[redacted]

(NASA-CR-120958) HIGH FREQUENCY FATIGUE TESTING OF UDIMET 700 AT 1400 F (Hydronautics, Inc.) 35 p HC $3.75 CSCL 20K

N73-21845

Unclas
G3/32 67938

HYDRONAUTICS, incorporated
research in hydrodynamics

Research, consulting, and advanced engineering in the fields of NAVAL and INDUSTRIAL HYDRODYNAMICS. Offices and Laboratory in the Washington, D. C. area: Pindell School Road, Howard County, Laurel, Md.

36

HYDRONAUTICS, Incorporated

NASA CR-120958
TECHNICAL REPORT 7150-1

HIGH FREQUENCY FATIGUE TESTING OF UDIMET 700 AT 1400°F

By

Andrew F. Conn and S. Lee Rudy

June 1972

Prepared for

National Aeronautics and Space Administration
Contract NAS3-14335

Technical Management
NASA Lewis Research Center
Cleveland, Ohio
Materials and Structures Division
Gary R. Halford

I

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

This report summarizes the results of a portion of an investigation pertaining to the development of life prediction methods for materials subjected to high temperature creep/fatigue conditions. High frequency (13.4 kHz) fatigue data were measured, at 1400°F, on specimens of the nickel-based alloy Udimet 700. Tests were conducted on the virgin material, as well as specimens which had received prior exposures to high temperature, fatigue, and creep.

INTRODUCTION

Scientists at HYDRONAUTICS, Incorporated have gained considerable experience in conducting high cycle, high frequency fatigue experiments during the past several years under a series of research programs (see References 1-6). These studies include the testing of ordinary structural alloys as well as advanced high temperature resistant and high strength materials. Particular experience with the effect of elevated temperatures on high frequency fatigue lifetimes was obtained under a recent NASA contract (see Reference 7). An understanding of this phenomenon is important in long-life engineering systems such as:

1. Gas-turbine engines for supersonic aircraft and other air breathing engines.
2. Propulsion and auxiliary power systems for extended space missions.
3. Atomic power generation equipment.

Experimental facilities have been modified and developed which provide the capability for economical fatigue testing to billions of cycles at temperatures which simulate the actual service conditions of advanced high temperature alloys.

NASA-Lewis has been pursuing a continuing program on cyclic life prediction methods, particularly at elevated temperature. The most recent approach uses a linear life-fraction creep/fatigue damage rule since this rule has been found to be adequate over the range of variables that are immediately available in the NASA-Lewis low-cycle fatigue laboratory. There are, however, theoretical reasons to suspect that a linear damage accumulation rule may be inadequate for reliable life prediction, especially in the very long life region.

The broad objective of this investigation is to learn more about cumulative damage effects in situations where there is a potential for large interaction between crack initiation and crack propagation in creep and fatigue. This information should permit the improvement of existing life prediction methods. The fatigue portion of this testing program was designed to yield results in a region where the largest deviations from a linear life fraction rule are expected to occur. This is a distinct advantage that should help isolate cause and effect from a scatter that is inherent in high endurance fatigue. The fatigue testing program described in this report was designed with the specific objective of obtaining critical data for use by the NASA-Lewis Research Center in the further development of life prediction methods under high-temperature creep/fatigue conditions. High frequency (13.4 kHz) fatigue data in the life range of 10^6 to 10^9 cycles to failure was generated at 1400°F on virgin, temperature exposed, fatigue exposed, and creep exposed specimens of the nickel-base alloy Udimet 700. All fatigue tests were completely reversed, axial push-pull, using an hour-glass specimen. The specimens were specially designed so as to be compatible with both the NASA-Lewis creep testing equipment and the HYDRONAUTICS high frequency fatigue facilities. For this reason, a new analysis of this unusual specimen configuration was required, in order to verify the large strain magnification factors which were experimentally observed.

Temperature and creep exposures were conducted by NASA-Lewis. The results will be analyzed by NASA-Lewis and compared with current theoretical predictions of damage accumulation during creep/fatigue conditions. The results will also be used as may be required to formulate improved predictions.

TEST FACILITY

The HYDRONAUTICS, Incorporated high frequency fatigue facility was utilized to conduct the high temperature fatigue tests for this program. A photograph of the facility is seen in Figure 1, and the equipment is schematically depicted in Figure 2. The specimen configuration used for these tests of wrought Udimet 700 is given in Figure 3.

In essence the apparatus consists of a magnetostriction transducer,a signal generator, an amplifier, a power supply, a displacement pick-up coil, an oscilloscope, and a frequency counter. In addition, the facility has been modified for operation at elevated temperatures. As shown in Figure 1, a cylindrical electric resistance type furnace has been incorporated, with power supply and temperature readout, to provide heating of test specimens in excess of 2000°F. Special extension rods, with suitable heat-shielding to protect the magnetostriction transducer, were developed for high temperature tests. Details of the experimental components, seen schematically in Figure 2, may be found in References 3 or 7. All of the tests for this study were conducted at a nominal frequency of 13.4 kHz.

CALCULATION OF FATIGUE STRESSES

The basis for this high frequency technique is the creation of longitudinal oscillations in a fatigue specimen at its resonant frequency, producing uniaxial, alternating strains. The maximum alternating strains are produced at the node of the resonant specimen. These strains are further amplified by means of a carefully designed dumbbell shape. The fatigue specimen design is based on the theory developed by Neppiras (8).

The strain at the node is given by:

$$\epsilon = G \cdot \frac{2\pi\zeta}{\lambda} \qquad [1]$$

where

ϵ the strain amplitude at the node,

ζ the displacement amplitude at the antinode,

λ the wavelength in the material, and

G the strain magnification factor:

$$G = \frac{\text{strain in stepped specimen}}{\text{strain in uniform specimen (without step)}}$$

The value of the strain magnification factor for stepped specimens may be calculated from Neppiras' theory (8). He shows that the value of G may be calculated for a decrease in specimen diameter from d_α to d_β, by:

$$G_{\alpha\beta} = \frac{\cos k\ell_\alpha}{\cos k\ell_\beta} \qquad [2]$$

where ℓ_α and ℓ_β are respectively the lengths of the larger and smaller sections of the tuned specimen, and $k = 2\pi/\lambda$, where λ is the wave length for the material at the test temperature and resonant frequency.

As seen in Figure 3, the specimens used for this program have two area reductions. The first is from the large threaded section, with effective diameter: $d_o = 0.596$ in., to the straight portion: $d_1 = 0.375$ in. The second strain magnification occurs during the reduction from d_1 to the minimum cross-section at $d_2 = 0.125$ in., where the maximum strain occurs.

Using the value of $\lambda = 13.68$ in., which was determined for the Udimet 700 at 1400^oF, at the resonant frequency of 13.4 kHz, the values of $G_{\alpha\beta}$ may be calculated, with the section lengths, ℓ_o, ℓ_1 and ℓ_2, as presented on Figure 3.

Therefore,

$$G_{o_1} = \frac{\cos k\ell_o}{\cos k\ell_1} = 2.133 \qquad [3]$$

would be the strain magnification if the specimen did not contain the reduced section, d_2. However, the standing wave pattern is clearly influenced by this second area reduction and the use of ℓ_1 for this first magnification factor yields a value of G which is the maximum it would be with no reduced central section. Let us consider the other extreme, namely to assume that the portion of the specimen with diameter d_1 is of length:

$$\ell_1' = \ell_1 + \ell_o = 1.425 \text{ in.}$$

Thus, there is again no reduced section of diameter d_o, but one assumes a length equivalent to the sum of the two smaller cross-sections. Then,

$$G_{o1}' = \frac{\cos k\ell_o}{\cos k\ell_1'} = 1.624, \qquad [4]$$

is the minimum value for this factor, for a specimen having no reduced central section. The volume reduction in the central region is one-half, which suggests averaging the two extreme values given by Equation [3] and [4] to obtain the effective strain magnification factor:

$$G_o = \tfrac{1}{2}\,(2.133 + 1.624) = 1.8785, \qquad [5]$$

for the first area reduction.

Similarly, the second area reduction provides:

$$G_{12} = \frac{\cos k\ell_1}{\cos k\ell_2} = 5.172 \qquad [6]$$

Combining the results of Equations [5] and [6], we have:

$$G = G_o \cdot G_{12} = 9.72 \qquad [7]$$

as the overall magnification factor for the specimen shown in Figure 3.

To confirm this calculation, two specimens were fitted with BLH Type HT-1212-2A high temperature strain gages. Two gages were mounted on each specimen using the BLH Rokide process, as shown in Figure 4. One specimen was loaded statically at 1400°F to obtain the correct gage factor. The gages on this specimen failed before the dynamic tests could be started. A second specimen was tested dynamically using the previously obtained gage factor. The results of the calibration tests are averages of the two gages, and are plotted on Figure 5, for comparison with the theoretical G = 9.72. It was found that the experimental value of G was 9.73. This agreement seems to support the stress calculation procedures which were used. The stress is given by:

$$\sigma = E\epsilon,$$

where: $E = 24 \times 10^6$ psi and ϵ is determined from Equation [1], with G = 9.73 and $\lambda = 13.68$.

EXPERIMENTAL INVESTIGATION

The fatigue experiments for this study were divided into a series of tasks. Each task was designed to systematically develop the data needed to contribute to the development of life prediction methods for materials which experience the combined effects of creep and fatigue loading, and elevated temperature exposure.

Task 1: Determination of Fatigue Loading Level

The objective of this task was to determine a stress, S_1, which would produce fatigue failure in approximately 10^8 cycles. A series of tests were run at selected stress levels, and the results are summarized in Table 1, and plotted in Figure 6. Testing was stopped on Specimen No. 149 after it had run for 2 hours and 40 minutes, as this clearly established that a stress of 35.4 ksi would yield testing times greater than desired for this program.

The stress amplitude of 37.0 ksi provided a failure cycle of just under 10^8, and required a testing time in the range of one to two hours. This seemed to be a practical testing time, and hence S_1 was selected to be 37.0 ksi.

Task 2: Measurement of Baseline Fatigue Data

A total of nineteen (19) specimens were tested during this task. One specimen, which did not fail during the normal operating shift, was not included in the averaging as all of the other specimens were tested without interruptions.

The test data are listed on Table 2-A and 2-B and are plotted on Weibull probability paper in Figure 7. A Weibull shape parameter, b, of approximately 1 fits the upper portion of this curve. The algebraic mean for the fatigue life of the eighteen specimens of Udiment 700, all tested at a stress amplitude of 37.0 ksi, was 1.06×10^8 cycles. The geometric mean fatigue life was 5.99×10^7 cycles. This geometric mean will be used for the value of N_1 which is required for Task 4 of this investigation.

Task 3: Fatigue of Temperature Exposed Specimens

A total of nine (9) specimens were used for this task. Four were tested, that had been previously exposed to $1400^{\circ} \pm 5^{\circ}F$ for a forty-eight (48) hour period, and five were used, that had previously been exposed to the same temperature, for a five hundred and four (504) hour period. One of the specimens, No. 87, previously exposed for a forty-eight hour period ran for over two working days (16.4 hours) without failure. This was noted as a Run Out on Table 3. The results of all the tests for Task 3 are shown on Table 3.

Task 4: Fatigue Exposure Tests

The purpose of this task was to expose specimens to prescribed amounts of fatigue cycling, so as to be able to study the effects of such exposure on subsequent creep behavior. The approach used was to expose at least six specimens to 0.1 N_1 cycles at the loading level S_1 of 37 ksi, and at least six specimens to 0.4 N_1 cycles of fatigue at this same value of S_1.

Using the geometric mean ($N_1 = 5.99 \times 10^7$ cycles) obtained from Task 2, the exposure times were calculated as follows:

$$N_1 = 5.99 \times 10^7 \text{ cycles}$$

Frequency of test apparatus = 13.4 kHz

$$13.4 \text{ kHz} = 13.4 \times 10^3 \text{ cyc./sec.} = 8.04 \times 10^5 \text{ cyc./min.},$$

therefore,

(a) For: $0.1N_1 = (0.1)(5.99 \times 10^7 \text{ cycles}) = 5.99 \times 10^6$ cycles. Therefore the testing time is:

$$T = \frac{5.99 \times 10^6 \text{ cycles}}{8.04 \times 10^5 \text{cyc./min.}} = 7.45 \text{ minutes exposure}$$

(b) For: $0.4N_1 = (0.4)(5.99 \times 10^7 \text{ cycles}) = 2.40 \times 10^7$ cycles. Therefore the testing time is:

$$T = \frac{2.40 \times 10^7 \text{ cycles}}{8.04 \times 10^5 \text{ cyc./min.}} = 29.85 \text{ minutes exposure}$$

A total of thirteen (13) specimens were used for this task. Six were exposed to 5.99×10^6 cycles, six were exposed to 2.40×10^7 cycles. One specimen, No. 141, failed before the correct exposure time was achieved. The results of all the tests for Task 4 are shown on Table 4.

Task 5: Fatigue of Creep Exposed Specimens

The purpose of this task was to determine the effect of prior creep exposure on the subsequent fatigue life of Udimet 700 at 1400°F. A total of fourteen (14) specimens were used for this task. Five specimens had been previously exposed to a constant tensile creep load of 90 ksi at 1400°F for 16.6 hours. Another five specimens had received the same tensile creep loading but were held at 1400°F for an additional four hours with no load. The remaining four specimens had received the same tensile creep loading but also received a constant compressive creep load of 90 ksi at 1400°F for one minute. One of the specimens, No. 133, previously exposed to both tensile and compressive creep loading, ran for over twenty hours without failing. This is noted as a run-out on Table 5. The results of all the tests for Task 5 are shown on Table 5. All tests were conducted at the same S_1 of 37.0 ksi.

Task 6: Fatigue of Creep Exposed Specimens

This task had the same purpose as Task 5. A total of eight (8) specimens, with prior creep exposure, were used for this task. Four (4) of these specimens ran for over twenty hours without failing. These are noted as run-out points on Table 6. The results of all the tests for Task 6 are shown on Table 6. All tests were conducted at the same S_1 of 37.0 ksi.

Task 7: Fatigue of Creep Exposed Specimens

This task had the same purpose as Task 5. A total of eight (8) specimens, with prior creep exposure, were used for this task. One (1) of these specimens ran for over twenty hours without failing. This is noted as a run-out point on Table 7. The results of all the tests for Task 7 are shown on Table 7. All tests were conducted at the same stress level, S_1, of 37.0 ksi.

Task 8: Fatigue of Creep Exposed Specimens

This task had the same purpose as Task 5. A total of five (5) specimens, with prior creep exposure, were used for this task. The results of all the tests for Task 8 are shown on Table 8. All of these tests were conducted at the same S_1 of 37.0 ksi.

Task 9: Contingency Fatigue Testing

The purpose of this task was to allow for additional tests which were found to be necessary as a result of examining the results of the earlier tasks. The following tests were performed at the same S_1 of 37.0 ksi, 13.4 kHz, 1400°F:

(a) Fatigue of Creep Exposed Specimens

A total of five (5) specimens were used for this portion of the task. These specimens had received prior, unspecified, creep exposure before testing to failure.

(b) Fatigue Exposure Tests

The required exposure for these tests was $0.4N_1 = 2.40 \times 10^7$ cycles as previously outlined for Task 4. A total of seven (7) specimens were used for this portion of the task. Five were exposed to 2.40×10^7 cycles. Two specimens numbers 41 and 77, failed before the correct exposure time was achieved. The results of all the tests conducted for Task 9 are shown on Table 9.

CONCLUDING REMARKS

These high frequency fatigue tests of Udimet 700, under high temperature conditions, showed considerable scatter in the lifetimes which were observed for the virgin material as well as for those specimens which had received prior creep loading and/or prior high temperature exposure. This material is apparently highly sensitive to factors which contribute to the initiation of the fatigue crack. In particular, very short lifetimes were often associated with the presence of minute scratches in the gage section.

In contrast, many of the specimens achieved 10^9 cycles without failure, suggesting the possibility of very desirable applications of this alloy under high temperature, cyclical loading if suitable control of the crack initiating factors could be achieved. Comparable lifetime scatter has been observed (2) in high frequency fatigue tests of other high strength alloys which were developed especially for their ability to operate at high temperatures.

REFERENCES

1. Thiruvengadam, A., "High Frequency Fatigue of Metals and their Cavitation Damage Resistance," HYDRONAUTICS, Incorporated Technical Report 233-6, December 1964. (Also see Trans. ASME, Journal of Engineering for Industry, August 1966).

2. Thiruvengadam, A., and Preiser, H. S., "Cavitation Damage in Liquid Metals," HYDRONAUTICS, Incorporated Technical Report 467-Final, NASA CR-72035, November 1965.

3. Thiruvengadam, A., and Rudy, S. L., "Experimental and Analytical Investigations on Multiple Liquid Impact Erosion," HYDRONAUTICS, Incorporated Technical Report 719-1, June 1968, (Also NASA CR-1288, March 1969).

4. Thiruvengadam, A., and Rudy, S. L., "The Determination of High Frequency Fatigue Strength of Depleted Uraniam Oxide Fuel Elements," HYDRONAUTICS, Incorporated Technical Report 848-1, June 1968.

5. Thiruvengadam, A., Rudy, S. L., and Gunasekaran, M., "Experimental and Analytical Investigations on Multiple Liquid Impact Erosion," HYDRONAUTICS, Incorporated Technical Report 719-2, August 1969 (Also NASA CR-1638, September 1970, and ASTM STP 474, pp. 249-287, 1970).

6. Preiser, H. S., "Research on the Corrosion Behavior of 17-4 Ph Stainless Steel in High Velocity Seawater," HYDRONAUTICS, Incorporated Technical Report 838-Final, September 1969.

7. Conn, A. F., and Thiruvengadam, A., "Experimental Research on High Frequency Fatigue and Dynamic Tensile Tests at Elevated Temperatures," HYDRONAUTICS, Incorporated Technical Report 829-1, (NASA CR-72618) July 1969. (Also see, "On High-Frequency Fatigue and Dynamic Properties at Elevated Temperatures," Experimental Mechanics, Vol. 11, pp. 315-320, 1971.)

8. Neppiras, E. A., "Techniques and Equipment for Fatigue Testing at Very High Frequencies," Proc. ASTM, Vol. 59, pp. 691-709, 1959.

TABLE 1

Fatigue Data for Task 1

Test No.	Specimen No.	Applied Stress - KSI	Cycles to Failure	Frequency KHZ	Test Temp. °F
1	110	57.3	2.41×10^6	13.39	1397
2	152	49.1	3.48×10^6	13.38	1401
3	150	37.0	9.01×10^7	13.40	1398
4	123	37.0	4.58×10^7	13.39	1397
5	156	35.4	1.19×10^8	13.40	1400
6	149	35.4	1.26×10^8 *	13.41	1398

* Stop early (driving O.K.)

TABLE 2-A

Fatigue Data for Task 2

Test No.	Specimen No.	Frequency, KHZ	Cycles to Failure	Test Temp. °F
1	122	13.42	1.60×10^8	1400
2	136	13.41	1.19×10^8	1397
3	99	13.42	8.05×10^6	1400
4	85	13.40	7.05×10^7	1398
5	118	13.41	5.54×10^7	1400
6	97	13.40	4.35×10^7	1398
7	117	13.40	2.18×10^8	1400
8	96	13.41	2.41×10^7	1400
9	127	13.40	1.37×10^8	1397
10	79	13.41	1.77×10^7	1400
11	128	13.40	4.10×10^7	1400
12	102	13.40	2.22×10^8	1400
13	113	13.40	6.62×10^7	1400
14	112	13.40	2.12×10^8	1400
15	101	13.40	7.22×10^6	1400
16	130	13.40	1.65×10^8	1400
17	137	13.40	6.44×10^6	1400
18	151	13.40	3.64×10^8	1400

TABLE 2-B

Baseline Fatigue Data: To Define N_1

Order q	Cycles to Failure, N	F(N) x 100 Mean Rank 100(q/n+1)	log N	Specimen No.
1	6.44×10^6	5.26	-1.80889	137
2	7.22×10^6	10.53	-1.85854	101
3	8.05×10^6	15.79	-1.90580	99
4	1.77×10^7	21.05	0.24797	79
5	2.41×10^7	26.32	0.38202	96
6	4.10×10^7	31.58	0.61278	128
7	4.35×10^7	36.84	0.63849	97
8	5.54×10^7	42.11	0.74351	118
9	6.62×10^7	47.37	0.82086	113
10	7.05×10^7	52.63	0.84819	85
11	1.19×10^8	57.90	1.07555	136
12	1.37×10^8	63.16	1.13672	127
13	1.37×10^8	68.42	1.13672	130
14	1.60×10^8	73.68	1.20412	122
15	2.12×10^8	78.95	1.32634	112
16	2.18×10^8	84.21	1.33846	117
17	2.23×10^8	89.47	1.34830	102
18	3.64×10^8	94.74	1.56110	153
Sum	191.011×10^7		$13.99436 \div 18 = 0.77746$	
Mean	1.06×10^8		$5.99 \times 10^7 = N_1$	

TABLE 3

Fatigue Data for Task 3

Test Number	Specimen Number	Cycles to Failure	Prior Exposure 1400°F	Remarks
1	82	1.36×10^7	48 hrs.	
2	81	1.89×10^8	48 hrs.	
3	87	7.92×10^8	48 hrs.	Run out
4	83	1.36×10^7	48 hrs.	
5	95	4.78×10^8	504 hrs.	
6	86	1.66×10^8	504 hrs.	
7	92	8.2×10^5	504 hrs.	
8	89	8.2×10^5	504 hrs.	
9	91	1.24×10^8	504 hrs.	

TABLE 4

Fatigue Data for Task 4

Test Number	Specimen Number	Exposure Cycles	Remarks
1	142	5.99×10^6	
2	126	5.99×10^6	
3	129	5.99×10^6	
4	119	5.99×10^6	
5	158	5.99×10^6	
6	121	5.99×10^6	
7	141	1.28×10^7	Failure
8	154	2.40×10^7	
9	54	2.40×10^7	
10	47	2.40×10^7	
11	55	2.40×10^7	
12	48	2.40×10^7	
13	53	2.40×10^7	

TABLE 5

Fatigue Data for Task 5

Test Number	Specimen Number	Cycles to Failure	Remarks
1	160	8.05×10^5	
2	134	7.95×10^7	
3	138	5.69×10^8	
4	139	Bad Test	Amplitude too high Scope bad
13	90	1.47×10^7	Reduced section badly searched
5	58	Bad Test	Amplitude too high scope bad
6	42	1.63×10^8	
7	51	3.22×10^6	
8	52	8.71×10^8	
14	93	1.33×10^8	
9	133	1.0×10^9	Run out
10	105	4.41×10^6	
11	94	3.24×10^6	
12	106	7.30×10^7	

TABLE 6

Fatigue Data for Task 6

Test Number	Specimen Number	Group	Cycles to Failure	Remarks
1	40	2	1×10^9	Run out. Reduced section scratched.
2	45	2	2.33×10^6	
3	111	2	9.97×10^6	
4	46	2	1.02×10^9	Run out
5	108	1	1.57×10^6	
6	66	1	1.09×10^9	Run out
7	107	1	2.37×10^6	
8	64	1	1×10^9	Run out

TABLE 7

Fatigue Data for Task 7

Test Number	Specimen Number	Group	Cycles to Failure	Remarks
1	71	1	2.49×10^7	
2	72	1	4.41×10^8	
3	74	1	3.78×10^6	
4	73	1	5.83×10^6	
5	114	2	9.79×10^7	Reduced section looked repolished
6	145	2	2.19×10^8	Reduced section looked repolished
7	104	2	1×10^9	Run out
8	135	2	2.76×10^7	

TABLE 8

Fatigue Data for Task 8

Test Number	Specimen Number	Cycles to Failure	Remarks
1	103	4.44×10^6	
2	151	1.18×10^6	
3	147	2.31×10^6	
4	163	1.12×10^6	
5	100	2.62×10^8	

TABLE 9

Fatigue Data for Task 9

Test No.	Specimen Number	Condition	Cycles to Fail	Cycles of Exposure	Remarks
1	36	Unspecified-prior exp.	4.45×10^8		
2	116	"	1.90×10^7		
3	39	"	4.79×10^8		
4	80	"	4.86×10^6		
5	155	"	6.43×10^5		
6	59	New		2.40×10^7	0.4 of N_1 cycles
7	49	New		2.40×10^7	
8	77	New	6.07×10^6		Reduced sect. had rough marks or tool chatter from machining
9	60	New		2.40×10^7	
10	41	New	9.65×10^6		
11	140	New		2.40×10^7	
12	84	Prior Exp.		2.40×10^7	

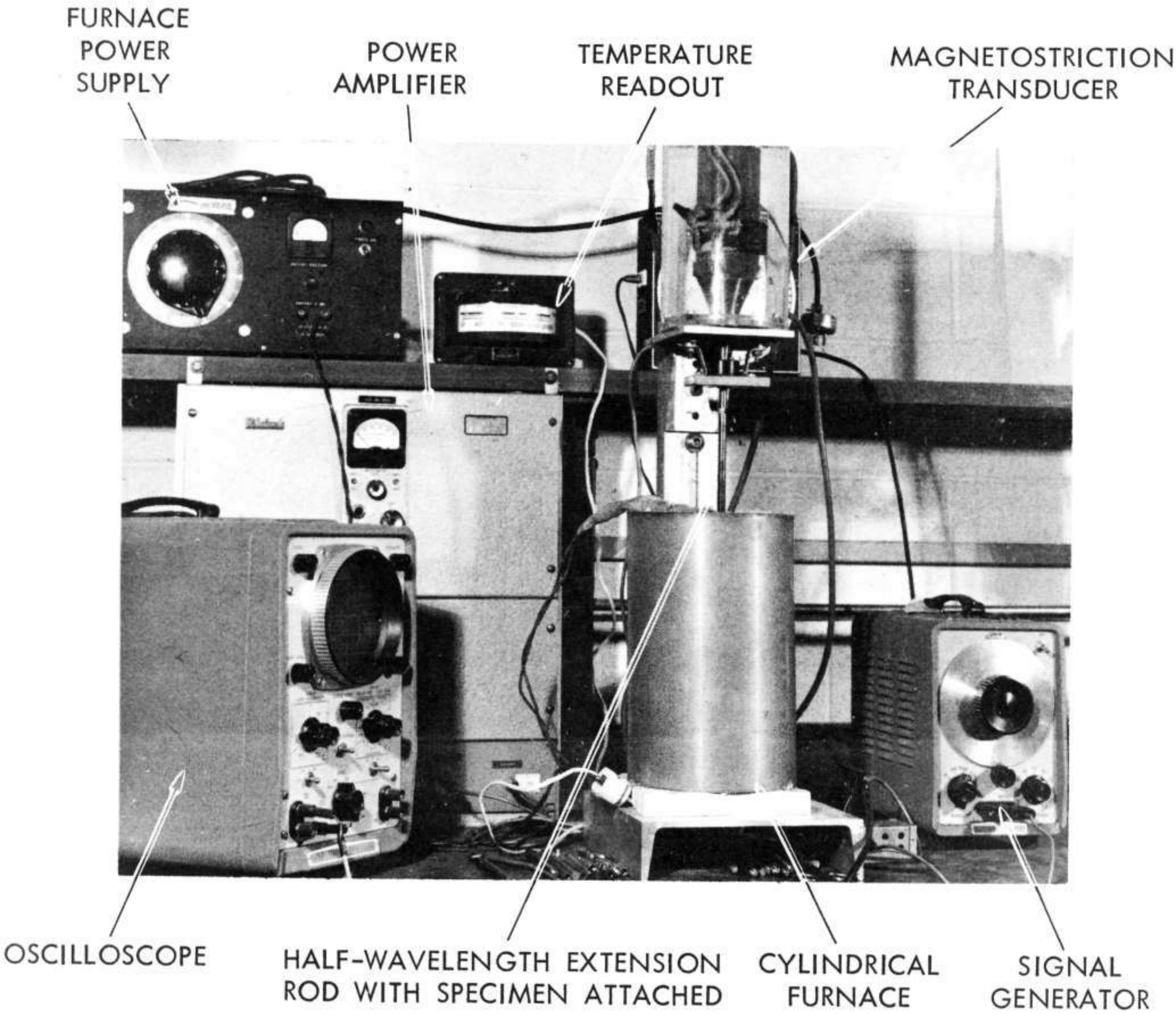


FIGURE 1 - HIGH FREQUENCY FATIGUE APPARATUS WITH HIGH TEMPERATURE MODIFICATION

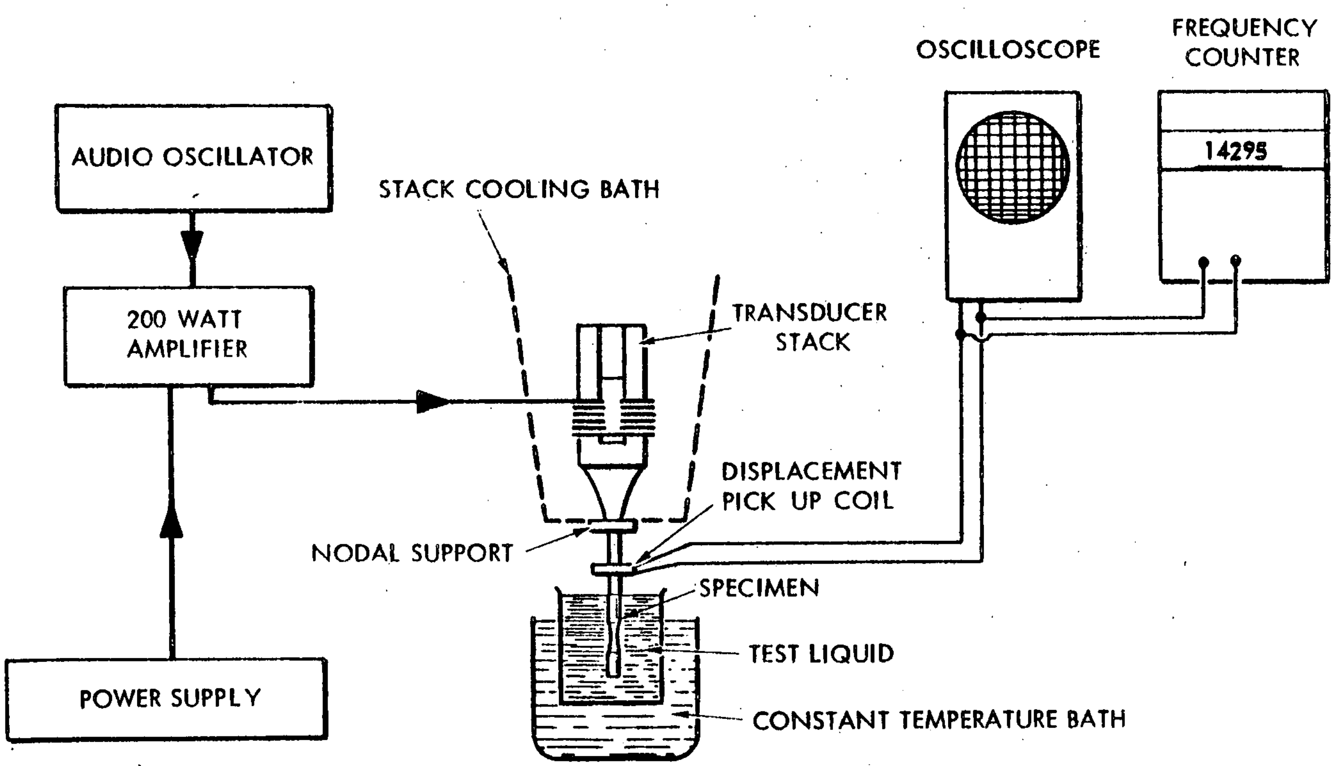


FIGURE 2 - BLOCK DIAGRAM OF THE MAGNETOSTRICTION APPARATUS USED FOR HIGH FREQUENCY FATIGUE TESTS

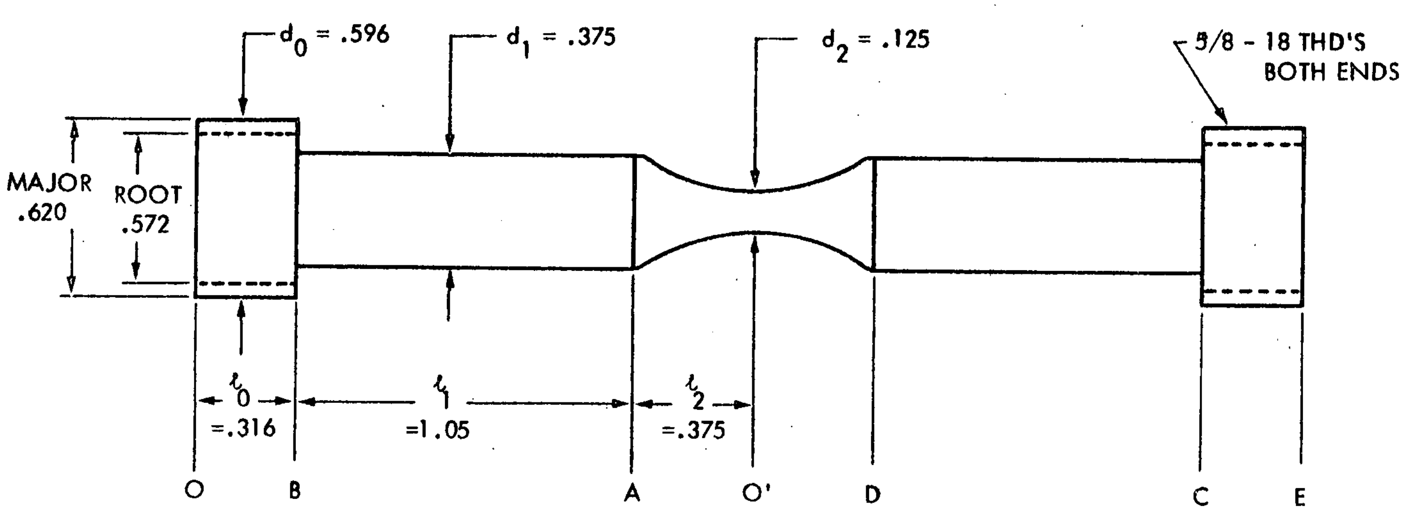
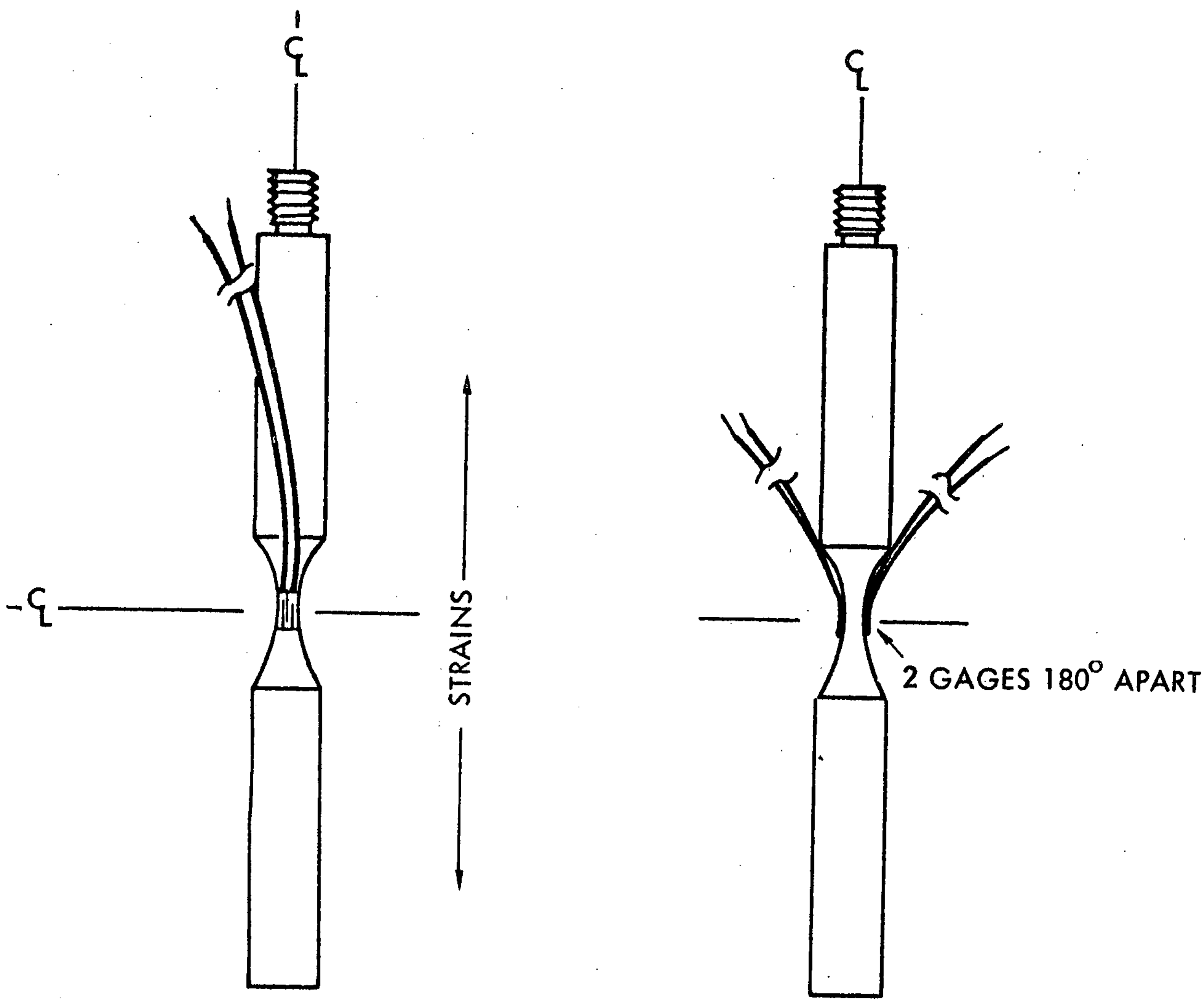


FIGURE 3 - SCHEMATIC OF HIGH-TEMPERATURE UDIMET 700 FATIGUE SPECIMEN.



NOTE: REDUCED SECTION HAS 0.625" RADIUS WITH 0.125" ROOT DIAMETER

FIGURE 4 - STRAIN GAGE ORIENTATION ON FATIGUE SPECIMEN; BLH TYPE HT-1212-2A

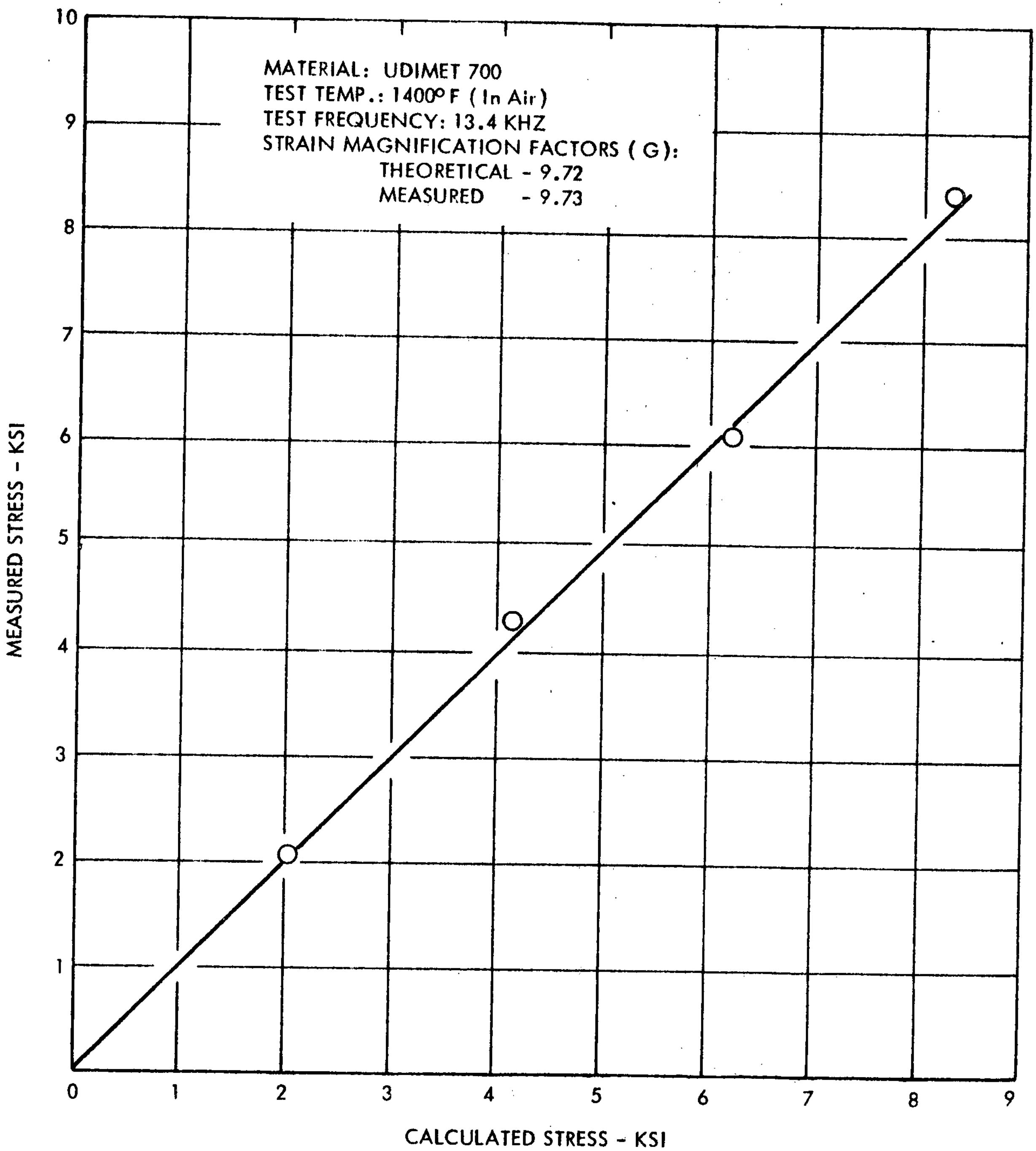


FIGURE 5 - COMPARISON OF THEORETICAL AND MEASURED STRESSES IN DUMB-BELL FATIGUE SPECIMENS

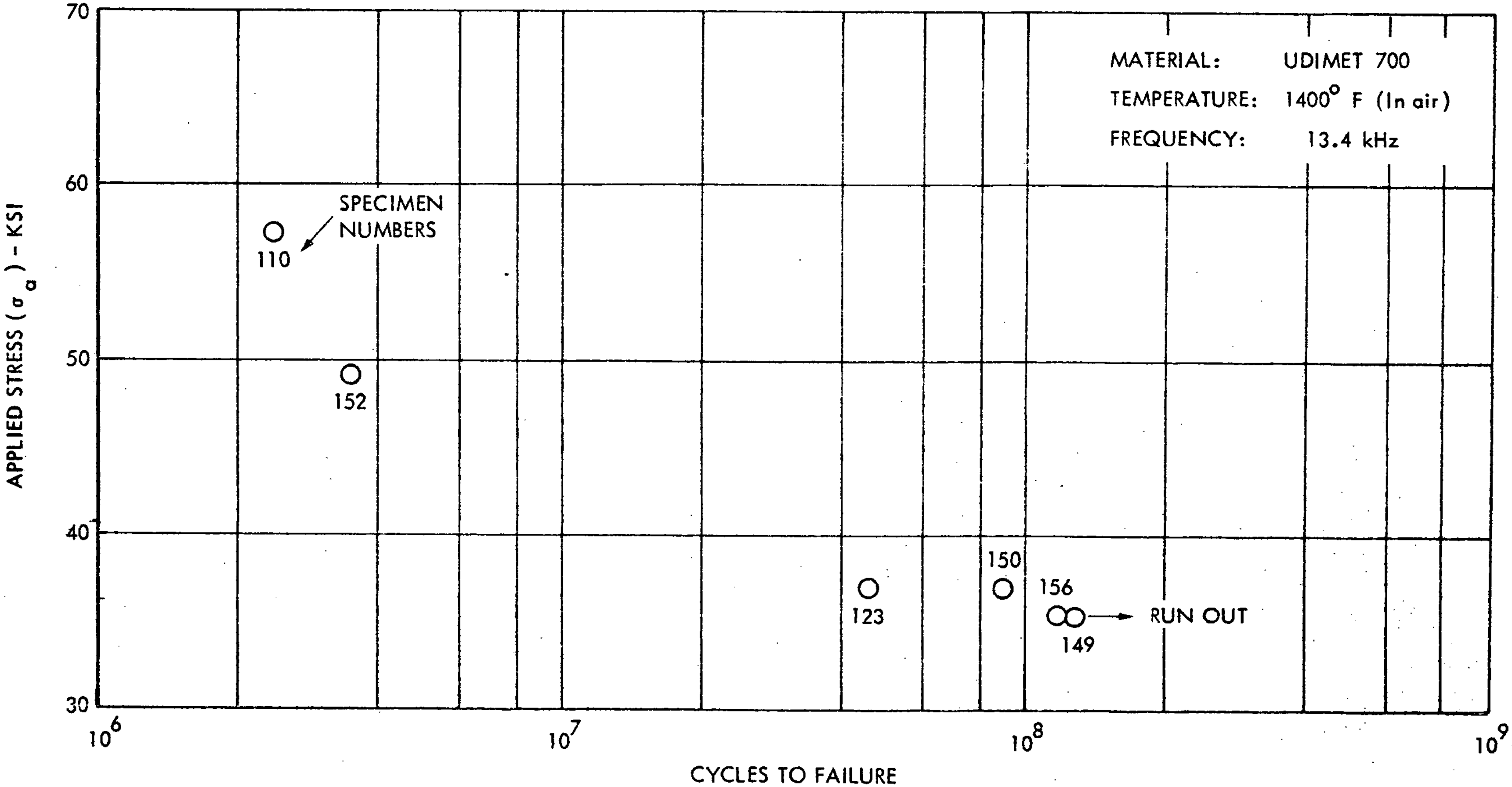


FIGURE 6 - PRELIMINARY DATA ESTABLISHING σ_a FOR A MEAN LIFE OF 10^8 CYCLES.

MATERIAL	: UDIMET 700	STRESS	: 37.0 ksi
SAMPLE SIZE	: 18	TEMPERATURE	: 1400° F
FREQUENCY OF TEST:	13.4 kHz	ENVIRONMENT :	STILL AIR

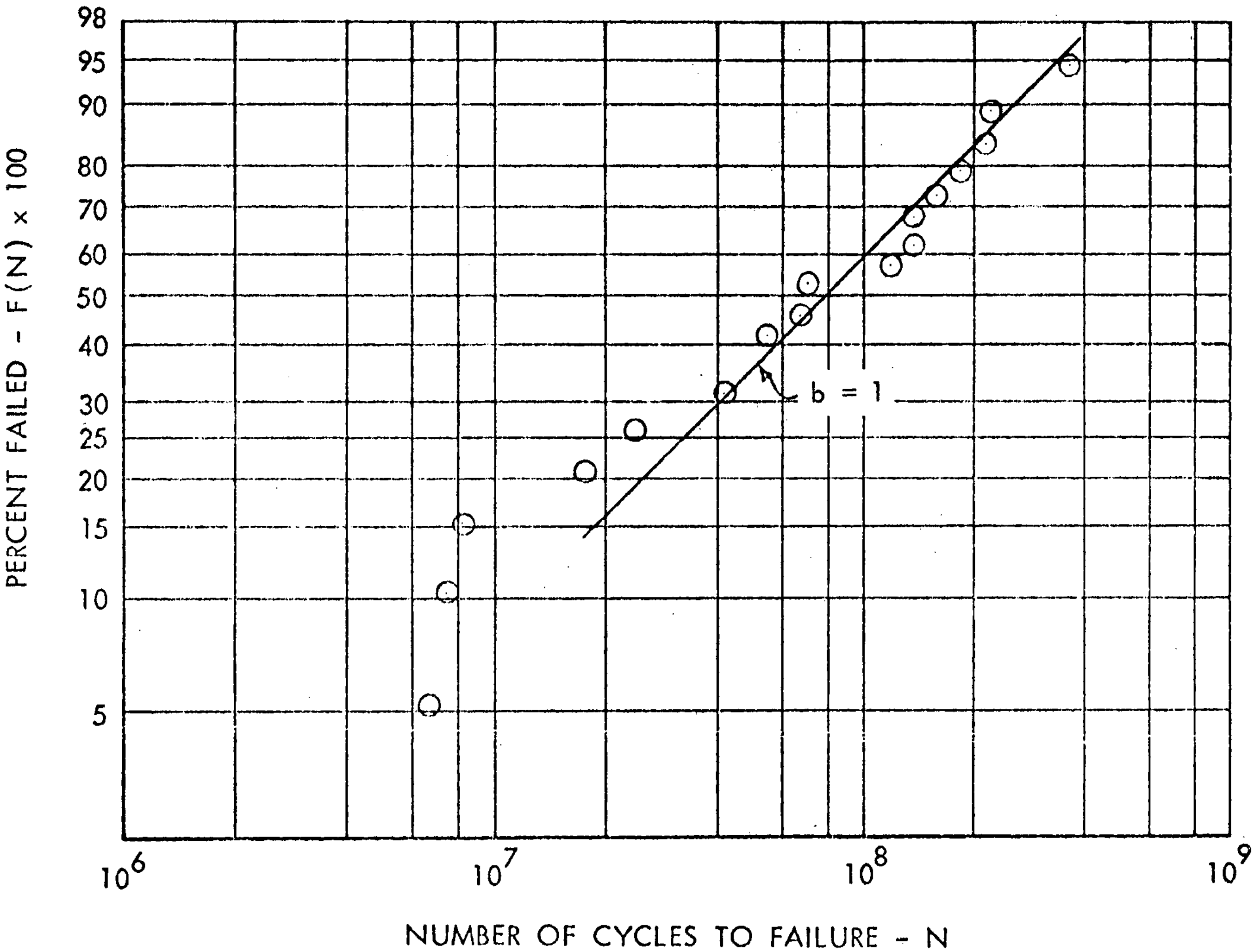


FIGURE 7 - WEIBULL DISTRIBUTION FOR HIGH FREQUENCY FATIGUE OF UDIMET 700 AT 1400° F.