ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

BIMONTHLY PROGRESS REPORT NO. XIV

THERMAL-SHOCK INVESTIGATION

By

T. A. HUNTER

L. L. THOMAS

A. R. BOBROWSKY

Project M949

WRIGHT AIR DEVELOPMENT CENTER, U.S. AIR FORCE
CONTRACT AF 33(038)-21254, E. O. No. 605-227 SR 3a

January, 1954

BIMONTHLY PROGRESS REPORT NO. XIV

THERMAL-SHOCK INVESTIGATION

OBJECT

The object of this research is to evaluate optimum design of test specimens and to develop criteria which will permit correlation of thermal-shock data with performance of the material in the form of turbine buckets.

SUMMARY

Construction of the operating units for the four new testing rigs has been completed. Calibration tests must still be made, and the automatic camera equipment installed.

Tensile tests have been run on H.S. 21 material to check the effects of aging at 1350°F for 50 hours. Tests at room temperature verify published data for the as-cast condition, but for the heat-treated condition the observed figure of 7.2 percent elongation differs considerably from the published figure of 1.7 percent.

Tests have been completed on Inconel at temperatures of 1900 and 2000°F. At these temperatures this material fails rapidly, crack detection is difficult, and scale formation is severe. For these reasons the scatter of the results is greater than usual.

INTRODUCTION

As stated in previous progress reports, construction of new testing facilities has been under way since May, 1953. This construction program has increased the testing facilities from one active and one standby assembly to five active and one standby unit. The standby unit is now used for calibration purposes only, but can be made active if it is needed.

The new units have been checked out both mechanically and electrically and found to operate in a satisfactory manner. Completion of the units requires attention to a few nonoperating details, such as soundproofing and calibrating. Following the calibration procedure, a series of reproducibility tests will be run to make certain that the data obtained from the new machines will be the same as those obtained from previous tests on the old equipment.

The outstanding feature of the new equipment is that it is practically automatic in operation. An automatic camera is to be installed on each unit to make a record of the condition of the specimen at chosen intervals; this record will permit running tests during the night without attendance.

In Progress Report XI it was reported that tests had been run to determine the effect of change in ductility on the thermal-shock properties of H.S. 21 (cast Vitallium). Tensile tests have been run at room temperature to find the amount of change in ductility which has been produced by aging the material for 50 hours at 1350°F. A graphical presentation of the data obtained is given in Fig. 1.

These data are to be compared with the published information from the alloy manufacturer.[1] The manufacturers state that for the as-cast condition, a room-temperature test will show a tensile strength of 101,300 psi and a percentage elongation of 8.2. It would appear that the observed tensile strength is only slightly below the published figure, and that the elongation is very close to the Haynes value. It is to be noted that none of the Haynes tables give any probable errors, and none of the graphs show any plotted data points. An exact comparison is thus rendered difficult.

For the heat-treated condition the difference between the observed and the published data for the tensile strength is within the limit of the

[1] "Haynes Alloys for High-Temperature Service", Haynes Stellite Company, p. 9, 11.

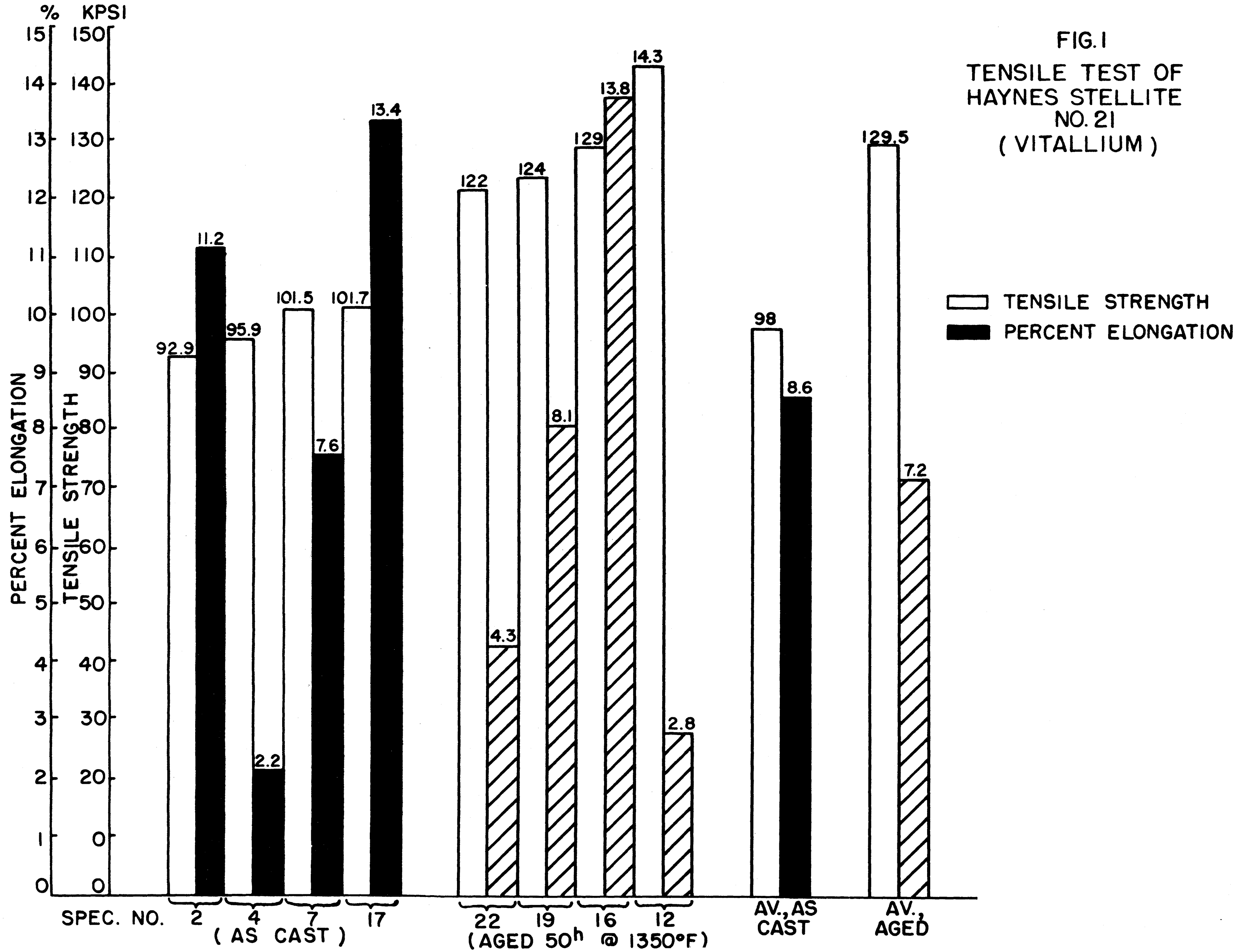


FIG. I
TENSILE TEST OF HAYNES STELLITE NO. 21 (VITALLIUM)

observed probable error. However, the values for the observed elongations compare poorly with the published figure of 1.7 percent. In no case was the observed percentage elongation less than 2.8, and one test showed 13.8 percent.

At the request of Wright Air Development Center, thermal-shock tests have been run on Inconel at temperatures beyond those normally expected. Previous tests had been run at temperatures as high as 1800°F, but the new series was performed at 1900° and 2000°F. As expected, the thermal-shock properties of the material deteriorated. However, any exact correlation with previous data on tests at the lower temperatures would be of doubtful value in view of the fact that the shape of the specimen has been changed since the early tests were performed. A complete set of tests on Inconel is scheduled for the near future.

This work was performed in the period October 12, 1953, to December 12, 1953.

APPARATUS AND PROCEDURE

Tests to measure the ductility properties of H.S. 21 were carried out in a standard tensile testing machine of 120,000-pound capacity, but using the 12,000-pound range. The specimens were made up from 1/2-inch-diameter bars which had been machined down to a 1/4-inch diameter in the test section. The ends of the test pieces were threaded to be held in holders. All gauge lengths were made 1 inch. These pieces are the usual ones for this type of work.

Since H.S. 21 is such a hard material, no gauge punch marks could be made in its surface. In order to get gauge marks from which to work, the surface was painted with lay-out blue and marks were scribed in the blue coating. It is to be noted that no preliminary x-ray tests were made to certify the soundness of the cast pieces.

After being pulled, the two halves of the broken piece were placed together in the mating position again. The distance between the scribed gauge lines was then measured with an optical comparator in order to get the gauge length after testing. The difference between the final and the initial distances between the gauge lines was taken as the amount of elongation in 1 inch. It is to be noted that in some cases the two pieces fitted back together in a very neat manner, but in some other cases the edges of the fracture were so rugged that a close fit was impossible to obtain. It is felt that, in a few cases at least, the error involved in the measurement of the broken length must include a comparatively large gap between the two pieces. Two typical fractures are shown in Fig. 2.

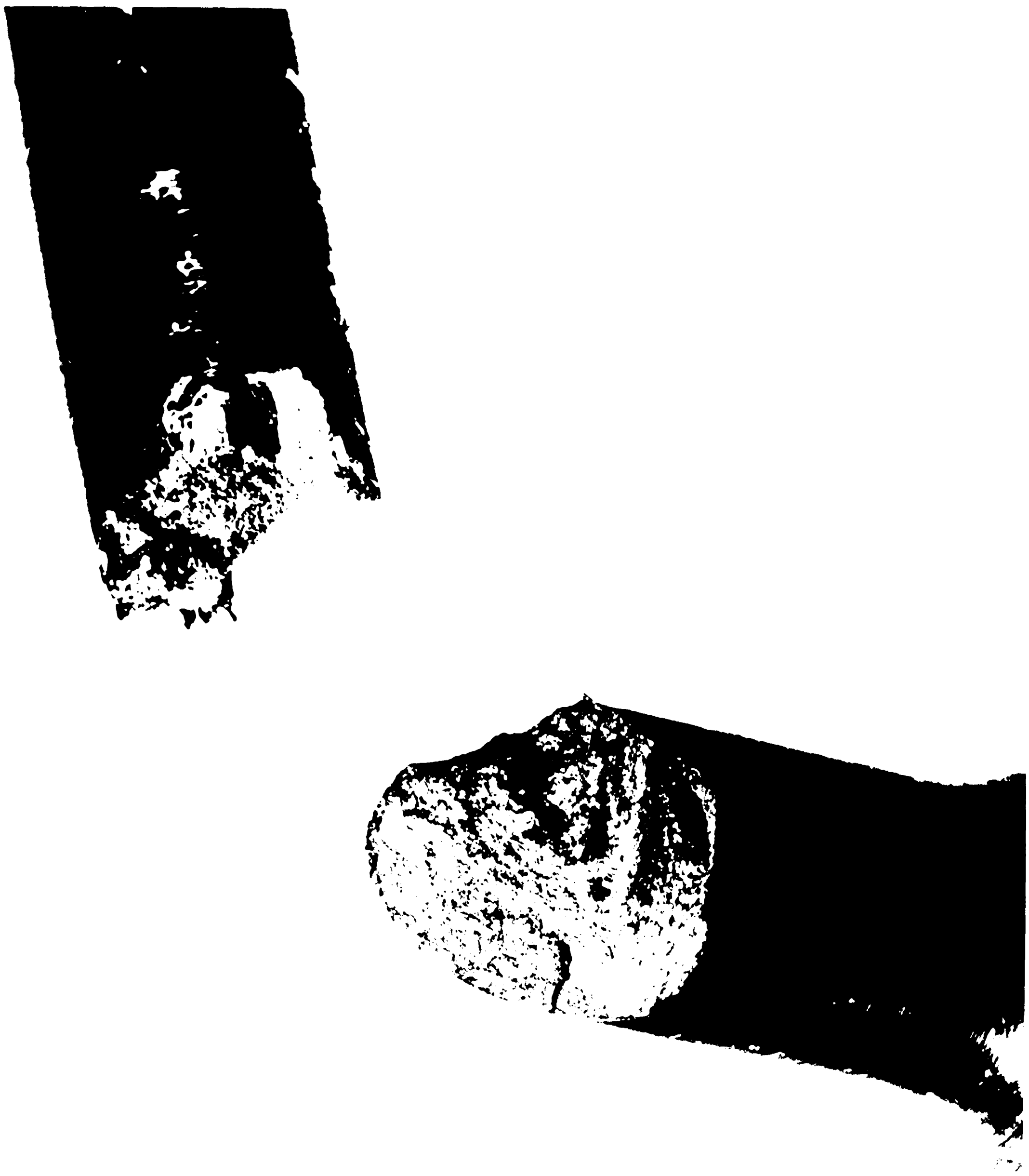


Fig. 2. Fracture on left can be mated easily to give an accurate measure of elongation. Fracture on right cannot be mated accurately.

The data on these specimens are given in Table I.

TABLE I

Condition	Specimen No.	Tensile Strength psi	Percent Elongation	Thermal-Shock Cycles	Average Tensile Strength psi	Average Percent Elongation
As-cast	2	92,900	11.2	3552	98,000 ±2,520	8.6 ± 2.9
	4	95,900	2.2	6820		
	7	101,500	7.6	1506		
	17	101,700	13.4	3279		
Aged 50 hours at 1350°F	22	122,000	4.3	18,411	129,500 ±5,530	7.2 ± 4.2
	19	124,000	8.1	10,060		
	16	129,000	13.8	14,489		
	12	143,000	2.8	7375		

The testing of Inconel at elevated temperatures was carried out on a series of nine specimens. Five were run at 2000°F and four at 1900°F. In each case the heating and cooling cycles were maintained at 30 seconds and 5 seconds, respectively, as in previous work.

Considerable difficulty was experienced in conducting these tests because of the formation of large amounts of heavy surface scale on the specimen. In almost every case the scale was so heavy, rough, and fissured that there appeared to be a crack in the specimen, but on examination after the specimen was removed from the test stand the crack became questionable. The data reported in Table II are subject to confirmation by metallographic examination.

TABLE II

DATA ON INCONEL, LOT II (1/2" D. H. R. ROD)

Cycle	Specimen No.	Cycles to Failure	Type of Failure	Remarks
2000/5	B4	958-	C	(1)
2000/5	B5	398	C?	(2)
2000/5	B6	212	C?	(2)
2000/5	B7	299	C?	(2)
2000/5	B12	143	C?	(2)
1900/5	B13	580 +	C 0.6	(3)
1900/5	B14	463	O?	(2)
1900/5	B15	659	C?	(2)
1900/5	B16	175	O?	(2)

(1) This test was continued until a clear indication of failure was obtained. The resulting crack was far over the end-point, as previously defined.

(2) These tests were stopped as soon as indications of failure were noted. After removing the specimen, the cracks were no longer visible, owing to heavy scale formation which is extremely rough and fissured. These failures are therefore considered questionable, pending metallographic examination.

(3) This test was clearly incomplete, the crack extending only 0.6 of the way across the edge land. It is impossible to determine the true number of cycles to failure because of the erratic nature of the crack propagation.

DISCUSSION OF RESULTS

The comparatively large probable errors in the measurement of the elongation of the H.S. 21 cast specimens may be laid to two primary causes: the nature of the fracture surface, which prevents an accurate measurement of the broken length, and the existence of shrinkages in the specimens. It is understood that vanes, buckets and blades used in aircraft turbines are subject to a 100% x-ray inspection when made from H.S. 21 material. This inspection is made primarily to find shrinkages, but it was not used on the test pieces for the elongation experiments. We have been advised by Haynes to have such tests made, and will report on them in the future. In any event, a probable error which is larger than some of the values recorded makes the data subject to suspicion.

Examination of the percentage elongation and thermal-shock cycles to failure shows little, if any, relationship between them. The tensile strength and thermal-shock cycles appear to be related in direct proportion: 30 percent increase in the tensile strength corresponds to an increase in thermal-shock resistance of about 400 percent.

CONCLUSIONS

1. The thermal-shock resistance of Inconel deteriorates at temperatures of 1900°F and 2000°F. Exact comparisons with lower temperatures depend on future data.

2. On the basis of available tenuous data, the ductility of cast H.S. 21 (Vitallium) alloy does not have an appreciable effect on thermal-shock resistance. The tensile strength does, however, appear to have a pronounced, directly proportional, effect on the thermal-shock resistance.

KEY TO LOG

Column (1)

(1)	Relative position on bar stock
1	Specimen number

Column (2)

	Arrow indicates direction and location of cooling jet; cooling medium is air unless otherwise stated
W	Cooling medium is water
.045	Width of cooled edge, inches
P.F.	Previously subjected to rotating beam fatigue as shown in column (6)
X	Failed during pre-fatigue
1700/5 (1718)	Number in parentheses indicates average of calibrations at beginning and end of test (Mean max test temp)

Column (3)

M	Thermal shock cycle manually controlled
1500/5	Automatic cycle control; maximum temperature, °F, and length of cooling period, seconds
P1800	Dead load, 1800 lbs
+10/100	Starting with stated maximum temperature, maximum temperature was increased 10°F after each 100 cycles
40.5K	Reversed-bending (rotating-beam) fatigue tests; maximum stress, 40,500 psi
to 1800	Maximum temperature held constant after 1800°F was reached

Column (4)

A	Air cooling for stated number of cycles
W	Water cooling for stated number of cycles
no symbol	Air cooling for stated number of cycles

Column (5)

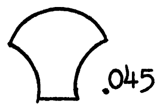
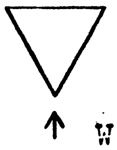
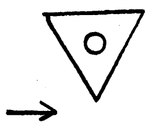
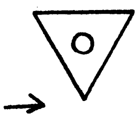
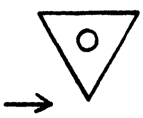
O	No failure visible
F	Fracture
C	Cracks
G	Grooves
FC	Face crack
PC	Possible crack

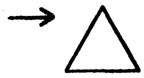
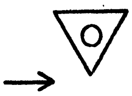
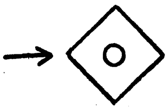
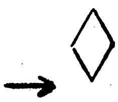
Column (6)

B	Specimen warped due to thermal strains
A 0.14	Area of cross section, square inch
T300/1600	Heat treated before testing 300 hr at 1600°F
G1500	Grooves first appeared at 1500 cycles

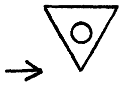
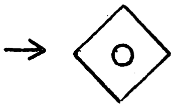
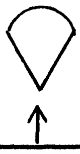
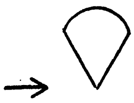
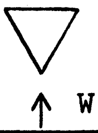
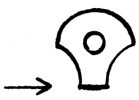
OH	Stated maximum temperature was exceeded due to malfunction of control unit
BT	Broke through to thermocouple hole
P $\left\{\begin{matrix}1700/60 \\ 1200/23\end{matrix}\right\}$	Previously subjected to cyclic heating and cooling (Max temp) $\underline{1700/60}$ (Heating time, seconds) (Min temp) $\overline{1200/23}$ (Cooling time, seconds) (Number of cycles) 1000
40.5K/ 82000	Previously subjected to 82000 cycles at 40,500 psi
R	Reproducibility test
N	Specimen formed a neck due to tensile strain.
+100/5108	Maximum temperature was increased 100°F at 5108 cycles.
Check II	Second test to determine the effect of alteration of testing procedure.
P	Study of crack propagation
PT1	Previously subjected to tensile strain of 1% at room temperature
LRSI	Long-time test at reduced severity, Test No. I
T{ }I	Heat treated as shown in braces { }. Lot No. I
C20/1700	Heat treated for 20 hours by heating to 1700°F and allowing to cool for 5 seconds by natural convection.
Column (2)	Letter at tail of arrow indicates test unit on which test was run. Two arrows indicate two separate tests with cooling on different edges. Horizontal arrow indicates first test
Column (3)	Number [e.g., (1)] indicates edge number, shown in Column (2), on which test was run.

TEST LOG

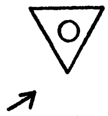
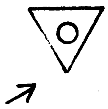
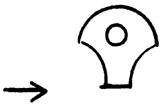
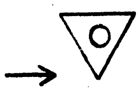
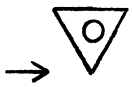
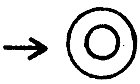
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Type 304 Stainless Steel					
1		M	——	O	B
2		1600/10	4400 A 300 W	C	B
3		1600/4	1783	C	
4a 4b	Fatigue Specimens	40.5K 40.5K	3300 2600	F F	
5		1700/4 1800/4	1100 675	O C	
6		1600/4 1900/4	6240 1240	O C	G6500
7		1500/4 P600	4130	F	A 0.16

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Type 304 Stainless Steel (cont)					
8		1600/5 1800/4	3082 517	O C	T300/1600
9		1500/3	5753	O	
10		1600/4 1700/4 1800/4	1000 1000 80	O O C	
11		1500/5 P1800	1000	F	A 0.132
12		1500/5 P600 P900 P1800	5000 1200 203	O O F	A 0.133
13		1600/4	1284	C	G115
14		1500/4	1000	F	OH

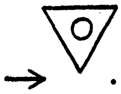
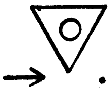
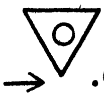
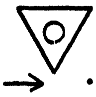
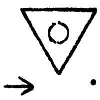
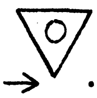
TEST LOG (cont)

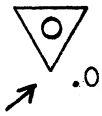
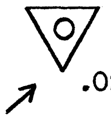
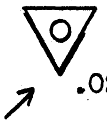
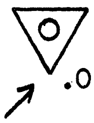
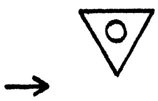
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Type 304 Stainless Steel (cont)					
15		1600/5	1900	C	T300/1600
16		1600/5	409	C	
17		1500/5 P1800	300	F	A 0.140
18		1800/4	1950	C	G 1500
19	 W	1700/3	530W	C	
20		1500/3	1000	O	BT

TEST LOG (cont)

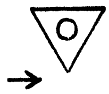
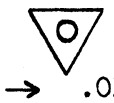
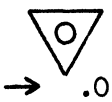
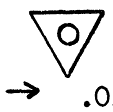
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Type 347 Stainless Steel					
1	 .045	1600/4 +10/100	866	C	
2	 .020	1600/4 +10/100	1147	C	
3		1500/4 +10/100	575	C	BT
4a 4b	Fatigue Specimens	54K 54K	5200 10400	F F	40.5K 82000
5		1500/4 +10/100	1326	C	
6		1500/4 +10/100	1990	C	
7		1600/3.5 +10/100 to 1800	2700	G	

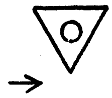
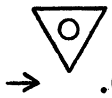
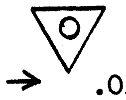
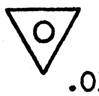
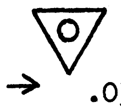
TEST LOG (cont)

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Type 347 Stainless Steel (cont)					
8	(Defective)				
9	 .035	1600/4	2863	C	R
10	 .020	1600/4	3787	C	Check II
11	 .050	1600/4	2580	C	
12	 .020	1600/4	3162	C	G 736
13	 .020	1600/4	2204	C	G 2072
14	 .020	1600/4	2707	C	G 2604

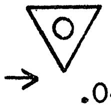
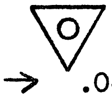
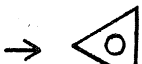
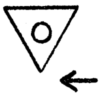
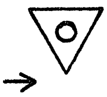
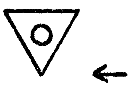
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Type 347 Stainless Steel (cont)					
15	 .035	1600/4	3003	C	G2820 R
16	 .020	1600/4	2518	C	R
17	 .023	1600/4	4850	O	Check I
18		Fatigue 64K	7200	F	54K 103300
19	 .035	1600/4	1825	C	R
20		Fatigue 64K	4300	F	37K/217100 42K/11000 48K/35600 54K/10000 59K/10400
21		1600/4	4430	C	

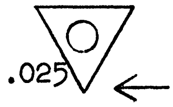
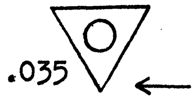
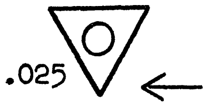
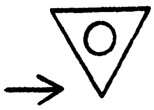
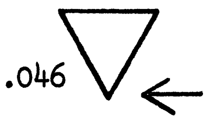
TEST LOG (cont)

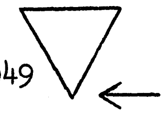
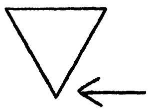
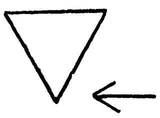
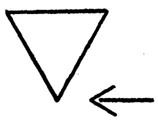
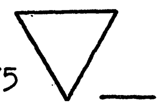
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Type 347 Stainless Steel (cont)					
22	(Defective)				
23		1600/5	2962	C	
24	 .010	Fatigue 59K	52900	F	
25	 .010	1600/5 P.F.	1562	C	54K/50000
26	 .010	1600/5	1960	C	53K/52000 59K/12000 64K/1000 70K/1000 75K/500
27	 .010	X P.F.	—	F	53K/52000 59K/11300
28	 .010	1600/5 P.F.	1594	C	53K/52000 59K/12000 64K/1000 70K/1000 75K/500

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Type 347 Stainless Steel (cont)					
29		X P.F.	—	C	53K/52000 59K/12000 64K/1000 70K/1000 75K/300
30	 .010	1600/5	1973	C	
31	 .010	1600/5	2764	C	
32	 .010	1600/5	1500	C	
33 (4)	 .040	X P.F.	—	F	59K/32600
34 (3)	 .036	P.F.	1811	C	60K/39000
35 (2)	(Used for calibration of Heat-Eye)				

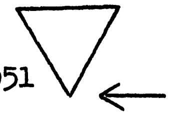
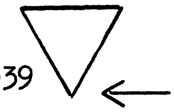
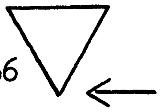
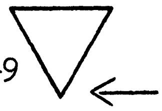
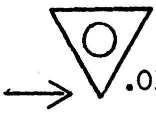
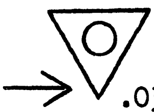
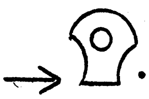
TEST LOG (cont)

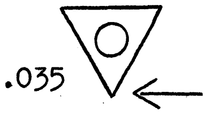
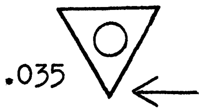
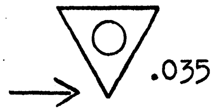
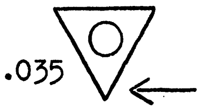
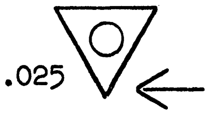
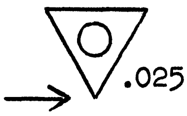
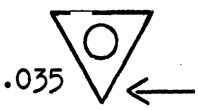
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Type 347 Stainless Steel (cont)					
36 (1)	 .040	1600/5 P.F.	1859	C	58K/30000
37 (5)	 .040	1600/5	4635	C	
38	 .025	1600/5	2114	C	T2/2000
39 (7)		1600/5	2440	G	G 2440 Rigid Support Nozzle No. 3
40 (8)		1600/5	3143	G	Nozzle No. 4
41		1600/5	2710	C	G 2000 Rigid Support Nozzle No. 3
42		(used for calibration)			

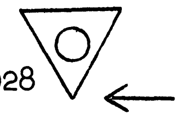
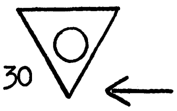
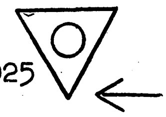
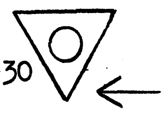
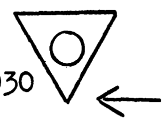
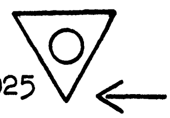
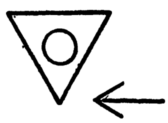
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Type 347 Stainless Steel (cont)					
43 (11)		1600/5	10708	C	P Rigid Support Nozzle No. 4
44		1600/5	2046	C	T2/2000
45		1600/5	1956	C	T2/2000
H. S. 21 (vitallium) Cast					
1		1500/3.5	1000	C	BT
2		1700/5 (1718)	3552	C	
3					

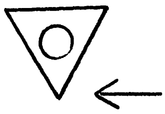
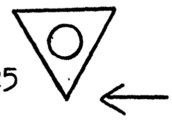
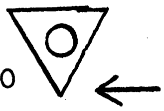
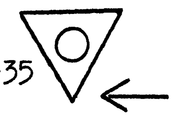
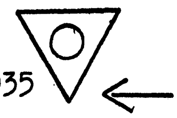
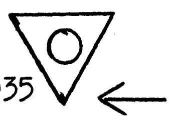
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
H. S. 21 (vitallium)		Cast (cont)			
4	.049 	1700/5 (1719)	6820	C	FC6003 .4C6561
5	.045 	1800/5 ✓	1252	C	
6					
7	.048 	1700/5 (1720)	1506	C	
8	.047 	1800/5 ✓	3468	C	
9	.0375 	1600/5 (1603)	5305	C	
10					

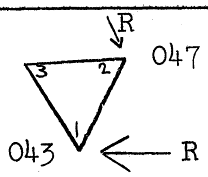
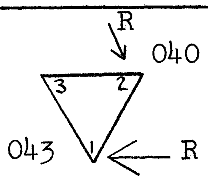
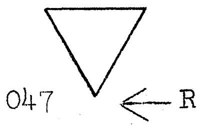
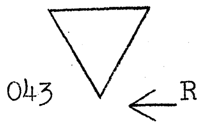
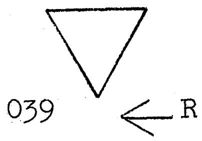
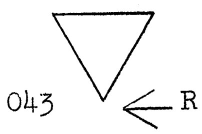
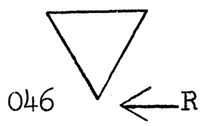
Specimen Number (1)	Cross Section (2)	Cycles (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
H. S. 21 (vitallium) Cast (cont)					
11	.043	1600/5 1605	17615	C	
12	.049	1700/5	7375		T51/1350
13	.044	1800/5 ✓	3902	C	
14					
15	.035	1600/5 (1607)	15334	O	
16	.038	1700/5	14489		T51/1350
17	.040	1700/5 (1708)	3279	C FC.004	

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
H. S. 21 (vitallium) Cast (cont)					
19	.051 	1700/5 (1710)	10060		T51/1350
20	.039 	1800/5 ✓	4147	C	
21	.036 	1600/5 ✓	9938	C	
22	.049 	1700/5 ✓	18411	C	T51/1350
Inconel					
1	 .015	1500/3	1450	C	
2	 .030	1500/3 +10/100	2730	C	
3	 .035	1500/3 +10/100	428	C	BT

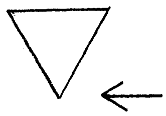
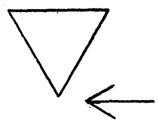
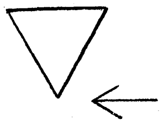
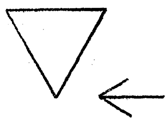
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Inconel (cont)					
4		1700/5	3167	C	T2/500 T1/3/1400
5		1700/5	1819	C	T2/500 T1/3/1400
6		1600/4	7449	C	
7		1700/5	4706	C	T2/500 T1/3/1400
8		1700/5	2090	C	T1/3/1400 PTI
9		1700/5	6465	C	T2/800
10		1700/5	3680	C	T1/3/1400 PT10

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Inconel (cont)					
11		1700/5	2860	C	T1/3/1400 PT5
12		1700/5	1884	C	T1/3/1400 C20/1700
13		1700/5	2500	C	T1/3/1400 PT1
14		1700/5	2527	C	T1/3/1400 PT5
15		1700/5	2804	C	T1/3/1400 PT10
16		1700/5	3590	C	T1/3/1400 PTO
17		1700/5	2270	C	T1/3/1400 PTI

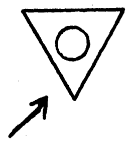
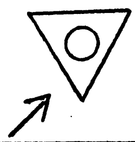
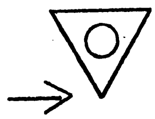
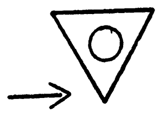
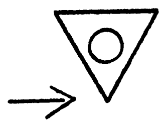
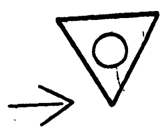
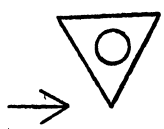
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Inconel (cont)					
18		1700/5	2576 3015	PC C	T1/3/1400 PT5
19	.025 	1700/5	1830	C	T1/3/1400 PT10
20	.030 	1700/5	2898	C	T1/3/1400 PT0
21					
22	.035 	1700/5	4339 6866	FC? C	T1/3/1400 flex. pipe to nozzle
23	.035 	1700/5	2250	C	T1/3/1400
24					
25	.035 	1700/5	3538 4229	FC C	T1/3/1400

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Inconel Lot II (1/2-Inch-Diameter H.R. Rod)					
B1		(Edge) (1) 1700/5 (2) 1700/5	 2267 1760	 C C	T 1/3/1400 2 tests on different edges
B2		(1) 1700/5 (2) 1700/5	2344 2527	C C	T 1/3/1400 2 tests on different edges
B3		1700/5	2622	C	T 1/3/1400
B4		2000/5	958^{-}	C	Crack far over usual ending point. T 1/3/1400
B5		2000/5	398	C ?	Metallo-graphic examination needed. T 1/3/1400
B6		2000/5	212	C ?	See B5 T 1/3/1400
B7		2000/5	140 ? 299	C ?	See B5 T 1/3/1400

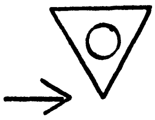
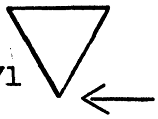
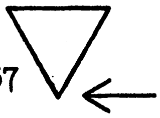
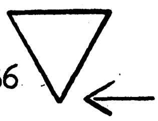
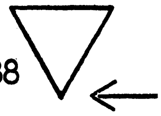
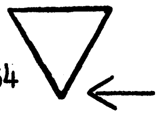
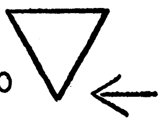
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Inconel Lot II (1/2 -Inch-Diameter H.R. Rod) (cont)					
B8	044 ← C	1700/5	2560	C	Reproduction Test on New Unit "C" T 1/3/1400
B9	040 ← C	1700/5	2283	C	do T 1/3/1400
B10	038 ←	1700/5	2206	C	do T 1/3/1400
B11	←				
B12	043 ← R	2000/5	110 ? 143	C ?	See B5 T 1/3/1400
B13	042 ← R	1900/5	580 +	C 0.6	T 1/3/1400
B14	044 ← R	1900/5	463	0 ?	See B5 T 1/3/1400

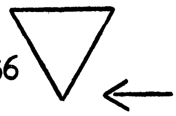
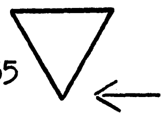
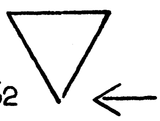
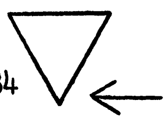
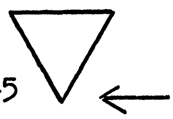
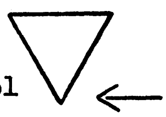
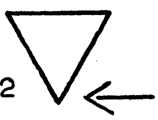
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Inconel Lot II (1/2-Inch-Diameter H.R. Rod) (cont)					
B15		1900/5	659	C ?	See B5 T 1/3/1400
B16		1900/5	175	O ?	See B5 T 1/3/1400
B17		1800/5	480	O	See B5 T 1/3/1400
B18		1800/5	1962	C ?	See B5 T 1/3/1400

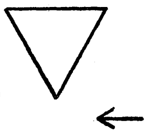
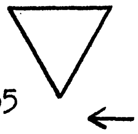
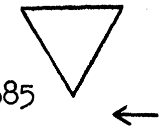
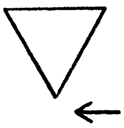
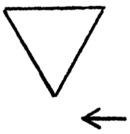
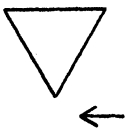
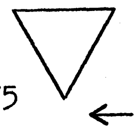
TEST LOG (cont)

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
S-816 Alloy (wrought)					
1		1500/4 P700 No load	 1788 18391	 O C	A 0.08 N +100/5108 +100/10000
2		1500/4 P1100 to P700	2657	F	A 0.08 N
3		1700/4	2256	C	
4		1700/4	2250	C	
5		1600/4	3870	C	
6		1500/4	2630	C	
7		1500/4	13280	C	

TEST LOG (cont)

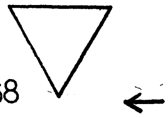
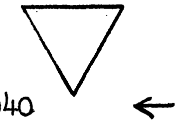
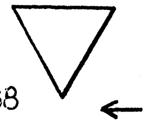
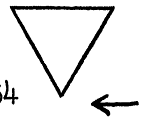
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
S-816 Alloy (wrought) (cont)					
8		1600/4	7497	C	
9	.0371 	1800/5	1069^-	C	T 1/2150 W 16/1800
10	.037 	1700/5	2426	C	T 1/2150 W 16/1800
11	.036 	1600/5	5130	C	T 1/2150 W 16/1800
12	.0388 	1800/5	956^-	C	T 1/2150 W 16/1800
13	.034 	1700/5	1903^+	C .003 short	T 1/2150 W 16/1800
14	.0350 	1800/5	1146^-	C	T 1/2150 W 16/1800

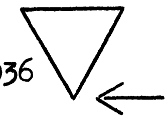
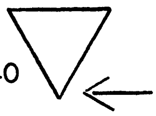
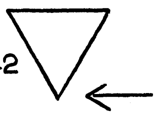
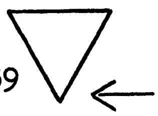
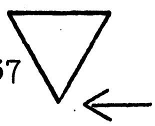
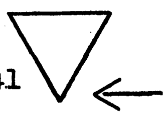
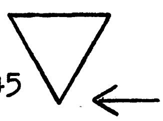
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
S-816 Alloy (wrought) (cont)					
15	.036 	1600/4	4600	C	T {1/2150 W; 16/1800} I
16	.0335 	1600/4	3620	C	T {1/2150 W; 16/1800} I Average test temp. was 1615°F
17	.0362 	1700/5	1956^{-}	C	T {1/2150 W; 16/1800} I
18	.0384 	1800/5	784	C	T {1/2150 W; 16/1800} I
19	.0345 	1700/5	2300^{-}	C	T {1/2150 W; 16/1800} I
20	.0331 	1600/5	3100^{-}	C	T {1/2150 W; 16/1800} I Average test temp. was 1660°F
21	.032 	1700/5	2190	C	T {1/2150; 16/1800} II P {1700/60; 1200/23; 1000}

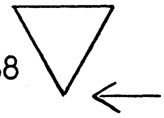
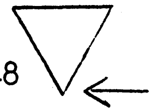
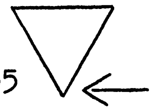
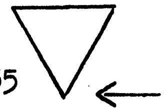
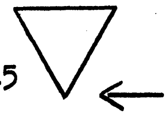
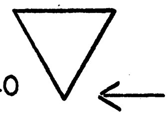
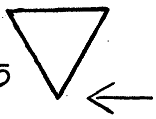
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
S-816 Alloy (wrought) (cont)					
22	 .035	1700/5	2050	C	T {1/2150 / 16/1800} II P {1700/60 / 1200/23} 600 N
23	 .0335	1700/5 (1685)	1414	C	T {1/2150 / 16/1800} II P {1700/60 / 1200/23} 1182 N
24	 .0385	1700/5 (1699)	1697	C	T {1/2150 / 16/1800} II P {1700/60 / 1200/23} 1040 N
25	 .034	1700/5 (1702)	2328	C	T {1/2150 / 16/1800} II
26	 .036	1700/5 (1713)	2239	C	T {1/2150 / 16/1800} II
27	 .035	1700/5 (1690)	1967	C	T {1/2150 / 16/1800} II
28	 .0375	1700/5 (1705)	1598	C	T {1/2150 / 16/1800} II

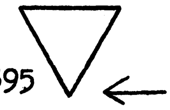
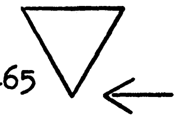
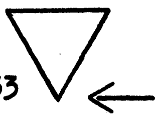
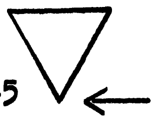
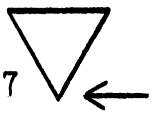
TEST LOG (cont)

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
S-816 Alloy (wrought) (cont)					
29	▽ .035 ←	1700/5 (1695)	1122	C	T {1/2150, 16/1800} II; P {1700/60, 1200/23}; 2000 N
30	▽ .0345 ←	1700/5 (1700)	2110	C	T {1/2150, 16/1800} II; P {1700/60, 1200/23}; 2000 N
31	▽ .032 ←	1700/5 (1702)	1542	C	T {1/2150, 16/1800} II; P {1700/60, 1200/23}; 2000 N
32	▽ .036 ←	1700/5 (1698)	2110-	C	T {1/2150, 16/1800} II; P {1700/60, 1200/23}; 1000 N
33	▽ .037 ←	1700/5 (1715)	1700	C	T {1/2150, 16/1800} II; P {1700/60, 1200/23}; 3121 N
34	▽ .036 ←	1700/5 (1719)	1543	C	T {1/2150, 16/1800} II; P {1700/60, 1200/23}; 3110 N
35	▽ .034 ←	1700/5 (1700)	2150	C	T {1/2150, 16/1800} II; P {1700/60, 1200/23}; 3000 N

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
N-155 Alloy (wrought)					
1	.038 	1700/5	3764 3878 4949	FC C 2C	T {1/3/2200 W 50/1400} I
2	.040 	1700/5	3211	C	T {1/3/2200 W 50/1400} I
3	.038 	1700/5	3248	C	T {1/3/2200 W 50/1400} I
4	.034 	1800/5	1508	C	T {1/3/2200 W 50/1400} I

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
N-155 Alloy (wrought) (cont)					
5	.036 	1600/5	3886	0	T {1/3/2200 W, 50/1400} I Removed for check No crack
6	.040 	1700/5	3105	C	T {1/3/2200 W, 50/1400} I
7	.042 	1800/5	1818	C	T {1/3/2200 W, 50/1400} I
8	.039 	1700/5	3195	C	T {1/3/2200 W, 50/1400} I
9	.037 	1700/5	2888	C	T {1/3/2200 W, 50/1400} I
10	.041 	1600/5	10124	0	T {1/3/2200 W, 50/1400} I
11	.045 	1800/5	2052	C	T {1/3/2200 W, 50/1400} I

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
N-155 Alloy (wrought) (cont)					
12	.038 	1800/5	1228	C	T { 1/3/2200 W 50/1400 } II
13	.048 	1800/5	1095	C	T { 1/3/2200 W 50/1400 } II
14	.035 	1800/5	1042	C	T { 1/3/2200 W 50/1400 } II
15	.0385 	1800/5	990	C	T { 1/3/2200 W 50/1400 } II
16	.0415 	1800/5	1130	C	T { 1/3/2200 W 50/1400 } II
17	.040 	1700/5	2229	C	T { 1/3/2200 W 50/1400 } II
18	.0365 	1700/5	1995	C	T { 1/3/2200 W 50/1400 } II

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
N-155 Alloy (wrought) (cont)					
19	.0395 	1600/5	5153	C	T {1/3/2200 W 50/1400} II
20	.0465 	1700/5	2320	C	T {1/3/2200 W 50/1400} II
21	.0433 	1600/5	3530	C	T {1/3/2200 W 50/1400} II
22	.045 	1600/5	7000	C	T {1/3/2200 W 50/1400} II
23	.047 	1600/5	6728	C	T {1/3/2200 W 50/1400} II