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BIMONTHLY PROGRESS REPORT NO. XV

THERMAL-SHOCK INVESTIGATION

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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

All testing rigs are now in full automatic operation. High-temperature tests have been performed on S-816 wrought alloy and on N-155 wrought alloy. S-816 shows little change in thermal-shock resistance when the temperature is elevated from 1800°F to 1900 and 2000°F. N-155 alloy also shows only a slight decrease in thermal-shock resistance at 1900 and 2000°F as contrasted to its properties at 1800°F.

Photomicrographs of HS-21 alloy, made to check the effects of heat treatment at 1350°F for 51 hours, verified the published results of the manufacturer. Hardness tests of the same material also matched the published figures.

Tests are being made on the following alloys: Inconel, Waspalloy, M-252, and Hastelloy C. Partial data are included in this report.

Construction of apparatus to permit testing of Inconel in an inert atmosphere (helium) is progressing. Previously reported data on Inconel tests at 1900 and 2000°F were inconclusive pending further examination for presence

of cracks. This examination has shown that no cracks were developed in the base metal, but only in the heavy surface scale.

INTRODUCTION

Final details involved in construction of the test apparatus were completed during the middle of December, 1953. This work included soundproof boxes, camera mountings, reproducibility tests, and installation of calibration equipment. Since January 1, 1954, all the test rigs have been in full automatic operation.

Certain operation must still be performed manually, however. The most important of these is the periodic resetting of the variac autotransformers to accommodate changes in the line voltage. Such voltage changes occur at about 8 a.m., 12 m., and 5 p.m. each week day, but seldom over the week end. The voltage change is usually only a few volts, but it produces a change of several seconds in the heating time of the specimen cycle. In order to maintain the cycle as nearly uniform as possible, regular checks are made of the apparatus at the times when changes are known to occur.

In addition to the line-voltage fluctuations, a change in the resistance of the test specimen develops simultaneously with the development of a crack. This resistance change also serves to change the heating time of the test cycle, since the place at which the crack is developing soon becomes a hotter spot than the rest of the piece. Such cyclic variations also require regulating the variacs manually.

Automatic camera equipment is used to monitor the development and progress of cracks during week-end tests or high-temperature tests. In most of the tests at 1900 and 2000°F the life of the specimen is less than a thousand cycles. To determine when a crack starts and to follow its progress across the face of the test piece would require almost constant attention. For such tests the automatic recording devices are used, but for the lower-temperature longer-time tests, a visual inspection is made at periodic intervals. This has proven to be close enough in the past, and results in a large saving in film costs on tests which last several thousands of cycles.

Temperature calibration of each test rig must still be performed manually at the beginning and the end of each test run with a special test piece in which a thermocouple has been imbedded. The information is read from a separate temperature recorder which is not connected to any of the

radiation pyrometer temperature controllers in the test rigs. Thus, a separate check is maintained of the amount of drift which has taken place in the radiation-measuring devices.

Thus far the operation of the test rigs has been trouble-free. It was expected that certain bothersome failures might occur in a device as complex as the test apparatus has become, but the present design has proven to be very satisfactory. About the only important improvement which seems in order is to arrange some sort of feedback mechanism between the heating timers and the variacs so that the heating time can automatically be kept at a constant value.

Previous work on Inconel has shown that this material is subject to severe surface corrosion at elevated temperatures. When tests were run at temperatures of 1900 and 2000°F it became very difficult to tell whether any cracks had developed in the body of a test piece because of the presence of very heavy surface scale. Several tests were reported in Progress Report XIV as being subject to examination subsequent to the test. Although it appeared at the time of the test that there were numerous large and rapidly progressing cracks in the material, an optical check at high magnification failed to find evidence of any cracks other than those in the surface scale. Once the scale was removed, the surface appeared to be undamaged.

In order to eliminate the surface oxidation on Inconel, a series of tests are to be run with helium substituted for the compressed air presently being used. In this inert atmosphere any surface scaling effects should be reduced to a minimum, thus permitting a more accurate determination of the crack development and progress. Certain changes are to be made in the air circuit of the test rigs to permit the introduction of helium into one of the sets of nozzles. These changes require the use of special manifolding equipment, which is now under construction.

DISCUSSION

Progress Report XIV contains a discussion of the results of tests performed on HS-21 in an effort to determine the effects of change in ductility on the thermal-shock properties of that material. After the results were reported there arose a question as to whether the heat treatment of 51 hours at 1350°F had actually accomplished the desired effect. To answer this question a set of photomicrographs were made of the material in both the as-cast and the heat-treated condition (Figs. 1 through 4). They show that the specified heat treatment accomplished the same results as those published by the manufacturer.

Tests have been run on six different materials in the period from December 12, 1953, to February 12, 1954. These materials are Waspalloy, Inconel, N-155, S-816, M-252 and Hastelloy C. None of the series of tests are complete as of the middle of February; therefore only partially complete data are being reported at this time.

For Waspalloy the data are as follows:

Specimen No.	Cycle	No. of Cycles	Type of Failure
A3-1	1600/5	10,050	C
A3-2	1600/5	15,048	C
A3-3	1800/5	1,789	C
A3-4	1800/5	613	C
A3-5	1800/5	784	C
A3-6	1700/5	1,319	C
A3-7	1700/5	742	C
A3-8	1700/5	879	C
A3-9	1650/5	1,690	C

Statistical analysis of these data shows that the number of cycles to failure for 1600°F is above 10,000 cycles. The average cycles to failure are 980 cycles for 1700°F and 1062 cycles for 1800°F with probable errors of 189 and 405 cycles respectively. The data indicate that there is a very large drop in thermal-shock resistance of Waspalloy above 1600°F but that it is still of the order of 1000 cycles. This is ten times the arbitrary standard of 100 cycles assumed for normal service conditions.

Data obtained for three tests of Hastelloy C are:

Specimen No.	Cycle	No. of Cycles	Type of Failure
C-1	1600/5	4,618	C
C-2	1600/5	2,240	C
C-3	1600/5	7,546	C

On the basis of these observations, the average thermal-shock resistance of this alloy at 1600°F is 4801 cycles with a probable error of 1557 cycles.

For alloy M-252 the data are as follows:

Specimen No.	Cycle	No. of Cycles	Type of Failure
B2-1	1600/5	15,548	C
B2-2	1600/5	7,717	C
B2-3	1700/5	3,747	C

Analysis of so few data would have little meaning and therefore is omitted at this time.

Seven more tests have been run on Inconel on rig C. All these tests have been in the 1600, 1700, and 1800°F range. Eight other tests in this same range which have been reported in the previous log are included here also as having been run on rig B. The data are as follows:

Specimen No.	Cycle	No. of Cycles	Type of Failure
B-1	1700/5	2,267	C edge 1
B-1	1700/5	1,760	C edge 2
B-2	1700/5	2,344	C edge 1
B-2	1700/5	2,527	C edge 2
B-3	1700/5	2,622	C
B-8	1700/5	2,560	C
B-9	1700/5	2,283	C
B-10	1700/5	2,206	C
B-17	1800/5	480	O
B-18	1800/5	1,962	C ?
C-1	1600/5	4,358	C
C-2	1600/5	3,416	C
C-3	1600/5	2,572	C
C-4	1700/5	1,693	C
C-5	1700/5	1,378	C
C-6	1700/5	1,537	C
C-7	1800/5	3,854-	C (far over usual end point)

Analysis of the data shows that at 1600°F the average thermal-shock resistance was 3449 cycles with a probable error of 505 cycles. At 1700°F the value became 2107 cycles with a probable error of 312 cycles. This would indicate a moderate loss of thermal-shock resistance between 1600 and 1700°F, but in both cases the value is several times the arbitrary 100-cycle value. The data for 1800°F is too sparse to be reliable.

High-temperature tests have been performed on S-816 wrought alloy and also on N-155 wrought alloy. The data are as follows:

HIGH-TEMPERATURE TESTS

S-816 wrought

Specimen No.	Cycle	No. of Cycles	Hours to Failure	Remarks
P6-1	1900/5	1,082	20	1 C thru; 2 C 0.9 thru; 3 FC
P6-2	1900/5	1,351	20	1 C thru; 1 C 0.1 over; 2 FC
P6-3	1900/5	1,077	23	1 C thru; 1 C 0.9 thru; 3 FC
P6-4	2000/5	786	14	1 C thru Sev. FC
P6-5	2000/5	1,001	19	1 C No FC
P6-6	2000/5	800	14	1 C 2 FC
P6-8	2000/5	976	18	2 C 0.2 over; 1 C thru 1 C 0.2 thru; 1 FC

N-155 wrought

Specimen No.	Cycle	No. of Cycles	Hours to Failure		Remarks
C5-1	2000/5	< 1,287	25		1 C over; 2 C 0.2 over [3 FC at 785 N]
C5-2	2000/5	1,083	26	*	1 C 0.1 over; 6 FC [0.95 thru at 993 N]
C5-3	2000/5	< 1,775	37		1 C over [0.3 thru at 984 N]
C5-4	2000/5	966	24		1 C 0.2 over
C5-5	1900/5	1,495	30		1 C thru; 1 C 0.5; 1 C 0.2
C5-6	1900/5	1,458	30		2 C thru 3 FC [0.4 at 1169]
C5-7	1900/5	1,535	27		1 C thru.

These data show that for S-816 alloy the average thermal-shock cycles to failure at 2000°F is 891 cycles with a probable error of 63 cycles. At 1900°F the average value is 1170 cycles, plus or minus 101 cycles. For N-155 alloy at 1900°F the average thermal-shock cycles to failure is 1496± 22 cycles. At 2000°F the data appear to be inconclusive, but a rough estimate places the thermal-shock resistance at about 1000 cycles. At high temperatures these two materials show more uniform results than any other materials tested, as indicated by the small probable-error values. Results of all data on N-155 and S-816 are shown in Figs. 5 and 6.

CONCLUSIONS

On the basis of available data the thermal-shock resistance of various materials tested is as follows:

Material	Test Temperature	Average Cycles	Probable Error
Waspalloy	1600	over 10,000	
Waspalloy	1700	980	189
Waspalloy	1800	1,062	405
Hastelloy C	1600	4,801	1557
Inconel	1600	3,449	505
Inconel	1700	2,107	312
S 816	1900	1,170	101
S 816	2000	891	63
N 155	1900	1,496	22
N 155	2000	about 1,000	

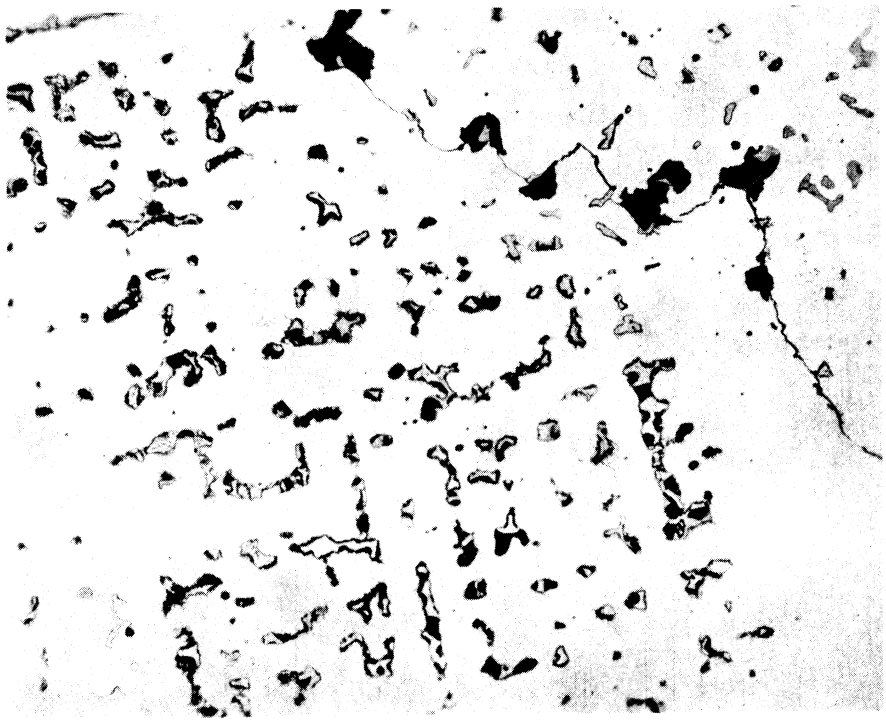


Fig. 1. HS 21 As cast. Tensile strength 101,700 psi
Elongation 13.4%. Hardness 26 Rockwell C.
Etch 10% HCl X100

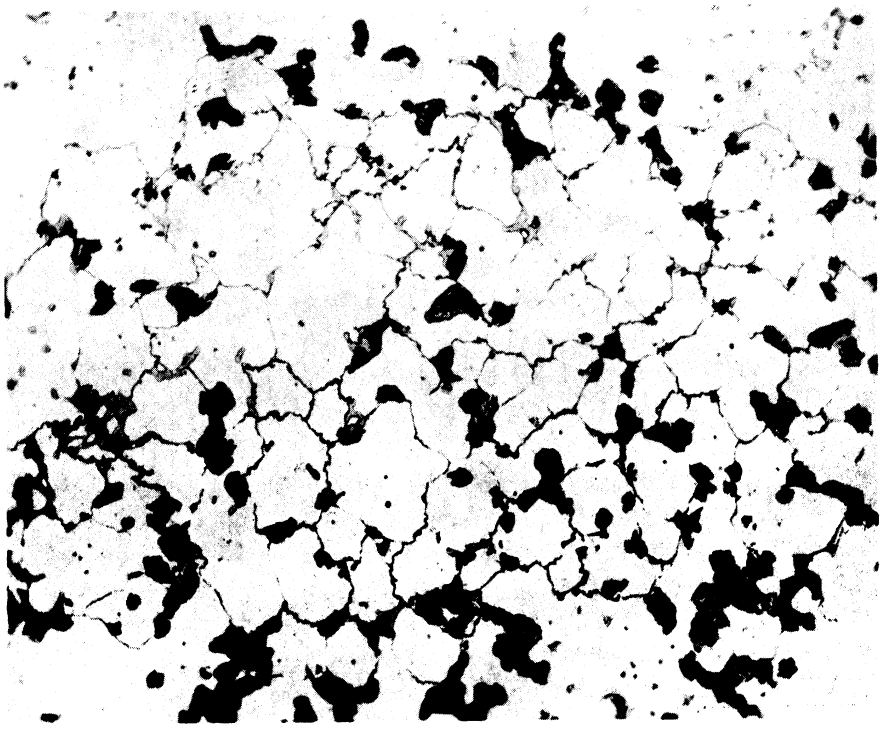


Fig. 2. HS 21 As cast. Tensile Strength 92,900 psi.
Elongation 11.2%. Hardness 26 Rockwell C.
Etch 10% HCl X100

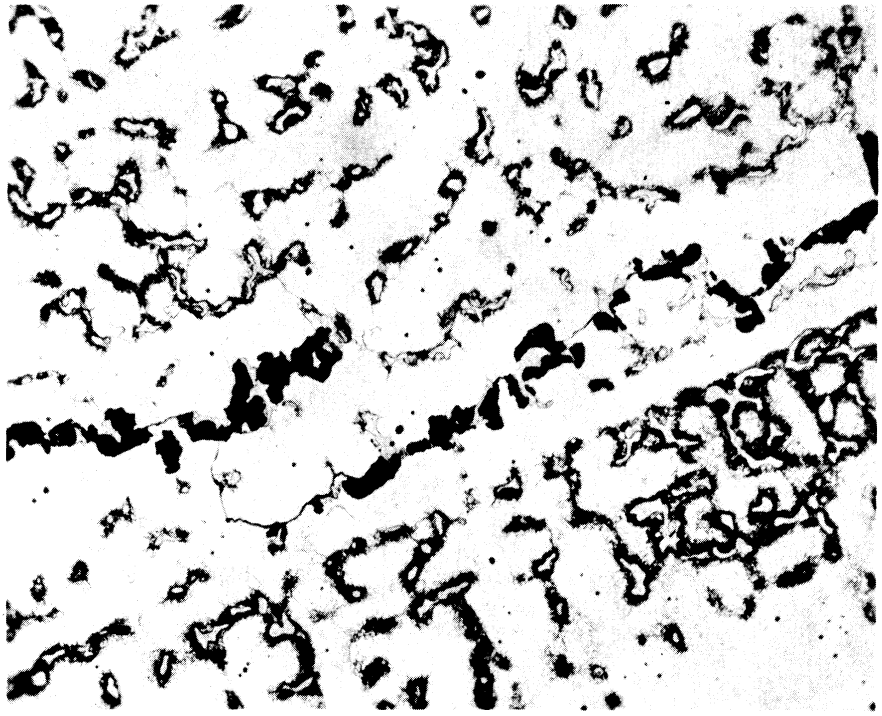


Fig. 3. HS 21 51 hours at 1350°F. Tensile strength 143,000 psi.
Elongation 2.8%. Hardness 32 Rockwell C.
Etch 10% HCl X100

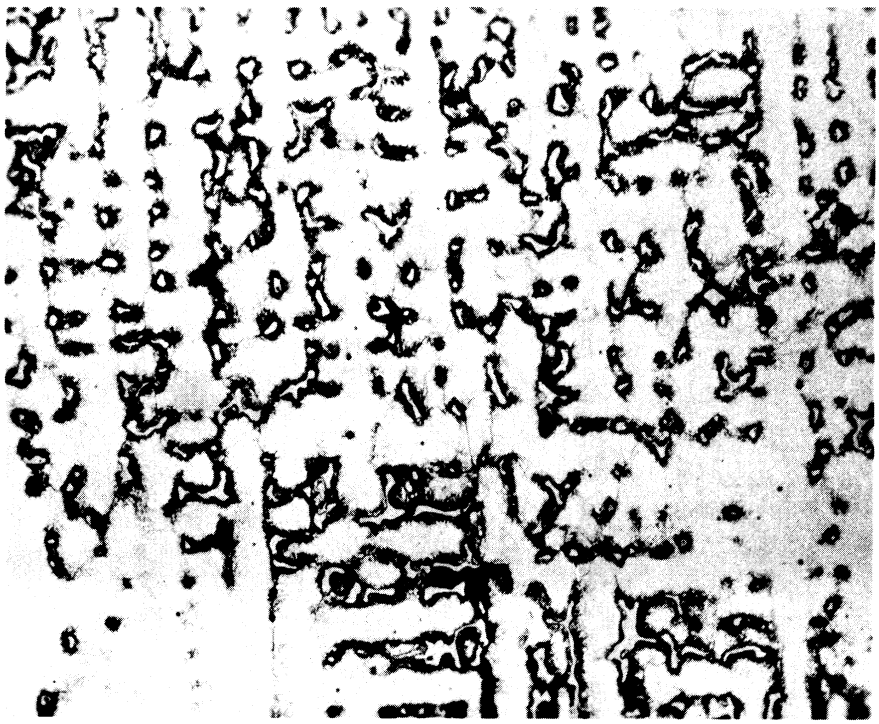


Fig. 4. HS 21 51 hours at 1350°F. Tensile strength 122,000 psi.
Elongation 4.3%. Hardness 33 Rockwell C.
Etch 10% HCl X100

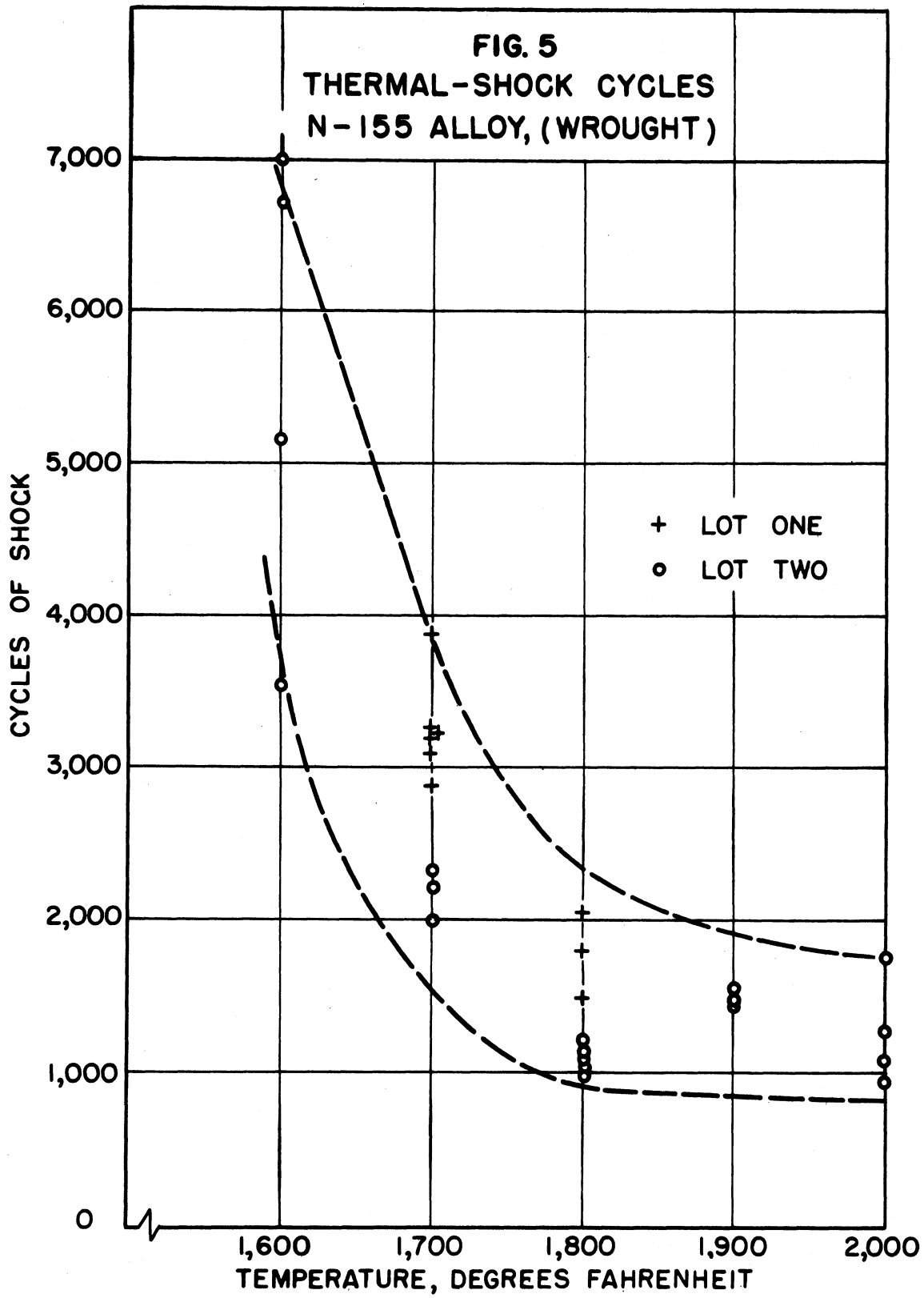


FIG. 5
THERMAL-SHOCK CYCLES
N-155 ALLOY, (WROUGHT)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
CYCLES OF SHOCK
+ LOT ONE
o LOT TWO
1,600
1,700
1,800
1,900
2,000
TEMPERATURE, DEGREES FAHRENHEIT

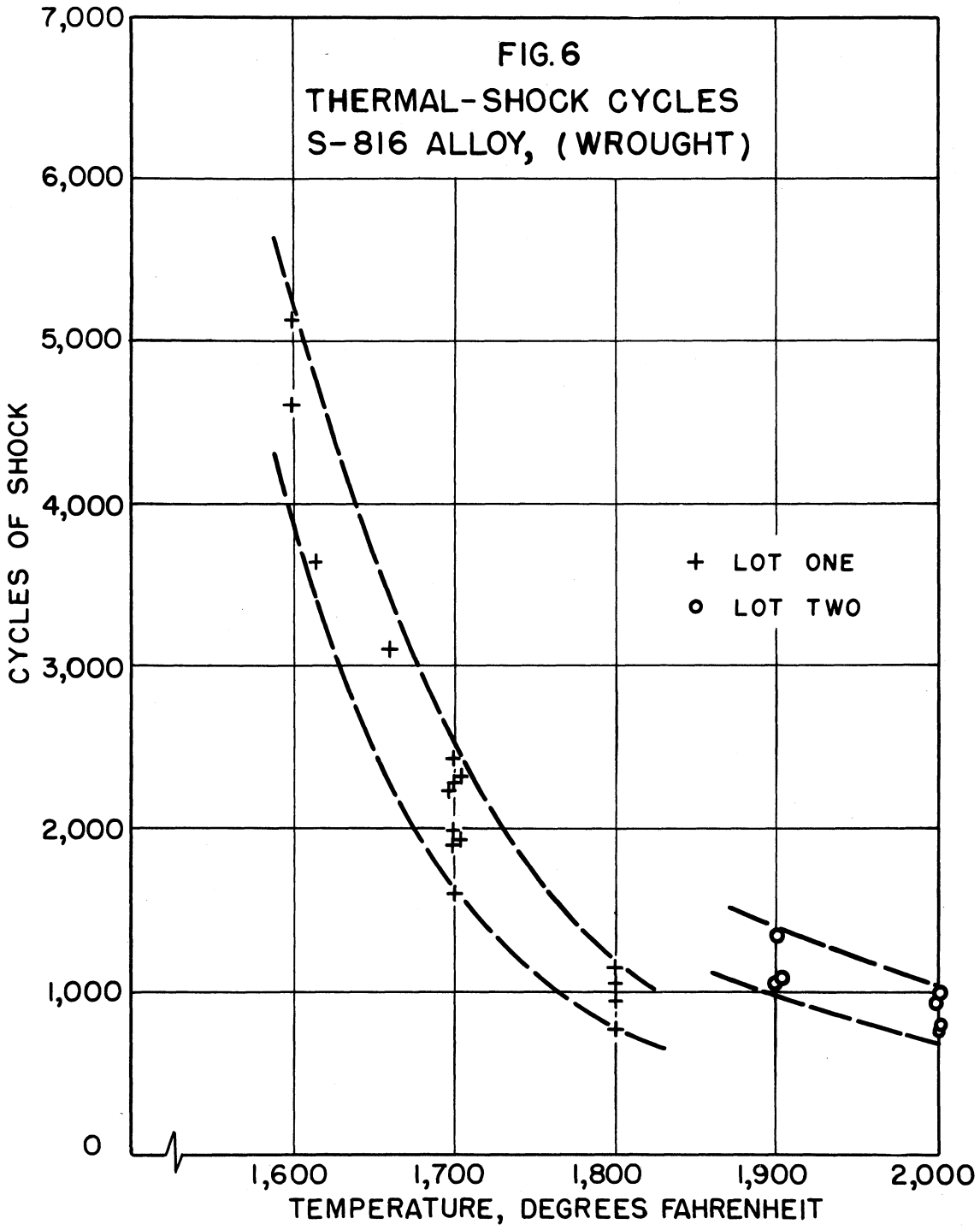


FIG. 6
THERMAL-SHOCK CYCLES
S-816 ALLOY, (WROUGHT)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
CYCLES OF SHOCK
+ LOT ONE
o LOT TWO
1,600
1,700
1,800
1,900
2,000
TEMPERATURE, DEGREES FAHRENHEIT

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

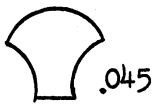
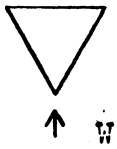
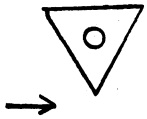
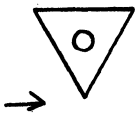
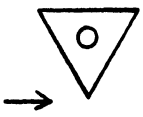
A 0.14 — Area of cross section, square inch

T300/1600 — Heat treated before testing 300 hr at 1600°F

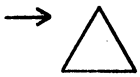
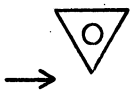
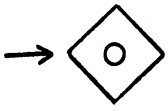
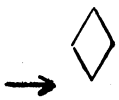
G1500 — Grooves first appeared at 1500 cycles

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) 1700/60 (Heating time, seconds) (Min temp) 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.

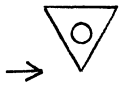
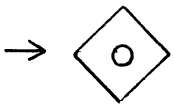
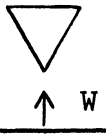
TEST LOG

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

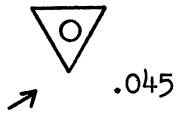
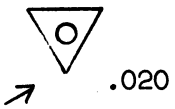
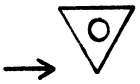
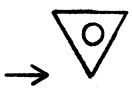
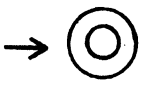
TEST LOG (cont)

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Type 304 Stainless Steel (cont)					
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

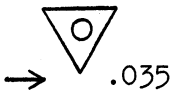
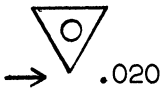
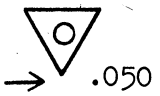
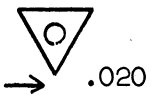
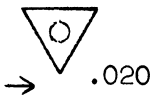
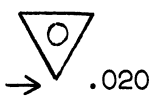
TEST LOG (cont)

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		1700/3	530W	C	
20		1500/3	1000	O	BT

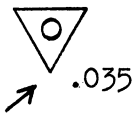
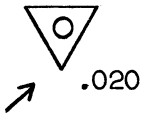
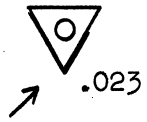
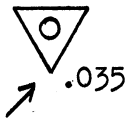
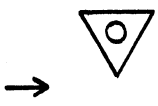
TEST LOG (cont)

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	

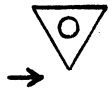
TEST LOG (cont)

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

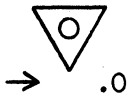
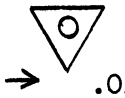
TEST LOG (cont)

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Type 347 Stainless Steel (cont)					
15		1600/4	3003	C	G2820 R
16		1600/4	2518	C	R
17		1600/4	4850	O	Check I
18		Fatigue 64K	7200	F	54K 103300
19		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	

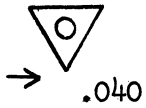
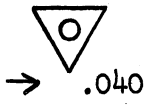
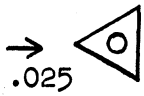
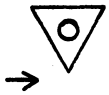
TEST LOG (cont)

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

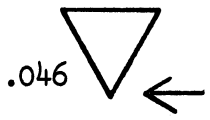
TEST LOG (cont)

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Type 347 Stainless Steel (cont)					
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)				

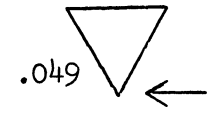
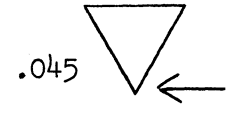
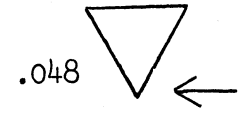
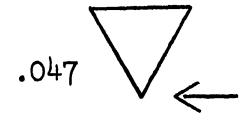
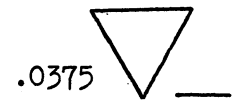
TEST LOG (cont)

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)		1600/5 P.F.	1859	C	58K/30000
37 (5)		1600/5	4635	C	
38		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)			

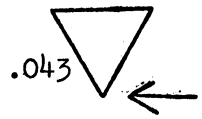
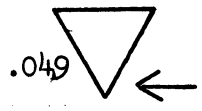
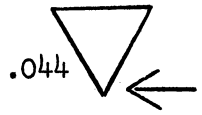
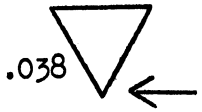
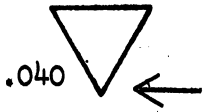
TEST LOG (cont)

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Type 347 Stainless Steel (cont)					
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					

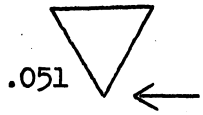
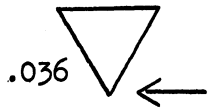
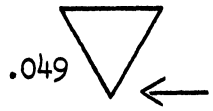
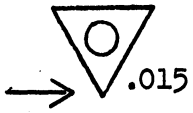
TEST LOG (cont)

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		1700/5 (1719)	6820	C	FC6003 .4C6561
5		1800/5 ✓	1252	C	
6					
7		1700/5 (1720)	1506	C	
8		1800/5 ✓	3468	C	
9		1600/5 (1603)	5305	C	
10					

TEST LOG (cont)

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		1600/5 1605	17615	C	
12		1700/5	7375		T51/1350
13		1800/5 ✓	3902	C	
14					
15		1600/5 (1607)	15334	O	
16		1700/5	14489		T51/1350
17		1700/5 (1708)	3279	C FC.004	

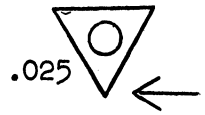
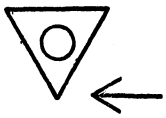
TEST LOG (cont)

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		1700/5 (1710)	10060		T51/1350
20		1800/5 ✓	4147	C	
21		1600/5 ✓	9938	C	
22		1700/5 ✓	18411	C	T51/1350
Inconel					
1		1500/3	1450	C	
2		1500/3 +10/100	2730	C	
3		1500/3 +10/100	428	C	BT

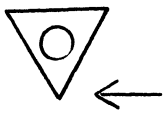
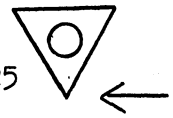
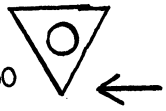
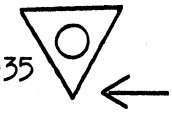
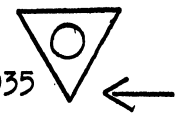
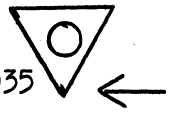
TEST LOG (cont)

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

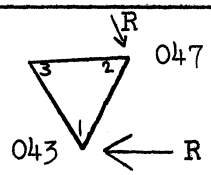
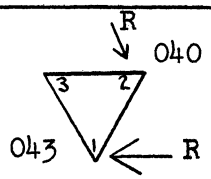
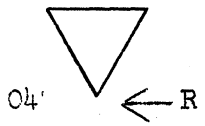
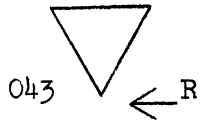
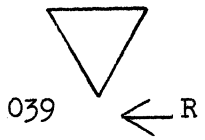
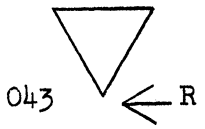
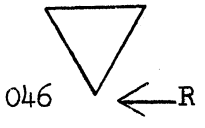
TEST LOG (cont)

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 PT0
17		1700/5	2270	C	T1/3/1400 PTI

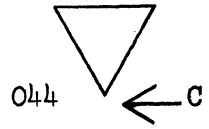
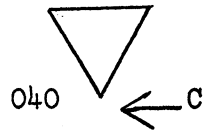
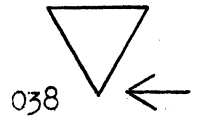
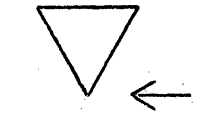
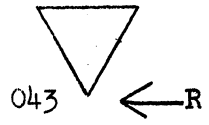
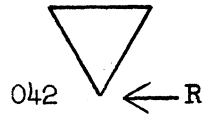
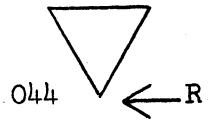
TEST LOG (cont)

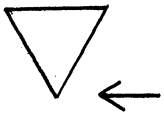
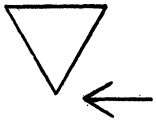
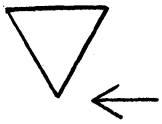
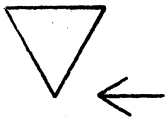
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Inconel (cont)					
18		1700/5	2576 3015	PC C	T1/3/1400 PT5
19	.025 	1700/5	1830	C	T1/3/1400 PT10
20	.030 	1700/5	2898	C	T1/3/1400 PT0
21					
22	.035 	1700/5	4339 6866	FC? C	T1/3/1400 flex. pipe to nozzle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

TEST LOG (cont)

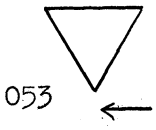
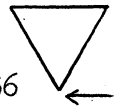
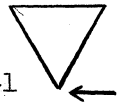
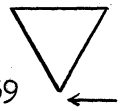
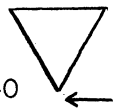
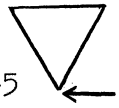
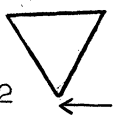
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Inconel Lot II (1/2 -Inch-Diameter H.R. Rod)					
B1		(Edge) (1) 1700/5 (2) 1700/5	 2267 1760	 C C	T 1/3/1400 2 tests on different edges
B2		(1) 1700/5 (2) 1700/5	2344 2527	C C	T 1/3/1400 2 tests on different 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 ?	Metallographic 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

TEST LOG (cont)

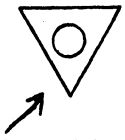
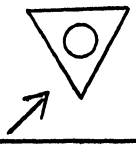
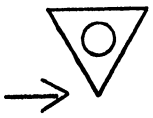
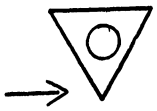
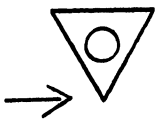
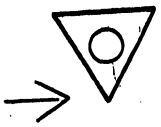
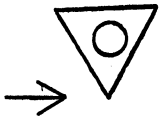
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Inconel Lot II (1/2 -Inch-Diameter H.R. Rod) (cont)					
B8		1700/5	2560	C	Reproduction Test on New Unit "C" T 1/3/1400
B9		1700/5	2283	C	do T 1/3/1400
B10		1700/5	2206	C	do T 1/3/1400
B11					
B12		2000/5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

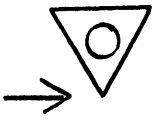
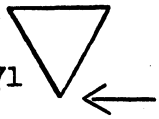
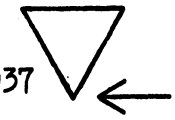
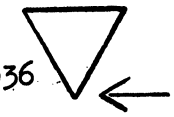
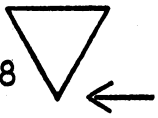
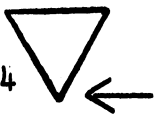
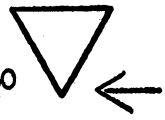
TEST LOG (cont)

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Inconel					
C-1	 053	1600/5	4358	C	T 1/3/1400
C-2	 036	1600/5	3416	C	do.
C-3	 041	1600/5	2572	C	do.
C-4	 039	1700/5	1693	C	do.
C-5	 040	1700/5	1378	C	do.
C-6	 045	1700/5	1537	C	do.
C-7	 042	1800/5	3854	C	do.

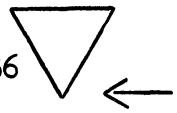
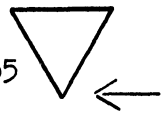
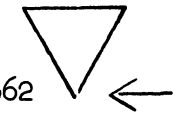
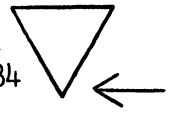
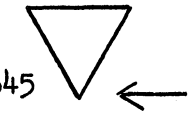
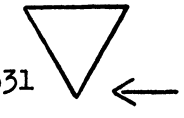
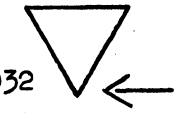
TEST LOG (cont)

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	

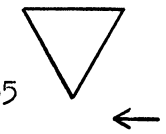
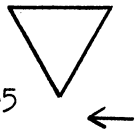
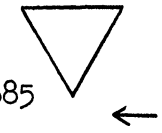
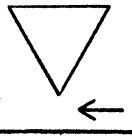
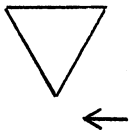
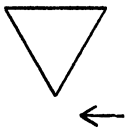
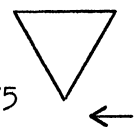
TEST LOG (cont)

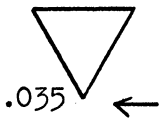
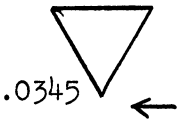
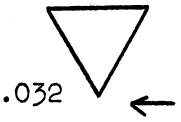
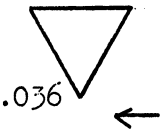
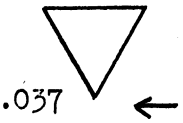
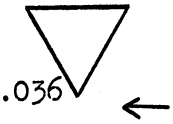
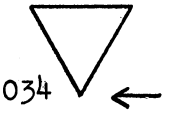
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
S-816 Alloy (wrought) (cont)					
8		1600/4	7497	C	
9	.0371 	1800/5	1069-	C	T {1/2150 W 16/1800
10	.037 	1700/5	2426	C	T {1/2150 W 16/1800
11	.036 	1600/5	5130	C	T {1/2150 W 16/1800
12	.0388 	1800/5	956-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

TEST LOG (cont)

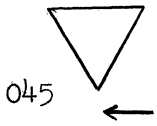
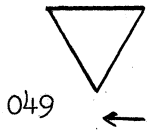
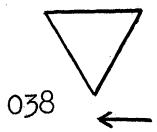
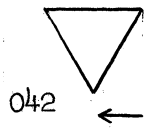
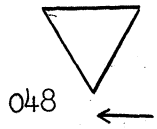
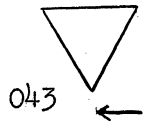
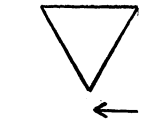
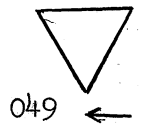
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
S-816 Alloy (wrought) (cont)					
15	.036 	1600/4	4600	C	T {1/2150 W, 16/1800} I
16	.0335 	1600/4	3620	C	T {1/2150 W, 16/1800} I Average test temp. was 1615°F
17	.0362 	1700/5	1956⁻	C	T {1/2150 W, 16/1800} 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}

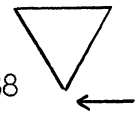
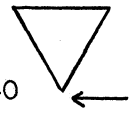
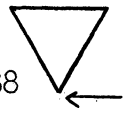
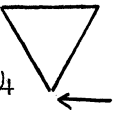
TEST LOG (cont)

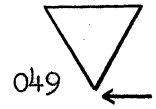
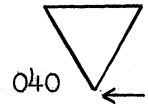
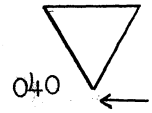
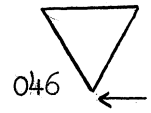
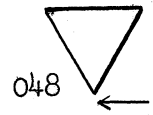
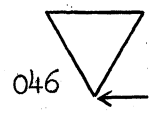
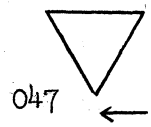
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
S-816 Alloy (wrought) (cont)					
22	.035 	1700/5	2050	C	T {1/2150 | 16/1800} II P {1700/60 | 1200/23} 600 N
23	.0335 	1700/5 (1685)	1414	C	T {1/2150 | 16/1800} II P {1700/60 | 1200/23} 1182 N
24	.0385 	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

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

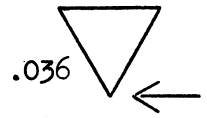
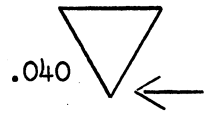
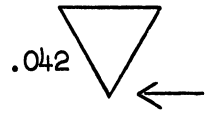
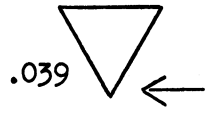
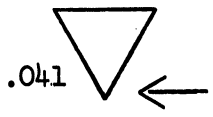
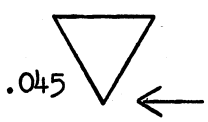
TEST LOG (cont)

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
S-816					
P6-1	 045	1900/5	1082	C	T {1/2150 16/1800
P6-2	 049	1900/5	1351	C	do.
P6-3	 038	1900/5	1077	C	do.
P6-4	 042	2000/5	786	C	do.
P6-5	 048	2000/5	1001	C	do.
P6-6	 043	2000/5	800	C	do.
P6-7					
P6-8	 049	2000/5	976	C	do.

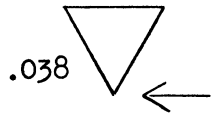
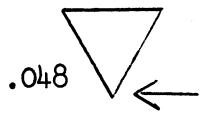
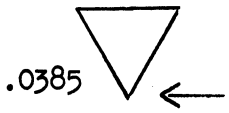
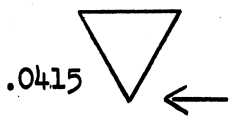
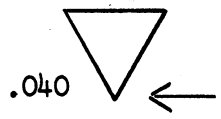
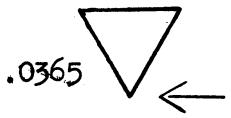
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
N-155 Alloy (wrought)					
1	.038 	1700/5	3764 3878 4949	FC C 2C	T {1/3/2200 W 50/1400} I
2	.040 	1700/5	3211	C	T {1/3/2200 W 50/1400} I
3	.038 	1700/5	3248	C	T {1/3/2200 W 50/1400} I
4	.034 	1800/5	1508	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)					
C5-1	 049	2000/5	1287	C	T {1/3/2200 50/1400
C5-2	 040	2000/5	1083	C	do.
C5-3	 040	2000/5	1775	C	do.
C5-4	 046	2000/5	966	C	do.
C5-5	 048	1900/5	1495	C	do.
C5-6	 046	1900/5	1458	C	do.
C5-7	 047	1900/5	1535	C	do.

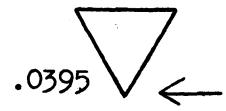
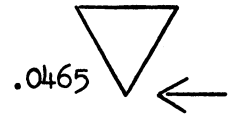
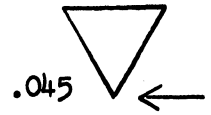
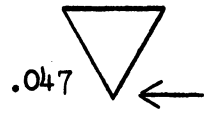
TEST LOG (cont)

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

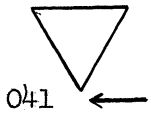
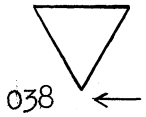
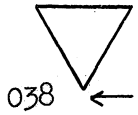
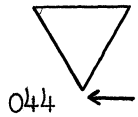
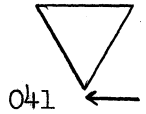
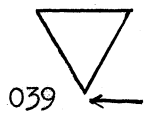
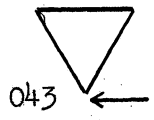
TEST LOG (cont)

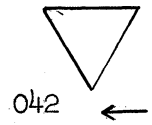
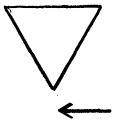
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
N-155 Alloy (wrought) (cont)					
12		1800/5	1228	C	T {1/3/2200 W 50/1400} II
13		1800/5	1095	C	T {1/3/2200 W 50/1400} II
14		1800/5	1042	C	T {1/3/2200 W 50/1400} II
15		1800/5	990	C	T {1/3/2200 W 50/1400}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

TEST LOG (cont)

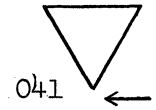
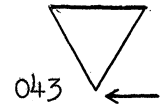
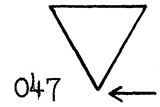
Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
N-155 Alloy (wrought) (cont)					
19		1600/5	5153	C	T {1/3/2200 W, 50/1400} II
20		1700/5	2320	C	T {1/3/2200 W, 50/1400} II
21		1600/5	3530	C	T {1/3/2200 W, 50/1400} II
22		1600/5	7000	C	T {1/3/2200 W,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

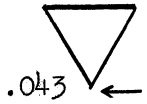
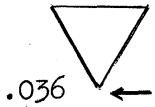
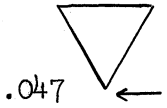
TEST LOG (cont)

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Waspalloy					
A3-1	 041	1600/5	10050	C	T {4/1975 16/1400
A3-2	 038	1600/5	15048	C	do.
A3-3	 038	1800/5	1789	C	do.
A3-4	 044	1800/5	613	C	do.
A3-5	 041	1800/5	784	C	do.
A3-6	 039	1700/5	1319	C	do.
A3-7	 043	1700/5	742	C	do.

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Waspalloy (cont)					
A3-8	 042	1700/5 (1695)	879	C	do.
A3-9		1650/5 (1680)	1690	C	do.

TEST LOG (cont)

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
M-252 Alloy					
B2-1	 041	1600/5 (1575)	15648	C	T 4/1950 15/1400
B2-2	 043	1600/5 (1595)	7717	C	do.
B2-3	 047	1700/5	3747	C	do.

Specimen Number (1)	Cross Section (2)	Cycle (3)	Number of Cycles (4)	Type of Failure (5)	Remarks (6)
Hastelloy C					
C-1		1600/5	4618	C	T {1/2200 16/1600
C-2		1600/5	2240	C	T {1/2200 16/1600
C-3		1600/5	7546	C	T {1/2200 16/1600