b and the INEL^c heat treatment. The additional data required will include: (1) tensile properties from room temperature to 704°C; (2) physical properties from room temperature to 760°C to include density, thermal expansion, heat capacity, and thermal conductivity; (3) creep-rupture properties from 538 to 760°C; (4) low-cycle fatigue (to 10^6 cycles) from room temperature

^a Task IN-1.3 (AF-151015), WPAS 6DA102.

^b 954°C SA 1 h, duplex age 718°C 8 h, FC to 621°C, and age an additional 8 h.

^c 1093°C SA 1 h, slow cool at 83°C/h to 718°C, age at 718°C 4 h, FC to 621°C, and age an additional 16 h.

to 704°C; (5) high-cycle fatigue (to 10^9 cycles) from room temperature to 704°C; (6) relaxation properties at 649°C; (7) creep-fatigue interaction from 538 to 704°C; and (8) long-term aging effects from 593 to 760°C at times up to 25,000 h.

High-cycle fatigue tests of Type 316 stainless steel are also being conducted at 593°C in support of LMFBR design needs. This is a cooperative program with Argonne National Laboratory.

1.2 MECHANICAL PROPERTY PROGRAM OF ALLOY 718

G. E. Korth and G. R. Smolik

1.2.1 Effects of Various Parameters on the High-Cycle Fatigue Behavior of Alloy 718

1.2.1.1 Surface Finish Effects

An investigation to determine the effects of various surface finishes on the high-cycle fatigue of Alloy 718 given the 954°C conventional heat treatment is continuing. In the last progress report,¹ tests with grit-blasted and belt-sanded surfaces were compared with the standard laboratory low-stress grind specimen surface. In this reporting period, additional tests have been conducted at 427°C on specimens with either electropolished or fine lathe-turned surfaces.

Also, three specimens with circumferential scratches were tested. These scratches were produced by scoring with a diamond stylus and ranged in depth from a visual indication only to 0.020-mm. All tests were conducted in axial load control with hourglass specimens except for one electropolished specimen which was loaded by rotating bending. Results are listed in Table 1.1 and are compared with previous data in Figure 1.1. A best-fit curve of high-cycle fatigue data of the same heat determined by Snow² is also shown in Figure 1.1, and a plot of the residuals [residual = $(S_a)_{\text{observed}} - (S_a)_{\text{calculated}}$] is shown in Figure 1.2. As can be seen from Figures 1.1 and 1.2, there is little effect of the various surface finishes. The lathe-turned finish appears to have a slight detrimental bias in the 5×10^5 to 5×10^6 cycle life regime but at higher cycle lives its behavior is equivalent to that of

TABLE 1.1. Alloy 718^a Load Control High-Cycle Fatigue Data at 427°C of Specimens with Various Surface Preparations

Specimen Number	Stress Amplitude (MPa)	Test Freq. (Hz)	Cycles to Fail, N _f	Surface Preparation ^b
R24-18	517	30	2 281 252	ELP
R21-16	496	30	2 109 893	ELP
R24-10	469	30	1 771 134	ELP
R24-3	469	30	2 302 230	ELP
R14-29	455	167	338 996 000 ^{c,h}	ELP
R9-3	414	30	25 409 098 ^c	ELP
RP7-84	517	20	477 000 ^d	LF
R3-38	517	20	556 700	LF
RP7-85	517	20	569 200 ^d	LF
R21-17	496	20	1 357 020	LF
R21-4	455	20	3 218 900	LF
R21-8	476	20	10 796 600	LF
R24-13	448	20	20 458 000 ^c	ELF w/scratch ^e
R21-12	448	20	6 935 790	LSG w/scratch ^f
R21-3	469	20	2 584 880	LF w/scratch ^g

^a Reference heat (2180-6-9458) 19-mm plate given the conventional 954°C heat treatment.

^b ELP = Electropolished, surface roughness = 56 μ-in. arithmetic average (AA) (0.075-mm removed per side from low-stress grind surface),

LF = Lathe finish, surface roughness = 12 μ-in. AA (0.075-mm removed per side from low-stress grind surface),

LSG = Low-stress grind, surface roughness = 10 μ-in. AA (standard surface preparation for fatigue specimens).

^c Test terminated before failure.

^d Uniform gage specimen, all others were hourglass.

^e Circumferential scratch 270° around diameter with maximum depth of 0.010-mm.

^f Circumferential scratch 180° around diameter with maximum depth of 0.020-mm.

^g Circumferential scratch 360° around diameter, visual indication only - depth not measurable.

^h Rotating beam test, all others were axially loaded.

Fig. 1.1. Surface finish effects on high-cycle fatigue of Alloy 718 at 427°C.

Fig. 1.2. Residuals plot of surface finish effects on high-cycle fatigue of Alloy 718 at 427°C.

other surfaces. Even the scratched specimens did not appear to be unduly affected in their high-cycle fatigue behavior. The surface roughness of the electropolished and lathe-turned finishes is noted in Table 1.1. The reason that the electropolished surface roughness is quite high is due to the carbides and other second-phase precipitates that stand out in relief on the material's surface.

1.2.1.2 Product Form Variability

An investigation to study the effects of different product forms on the high-cycle fatigue properties of Alloy 718 has been initiated. Tests are being conducted at 24, 427, and 649°C. All test specimens were fabricated from the Alloy 718 reference heat (2180-6-9458). The data base had been generated utilizing 12.7 to 19.1-mm-thick plate material, but other product forms are now being investigated on a limited basis. One or two tests with a target life of 5×10^5 to 5×10^6 cycles are scheduled to be conducted at three test temperatures for the following product forms: 203-mm-truncated square forgings, 25.4-mm-thick pancake forgings with various upset ratios, round bars from 12.7 to 50.8-mm in diameter, a 25.4 and 50.8-mm-thick plate, and a 1.6-mm-thick sheet. Tests conducted to date include those taken from the forgings and the round bars. Orientations of specimens with respect to the large forging are shown in Figure 1.3 and results are listed in Table 1.2 and are compared with reference heat plate material in Figures 1.4-1.6. The best-fit curves shown on the Figures are from the analysis by Snow.²

The results show that, in general, the forging material has superior high-cycle fatigue strength compared to plate material and the round bar is equivalent or slightly lower.

1.2.1.3 Thermal Exposure Effects

The tests to determine long-term aging effects on the mechanical properties of Alloy 718 given the 945°C conventional heat treatment are in progress. Strain-control and load-control fatigue data of notched specimens aged up to 10,000 h were reported in the last progress report.¹ Current data are for load-control, high-cycle fatigue tests

Parallel specimen blanks

203
mm

Transverse specimen blanks

INEL-A-16 025

Fig. 1.3. Truncated square forging showing orientation of specimen blanks.

Table 1.2. Alloy 718^a Product Variability
Load Control High-Cycle Fatigue Data

Specimen ^b Number	Test Temp. (°C)	Stress Amplitude (MPa)	Test Freq. (Hz)	Cycles to Fail, N _f	Specimen Type
RR5-9	24	517	30	301 000	P
RR2-9C	24	517	30	332 000	P
RF8-30	24	524	30	380 807	PS
RF8-9	24	524	30	435 000	TC
RR1-9	24	524	30	454 000	P
RR2-9S	24	517	30	515 000	P
RR7-9	24	524	30	608 000	P
RF8-33	24	517	30	4 104 370	PC
RR5-10	424	517	30	53 551 400 ^d	P
RR2-10S	427	524	30	210 000	P
RF8-10	427	531	30	878 000	TC
RR2-10C	427	524	30	914 000	P
RR1-10	427	531	30	1 387 031	P
RR1-11	427	524	30	1 784 792	P
RF8-31	427	531	30	1 847 000	PS
RR7-10	427	531	30	2 707 744	P
RF8-34	427	517	30	60 040 700 ^d	PC
RF8-35	649	517	30	163 050 000 ^d	PC
RF8-32	649	552	30	94 000	PS
RR2-11S	649	524	30	97 584	P
RR7-11	649	531	30	482 000	P
RR2-11C	649	517	30	1 149 390	P
RR5-11	649	517	30	1 450 000	P
RF8-11	649	531	30	2 376 565	TC

^a Reference heat [2180-6-9457(8)] given the 954°C conventional heat treatment.

^b Specimen identification:

RF3-XX 3:1 Upset forging (25.4-mm plate)

RF5-XX 5:1 Upset forging (25.4-mm plate)

RF8-XX 203-mm trunc, square forging

RR7-XX 19.0-mm round bar

RR1-XX 25.4-mm round bar

RR2-XX 50.8-mm round bar.

^c Specimen location in product form:

T = Transverse

P = Parallel

PS = Parallel surface

TS = Transverse surface

ES = Edge section

CS = Center section.

^d Test terminated before failure.

Fig. 1.4. Effects of product form on high-cycle fatigue of Alloy 718 at 24°C.

Fig. 1.5. Effects of product form on high-cycle fatigue of Alloy 718 at 427°C.

Fig. 1.6. Effects of product form on high-cycle fatigue of Alloy 718 at 649°C.

conducted at 24 and 649°C on smooth specimens aged at 649°C for 1,000, 5,000, and 10,000 h. Also, data from two additional tests of material aged for 5,000 h at 760°C are included. Test results are listed in Table 1.3 and are compared with unaged test results in Figure 1.7 for 24°C tests and Figure 1.8 for 649°C tests. The data from the 760°C aged test run at 760°C were not plotted since no 760°C base-line data were available for comparison. The results showed that the material aged at 649°C exhibited equivalent or superior high-cycle fatigue strength when compared with the unaged material of the same heat when the test temperature was 649°C but a slight detrimental effect of the aging was shown at 24°C. The cycle life of the specimen aged at 760°C was significantly reduced.

1.2.2 Creep-Fatigue Tests

Creep-fatigue testing of Alloy 718 given the 954°C conventional heat treatment is continuing. Tests are being conducted at 538, 593, 649, and 704°C. A series of tests has just been completed wherein results of tensile hold, compression hold, and the combination of tensile and compression hold periods have been compared to determine which hold is most damaging in reducing cycle life. In this series the total hold time for each cycle was 0.10 h. The results of this series of tests are listed in Table 1.4, and the 0.10 h hold-time data are compared with zero hold time best-fit curves³ in Figures 1.9, 1.10, 1.11, and 1.12 for 538, 593, 649, and 704°C, respectively. Some of the datum points plotted in these Figures have been reported in previous progress reports.^{4,5} The results show that tensile hold is the least and compressive hold is the most detrimental in reducing cycle life. The combination tensile and compressive hold is slightly more damaging than the compressive-only hold time in a few isolated tests, but the general trend indicates that compressive-only hold time to be the worst case.

Relatively high mean stresses develop during the hold time tests when the dwell period is at only one end of the cycle. The mean stress develops on the opposite end of the hysteresis loop from the hold period, and therefore it is possible that the mean tensile stress may well be the more damaging factor in a compression hold time test.

TABLE 1.3. Alloy 718^a Aged Load Control High-Cycle Fatigue^b Data

Specimen Number	Test Temp. (°C)	Stress Amplitude (MPa)	Test Freq. (Hz)	Cycles to Fail, N _f	Aging History	
					Time (h)	Temp. (°C)
R12-13	24	470	20	126 700	5 000	760
R12-19	24	475	20	963 500	5 000	649
R12-8	24	475	20	492 600	10 000	649
R12-17	649	475	30	14 740 850	1 000	649
R12-18	649	485	20	16 850 580	1 000	649
R12-20	649	485	20	21 125 000	5 000	649
R12-7	649	485	20	18 813 300	10 000	649
R12-14	760	290	20	3 926 000	5 000	760

^a Reference heat (2180-6-9458) 19-mm plate given the 954°C conventional heat treatment.

^b Stress ratio = -1, axially loaded hourglass specimens.

Fig. 1.7. Aging effect on high-cycle fatigue of Alloy 718 at 24°C.

Fig. 1.8. Aging effect on high-cycle fatigue of Alloy 718 at 649°C.

Table 1.4. Alloy 718^a Creep-Fatigue Data Tested in Strain Control

Specimen Number	Test Temp. (°C)	Total Strain Range (%)	Properties at $N_f/2$							Hold Mode ^b	Cycles to			Time to Fail (h)
			Plastic Strain Range (%)	Stress Range (MPa)	Stress Amplitude ^b (MPa)	Relaxed Stress		Hold Time (h)	N_0		N_5	N_f		
						Tens. (MPa)	Comp. (MPa)							
R23-23	538	1.30	0.41	1429	687 C	---	676	.10	C	3415	3435	3465	349.89	
R11-10	538	1.30	0.51	1379	785 C	---	717	.10	C	-----	----	4264	431.74	
R11-22	538	1.31	0.43	1333	629 T	611	---	.10	T	2502	2546	2570	260.76	
R23-33	538	1.31	0.41	1396	648 T	635	---	.10	T	2958	3119	3296	334.73	
R11-28	538	1.31	0.52	1280	599 T	533	627	.05	T&C	4074	4081	4102	414.07	
R11-21	538	1.31	0.47	1297	624 T	582	---	.10	T	5265	5330	5336	543.35	
R20-14	593	1.29	0.44	1317	663 C	---	615	.10	C	1576	1602	1644	179.60	
R11-25	593	1.30	0.51	1280	616 C	---	519	.10	C	918	942	959	97.31	
R11-5	593	1.30	0.44	1330	650 T	598	---	.10	T	1527	1547	1622	162.70	
R11-35	593	1.30	0.47	1053	500 T	463	529	.05	T&C	2360	2366	2375	241.20	
R23-25	593	1.31	0.44	1346	670 C	---	494	.50	C	1474	1498	1506	724.24	
R23-22	593	1.31	0.45	1324	604 T	575	---	.10	T	1816	1993	2046	206.62	
R11-17	593	1.31	0.50	1148	548 T	481	539	.05	T&C	2835	2875	2915	295.94	
R9-18	649	1.00	0.11	1235	544 T	479	---	.50	T	-----	-----	2385	1195.85	
R20-17	649	1.00	0.24	1197	579 C	---	527	.10	C	2908	3152	3382	341.37	
R23-31	649	1.01	0.19	1306	683 C	---	512	.50	C	1691	1727	1755	859.90	
R7-6	649	1.00	0.18	1306	663 T	626	558	.25	T&C	-----	-----	1020	498.79	
R11-11	649	1.00	0.17	1154	521 T	475	595	.05	T&C	8366	8590	8635	887.64	
R3-6	649	1.02	0.22	1279	559 T	518	---	.01	T	5131	5235	5541	87.87	
R11-6	704	0.99	0.19	1232	465 T	351	---	.10	T	2592	2655	2715	275.17	
R11-39	704	1.00	0.23	1205	672 C	---	571	.10	C	1041	1097	1134	115.04	
R11-19	704	1.01	0.43	1144	553 T	367	422	.05	T&C	665	694	725	73.11	
R11-3	704	1.01	0.23	1089	408 T	268	---	.10	T	1054	1121	1121	112.58	
R11-34	704	1.02	0.22	1235	515 C	---	371	.10	C	938	984	1078	108.72	
R11-20	704	1.02	0.34	1102	525 T	415	472	.05	T&C	1012	1066	1107	110.72	

^a Reference heat (2180-6-9458) 19-mm plate given the 954°C conventional heat treatment.^b T = Tensile hold
C = Compression hold.

Fig. 1.9. Effects of 0.10 hour hold time on strain fatigue of Alloy 718 at 538°C.

Fig. 1.10. Effects of 0.10 hour hold time on strain fatigue of Alloy 718 at 593°C.

Fig. 1.11. Effects of 0.10 hour hold time on strain fatigue of Alloy 718 at 649°C.

Fig. 1.12. Effects of 0.10 hour hold time on strain fatigue of Alloy 718 at 704°C.

1.2.3 Stress-Rupture Tests

Stress rupture and creep tests have been performed on Alloy 718 for both heat treatments, i.e., the 954°C conventional heat treatment and the INEL heat treatment, with the majority involving notched and thermally aged specimens given the 954°C conventional heat treatment. Results of these tests are reported in Table 1.5. The status of tests currently in progress are included. Data illustrating the effects of circumferential V-notches and pretest thermal exposures on rupture life of reference heat, 2180-6-9458, at test temperatures of 593, 649, 704 and 760°C are shown in Figures 1.13, 1.14, 1.15 and 1.16, respectively. The effects of pretest exposures on rupture life at 649°C of two other heats of material, 2180-1-9327 and 2180-2-9407, are shown in Figure 1.17. The results indicate, firstly, an increased rupture life for notched specimens at all test temperatures, Figures 1.13 through 1.16. Secondly, pretest exposures at 649°C for 1,000 h did not produce any noticeable change in rupture endurance of either notched or uniform gage specimens, however, longer exposures at 649°C, e.g., 5,000 and 10,000 h, reduced rupture life of uniform gage specimens, Figures 1.13 and 1.14. Reductions in rupture life are also noted for two other heats of materials exposed at 649 and 704°C for 25,000 h, Figure 1.17. Changes in the rupture life of notched specimens were not observed after pretest exposures at 649°C. However, a 5,000 h exposure at 760°C produced significant reductions in the rupture life of notched specimens.

A few base metal and weld metal specimens with the INEL heat treatment were tested. Results of these tests are listed in Table 1.6. Tests conducted on weldment specimens at 538°C required longer than expected failure times. This is shown by the stress versus rupture life plot in Figure 1.18 and indicates a lower slope than observed for the 954°C heat treatment.

TABLE 1.5. Creep Rupture Data of Alloy 718 Plates Having the 954°C Conventional Heat Treatment

Specimen ^a Number	Thermal History	Specimen Type ^h	Test Temp. (°C)	Applied Stress (MPa)	Rupture Life (h)	Min. Creep Rate (%/h)	Strain Intercept @t=0 (%)	Time to Tertiary Creep Shown by 0.2% offset (%)	Total Elong. (%)	Red. in Area (%)
RP5-1P	Conv.	U.G.	482	1 102	1 272 ^b	--	--	--	--	--
92-7	Conv.	U.G.	593	814	116 ^b	--	--	--	--	--
R2-31	Conv.	U.G.	593	641	5 312 ^b	--	--	--	--	--
RP7-183	Conv.	Notched	593	1 103	65	--	--	--	--	--
RP7-184	Conv.	Notched	593	1 034	421	--	--	--	--	--
R2-4	Conv. + c	U.G.	593	813	960	0.00115	0.550	546	10	31
R2-34	Conv. + d	U.G.	593	896	31	0.364	1.511	9.6	34	47
R2-24	Conv. + d	U.G.	593	785	512	0.0158	1.390	227	24	37
R2-13	Conv. + g	U.G.	593	552	152	0.0733	--	108	22	48
92-2	Conv. + e	U.G.	593	723	199 ^b	--	--	--	11	16
R2-38	Conv.	U.G.	649	380	512 ^b	--	--	--	--	--
RP7-181	Conv.	Notched	649	1 000	1.6	--	--	--	--	--
RP7-191	Conv.	Notched	649	1 000	1.7	--	--	--	--	--
RP7-192	Conv.	Notched	649	938	147	--	--	--	--	--
RP7-186	Conv.	Notched	649	883	187	--	--	--	--	--
RP7-182	Conv.	Notched	649	793	963	--	--	--	--	--
R2-3	Conv. + c	U.G.	649	621	559	0.00125	0.571	289	16	33
92-1	Conv. + e	U.G.	649	607	89	0.0818	0.943	59	11	17
72-20	Conv. + f	U.G.	649	518	20	0.894	1.524	5.0	40	57
72-21	Conv. + f	U.G.	649	399	60	0.298	1.247	15	30	57
R23-16	Conv.	U.G.	704	139	10 828 ^b	--	--	--	--	--
RP7-188	Conv.	Notched	704	607	249	--	--	--	--	--
RP7-187	Conv.	Notched	704	483	764	--	--	--	--	--
RP7-189	Conv.	Notched	760	414	137	--	--	--	--	--
RP7-190	Conv.	Notched	760	289	357	--	--	--	--	--
R2-14	Conv. + g	U.G.	760	138	210	0.0558	0.420	76	44	76

^a Specimens initiating with R, 7 and 9 are from heats 2180-6-9458 (19.1-mm plate), 2180-1-9327 (12.7-mm plate), and 2180-2-9407 (25.4-mm plate), respectively.

^b Specimen has not failed; test still in progress.

^c 1 Kh pretest exposure at 649°C.

^d 5 Kh pretest exposure at 649°C.

^e 25 Kh pretest exposure at 649°C.

^f 25 Kh pretest exposure at 704°C.

^g 5 Kh pretest exposure at 760°C.

^h U.G. = Smooth uniform gage, Notched = circumferential V-notch ($K_{theo.} = 3.6$).

Fig. 1.13. Rupture life of smooth and notched ($K_t=3.6$) specimens of Alloy 718 (Reference Heat 2180-6-9458) given the 954°C conventional heat treatment at 593°C and with and without additional pre-test thermal exposure.

Fig. 1.14. Rupture life of smooth and notched ($K_t=3.6$) specimens of Alloy 718 (Reference Heat 2180-6-9458) given the 954°C conventional heat treatment at 649°C and with and without additional pre-test thermal exposure.

Fig. 1.15. Rupture life of smooth and notched ($K_t=3.6$) specimens of Alloy 718 (Reference Heat 2180-6-9458) given the 954°C conventional heat treatment at 704°C.

Fig. 1.16. Rupture life of smooth and notched ($K_t=3.6$) specimens of Alloy 718 (Reference Heat 2180-6-9458) given the 954°C conventional heat treatment at 760°C. A specimen pre-exposed at 760°C is included.

Fig. 1.17. Rupture life of uniform gage stress rupture specimens from two heats of Alloy 718 at 649°C. Data include conventionally heat-treated specimens both with and without pre-test thermal exposures.

TABLE 1.6. Creep Rupture Data on INEL Heat-Treated Specimens^a

Specimen ^b Number	Spec. ^c Type	Test Temp. (°C)	Applied Stress (MPa)	Life Rupture (h)	Min. Creep Rate (%/h)	Strain Intercept @t=0 (%)	Time to Tertiary Creep shown by 0.2% offset	Total Elong. (%)	Red. in Area (%)
1A1-119	W-L	538	827	8 058 ^d	0.00012	1.072	6 170	2.2	3.4
6C6-122	W-L	538	765	10 721 ^d	0.00002	0.652	--	0.9	0.6
82-11	B-L	649	552	1 913	0.00044	0.461	1 114	8	19
1A1-114	W-L	649	552	2 155	0.00027	0.338	1 442	4	11
82-9	B-L	704	276	1 977 ^e	--	--	--	--	--

^a 1093°C solution anneal, slow cool, 718/621°C duplex age.

^b 1A1-XXX = heat 1 (2180-2-9251) 15.9-mm plate welded with filler wire A (heat 60C7E, 15.7-mm dia.).
 6C6-XXX = heat 6 (2180-4-9476) 12.7-mm plate welded with filler wire C (heat 52B0E, 1.14-mm dia.).
 8X-XX = heat 8 (2180-3-9443) 19.1-mm plate.

^c B = base metal, W = weld metal, and L = longitudinal orientation.

^d Specimen did not fail, test was terminated.

^e Test still in progress.

Fig. 1.18. Rupture life of base metal and weldments of Alloy 718 given the INEL heat treatment and tested at 538°C.

1.3 HIGH-CYCLE FATIGUE OF TYPE 316 STAINLESS STEEL

An investigation to determine the 10^8 cycle endurance limit on Type 316 stainless steel is continuing. Current tests are being run at 593°C in strain control at 1 Hz (sine waveform) to 10^6 cycles and then switched to load control and 20 Hz to failure. The ORNL reference heat of Type 316 stainless steel (8092297) is being utilized for this study. Current results are listed in Table 1.7, and all tests conducted to date (including those reported in Reference 1) are illustrated in Figure 1.19. A best-fit equation as proposed by Raske⁷ is also shown in Figure 1.19 for comparison as well as data generated and compiled by Jaske.⁸

A companion study at ANL^a using a psuedo stroke/strain control technique which allows much faster cycling rates at the beginning of the test is experiencing significantly longer fatigue lives for a given strain range (approximately a factor of 10 at 0.30% strain range). At this point, it appears that the high-cycle fatigue strength of Type 316 stainless steel is strain rate dependent during the initial cyclic hardening stages.

^aSee ANL contribution in this progress report.

Table 1.7. High-Cycle Fatigue^a Data of Type 316 Stainless Steel^b Tested at 593°C

Specimen Number	Total Strain Range (%)	Plastic Strain Range ^c (%)	Tensile Stress Range ^c (MPa)	Tensile Stress Amplitude ^c (MPa)	Cycles to Load Drop, N ₀	Strain Control Cycles	Cycles to Fail, N _f	Waveform
DR-9	0.32	0.023	449	228	910 898	910 898	910 898	d
DR-17	0.30	0.019	440	218	-----	1 176 202	3 416 836	d
DR-27	0.29	0.026	426	213	-----	1 213 757	1 675 317	e
DR-22	0.28	0.013	411	202	-----	1 032 960	8 750 310	e
DR-8	0.27	0.013	385	188	-----	1 201 860	3 647 320	e
DR-23	0.27	0.010	399	198	-----	859 080	1 295 620	e

^a Tests were run in strain control to failure or until 10^6 cycles were completed and then switched to load control at 20 Hz and cycled to failure.

^b Heat 8092297 25.4-mm plate laboratory vacuum anneal at 1065°C for 0.5 hour after fabrication.

^c Value for half-cycle life for specimens which were run in strain control until failure or value at end of strain cycling for specimens which were switched to load control after completing 10^6 cycles in strain control.

^d Strain control portion was triangular waveform, $\dot{\epsilon} = 4 \times 10^{-3} \text{ s}^{-1}$, load control portion was 20 Hz sine wave.

^e Strain control portion was 1 Hz sine wave, load control was 20 Hz sine wave.

Fig. 1.19. Fatigue of Type 316 stainless steel at 593-600°C.

1.4 REFERENCES

1. G. E. Korth and G. R. Smolik, "Mechanical Property Program of Alloy 718," Mechanical Properties Test Data for Structural Materials Semiannual Progress Report for Period Ending January 31, 1980, ORNL BRP-80/3, pp. 1.1-1.50.
2. Personal communication, A. L. Snow, Westinghouse Advanced Reactors Division, to G. E. Korth, EG&G Idaho, Inc., February 1980.
3. G. E. Korth, J. E. Flinn, and G. R. Smolik, "Mechanical Property Program of Alloy 718," Mechanical Properties Test Data for Structural Materials Semiannual Progress Report for Period Ending July 31, 1979, ORNL/BRP-7915, pp. 1.2-1.12.
4. G. E. Korth and G. R. Smolik, "Mechanical Property Program of Alloy 718," Mechanical Properties Test Data for Structural Materials Quarterly Progress Report for Period Ending April 30, 1978, ORNL/5416, p. 10.
5. G. E. Korth and G. R. Smolik, "Mechanical Property Program of Alloy 718," Mechanical Properties Test Data for Structural Materials Quarterly Progress Report for Period Ending July 31, 1978, ORNL/BRP-78/2, p. 8.
6. M. K. Booker, "An Interim Analytical Representation of the Creep Strain-Time Behavior of Commercially Heat-Treated Alloy 718," ORNL/TM-6232, May 1978.
7. Personal communication, D. T. Raske, Argonne National Laboratory, to G. E. Korth, EG&G Idaho, Inc., January 24, 1980.
8. C. E. Jaske and N. D. Frey, "High-Cycle Fatigue of Type 316 Stainless Steel at Temperatures up to 593°C (1100°F), ESG-DOE-13307, February 15, 1980.