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FLAW GROWTH OF 6Al-4V STA TITANIUM IN NITROGEN TETROXIDE WITH LOW NITRIC OXIDE CONTENT

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By

W. D. Bixler

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MANNED SPACECRAFT CENTER

Contract NAS 9-10364, Task 24

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May 1972

Contract NAS 9-10364, Task 24

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ABSTRACT

FLAW GROWTH OF 6Al-4V STA TITANIUM IN NITROGEN TETROXIDE WITH LOW NITRIC OXIDE CONTENTS

by

W. D. Bixler

The sustained load flaw growth characteristics of surface flawed 6Al-4V STA titanium specimens were determined when exposed to nitrogen tetroxide (N_2O_4) having nitric oxide (NO) concentrations of 0.06 to 0.30%. Test temperatures ranged from 70 to 150°F. It was observed that the threshold stress intensity for the titanium decreased abruptly below an NO concentration of 0.18% and also decreased as the temperature increased. The threshold stress intensity was determined to be $\geq$ 60% of the critical stress intensity for NO concentrations of 0.18 to 0.30% and temperatures of 90 and 120°F. Sustained load tests conducted in N_2O_4 vapor with a 0.30% NO concentration at 120°F indicated the threshold to be also $\geq$ 60% of critical.

KEY WORDS

6Al-4V STA Titanium
Nitrogen Tetroxide
Nitric Oxide
Sustained Load Test
Flaw Growth

FOREWORD

After the Lunar Module lands on the lunar surface, the temperature and pressure of the descent oxidizer tanks rises because of heat soakback and the concentration of nitric oxide decreases markedly immediately after long propulsive burns which deplete a large percentage of the total propellant. As the nitric oxide is removed from the oxidizer, the flaw growth characteristics of 6Al-4V STA titanium deteriorate rapidly as evidenced from previously generated data (Reference 3). No data was available at the low nitric oxide concentrations ($< 0.30\%$) but the data was required to enable a decision to be made for abort criteria after lunar landing if the dump valve system could not be operated. NASA/MSC requested the Boeing Company to conduct an experimental program to determine the effects of the low nitric oxide concentrations in nitrogen tetroxide on the sustained load characteristics of 6Al-4V STA titanium. A two week program was conducted under Task 24 of NAS 9-10364 and the results are reported herein. The work was administered under the direction of Mr. A. Fisher at NASA/MSC.

Boeing personnel who participated in this investigation include J. N. Masters, Program Leader, W. D. Bixler, Technical Leader and D. D. Miller. Structural testing of the specimens was conducted by H. M. Olden. The information contained in this report is released as Boeing Document D180-14853-1.

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ABBREVIATIONS AND SYMBOLS

a	=	surface flaw depth
$a/2c$	=	flaw shape
da/dt	=	sustained load flaw growth rate
K_{IE}	=	critical surface flaw stress intensity
K_{Ii}	=	initial stress intensity
K_{TH}	=	threshold stress intensity
LG	=	local flaw growth
M_K	=	deep flaw magnification factor
NO	=	nitric oxide
N_2O_4	=	nitrogen tetroxide
Q	=	flaw shape parameter
t	=	specimen thickness
$2c$	=	surface flaw length
Δa	=	amount of flaw depth growth
$\Delta 2c$	=	amount of flaw length growth
σ	=	gross stress

1.0 INTRODUCTION

The objective of this investigation was to determine the threshold stress intensities for 6Al-4V STA titanium exposed to nitrogen tetroxide (N_2O_4) with various concentrations of nitric oxide (NO) and at various temperatures. Precracked surface flawed specimens were sustained loaded in the specific test environments and temperatures indicated below:

NITRIC OXIDE CONTENT %	TEMPERATURE (°F)			
	70	90	120	150
0.30			✓ [1]	✓
0.18		✓	✓	
0.09	✓		✓	✓
0.06		✓	✓	

[1] Sustained load tests were conducted in N_2O_4 vapor as well as in the liquid.

2.0 MATERIALS

Specimens made of 6Al-4V STA titanium forging material were supplied to Boeing by NASA/MSC for this program. The specimens were fabricated from an actual Apollo Service Propulsion System propellant tank that was about 0.056 inches thick. The specimen configuration is shown in Figure 1. A yield strength of 150 ksi was assumed for the material over the temperature range of 70°F to 150°F.

Nitrogen tetroxide (manufactured by Hercules Inc., Hercules, California) containing various amounts of nitric oxide was used as the test environment and was also supplied by NASA/MSC. Chemical analysis of the N_2O_4 cylinders supplied are presented in Table 1.

3.0 TEST SETUP AND PROCEDURES

The specimens supplied by NASA/MSC contained precracked surface flaws. The flaws were introduced by electric discharge machining a rectangular starter notch in the specimen and then subjecting the notch to bending stresses. The crack length on the specimen surface was monitored during precracking until the desired length and corresponding depth was attained. One specimen was tested which was precracked in tension after a semi-circular starter notch was introduced. This specimen was fatigued at 30 ksi for 11,000 cycles. All precracking was done in air at room temperature.

A typical sustained load test setup for the specimens tested in the liquid N_2O_4 is shown in Figure 2. The dead load creep machines used have a 10 kip capacity. The entire plumbing system was thoroughly cleaned prior to assembling and then evacuated and purged with gaseous helium. The N_2O_4 was contained in 2 pressurized tanks connected with flex lines to each other and a small cup (see Figure 3) clamped to the test specimen. Periodically, one of the tanks was raised or lowered so that the fluid would flow through the specimen cup and thereby supplying fresh fluid to the crack area. A schematic of the fluid and pressurization system is shown in Figure 4. Temperature control was accomplished by surrounding the test specimen with an environmental box containing heating coils and a fan.

The sustained load test setup for the specimens tested in vapor of N_2O_4 is shown in Figure 5. The test cavity (see Figure 6) was filled with N_2O_4 to within about 0.5 inch of the surface flaw in the specimen. The test cavity was pressurized with gaseous helium to 250 psig. A schematic of the fluid and pressurization system is shown in Figure 7. Temperature control was maintained in the same manner as the liquid sustained load tests. All tests involving N_2O_4 were performed at Boeing's remote Tulalip Test Site.

The approach used to define the threshold stress intensity was to load the first specimens to target stress intensities less than critical. These specimens were held at constant load for 22 hours. After completing the test the specimens were low tension stress cycled in air to mark the flaw front and then pulled to failure. Evidence of sustained load flaw growth was then observed by a separation between the initial fatigue crack extension and that of the final marking. With evidence of growth, subsequent specimens were loaded at lower initial stress intensity values until no growth took place. Some long term tests of 72 hours were also conducted to verify the thresholds established.

Because of the difficulty encountered in distinguishing the entire precrack flaw front in a substantial number of the sustain loaded specimens (fractographic as well as low magnification visual methods were used), a conservative approach was used in establishing the no growth threshold. If any doubt existed whether or not flaw growth took place, it was assumed that growth had taken place.

4.0 DATA ANALYSIS AND EVALUATION

The stress intensity values for the data obtained were calculated using the expression:

$$K_I = 1.1\sigma \left(\frac{\pi a}{Q}\right)^{1/2} M_K$$

where

K_I	=	applied stress intensity
σ	=	gross stress
a	=	flaw depth
Q	=	flaw shape parameter
M_K	=	deep flaw magnification factor

The flaw shape parameter and deep flaw magnification factor are presented in Figures 8 and 9, respectively. The deep flaw magnification factor being used was first defined in Reference 1 for 2219-T87 aluminum but has since been determined to be adequate for 6Al-4V STA titanium (Reference 2).

Four static fracture tests were conducted to determine the critical surface flaw stress intensity (K_{IE}) of the 6Al-4V STA titanium being used in this program. K_{IE} for surface flawed specimen tests is analogous to plane strain fracture toughness (K_{Ic}) tests per ASTM E399-70T. One static fracture test was conducted in air at 120°F while the other 3 were at 70°F. The detailed specimen results are presented in Table 2.

The results of the sustained load tests are presented in Figures 10, 11 and 12 and Tables 3, 4 and 5 for temperatures of 70, 90, 120 and 150°F. A summary of the sustained load stress intensity threshold ratios (K_{TH}/K_{IE})[1] established are presented below:

[1] Based upon no growth specimen results.

NITRIC OXIDE CONTENT %	TEMPERATURE (°F)			
	70	90	120	150
0.30			≥ 0.60 in Liquid and Vapor	< 0.63
0.18		≥ 0.61	≥ 0.61	
0.09	< 0.53		< 0.54	< 0.54
0.06		< 0.46	≪ 0.41	

The results do indicate that a significant reduction in threshold stress intensity occurs at low NO concentrations; less than 0.18%. This is dramatically illustrated when the 6Al-4V STA titanium was exposed to N_2O_4 with a 0.06% NO concentration at 120°F as shown in Figure 11. The threshold indicated here was much less than 0.41 K_{IE} with significant amounts of flaw extension taking place at this value. Sustained load flaw growth rates were calculated for this environment/temperature condition and are presented in Figure 13.

The results also indicate that the threshold stress intensity decreases with increasing temperature. The most dramatic evidence of this is presented in Figure 12 with the 0.09% NO, 150°F tests. Two specimens failed in about 15 hours under sustained load at a K_{Ii}/K_{IE} ratio as low as 0.69. No other sustained load failures were recorded during the testing at any other temperatures.

In the area of concern with the Apollo 16 and 17 missions; namely, 90 to 120°F and an NO concentration of 0.18%, the results indicated that the threshold stress intensity is definitely greater than 0.61 K_{IE} (see Figures 10 and 11). The vapor and liquid tests conducted at 120°F in an NO concentration of 0.30% indicated the thresholds are also definitely greater than 0.60 K_{IE}.

It should be pointed out that the lower bound threshold values established are indeed conservative and easily could be higher than reported. As indicated in

Figures 10 and 11 for tests conducted in N_2O_4 with a 0.18% and 0.30% NO concentration, small amounts of growth (Δa = 0.001 – 0.002 inches) were reported in the stress intensity range from 0.60 to 0.81 K_{IE}. Two specimens were tested to determine if flaw growth occurs (or is indicated) when just loaded and immediately unloaded, marked and failed. The results of these two tests are presented in Table 2. The specimens were loaded and unloaded in air at 120°F to stress intensities ranging from 63 to 72% of critical. The fracture faces indicated flaw growth of about 0.001 to 0.002 inches in the depth direction.

Previous sustained load tests of 6Al-4V STA titanium specimens in N_2O_4 have indicated no growth below 72% of critical (Reference 3). These specimens were also 0.056 inches thick with about half depth flaws and were also from Apollo tanks of about the same toughness and yield strength. The only obvious difference in the test specimens was that the present program specimens were precracked in bending rather than tension. A previous investigation (Reference 4) compared the effects of tension versus bending precracking in Inconel 718 and it was concluded in that report the bending precracked specimen had growth-on-loading while the tension precracked specimens did not for the same applied stress intensity. This does not appear to be the case with the titanium tested in this program because a single precracked in tension specimen was sustained loaded to 0.66 K_{IE} (specimen TBC-1, Table 4) and indicated the same amount of growth (Δa = 0.001 – 0.002 inches) as the precracked in bending load/unload or sustain loaded specimens loaded to about the same stress intensity level. No explanation is offered for the apparent differences observed between Reference 3 and the results presented herein. Although the thresholds could be elevated by ignoring the 0.001 – 0.002 inches of growth observed in the sustain loaded specimens (assuming that amount is due to growth-on-loading), it was decided to be conservative and present the no growth thresholds in this report.

A summary of all the threshold results obtained in this investigation, along with the results of Reference 3, is presented in Figure 14.

5.0 OBSERVATIONS

The following observations were made from the sustained load testing of 6Al-4V STA titanium in N_2O_4:

1. K_{TH} decreases sharply with NO concentrations less than 0.18% at temperatures of 70 to 150°F. A $K_{TH}/K_{IE} \ll 0.41$ was indicated in 0.06% NO at 120°F.

2. K_{TH} decreases with increasing temperature at constant NO concentrations. Sustain load failures were recorded in 15 hours at K_{Ii}/K_{IE} as low as 0.69 in a 0.09% NO environment at 150°F.

3. $K_{TH} \geq 0.60\ K_{IE}$ in 0.18% NO at 90°F or 120°F and 0.30% NO at 120°F.

4. $K_{TH} \geq 0.60\ K_{IE}$ in vapor of 0.30% NO at 120°F.

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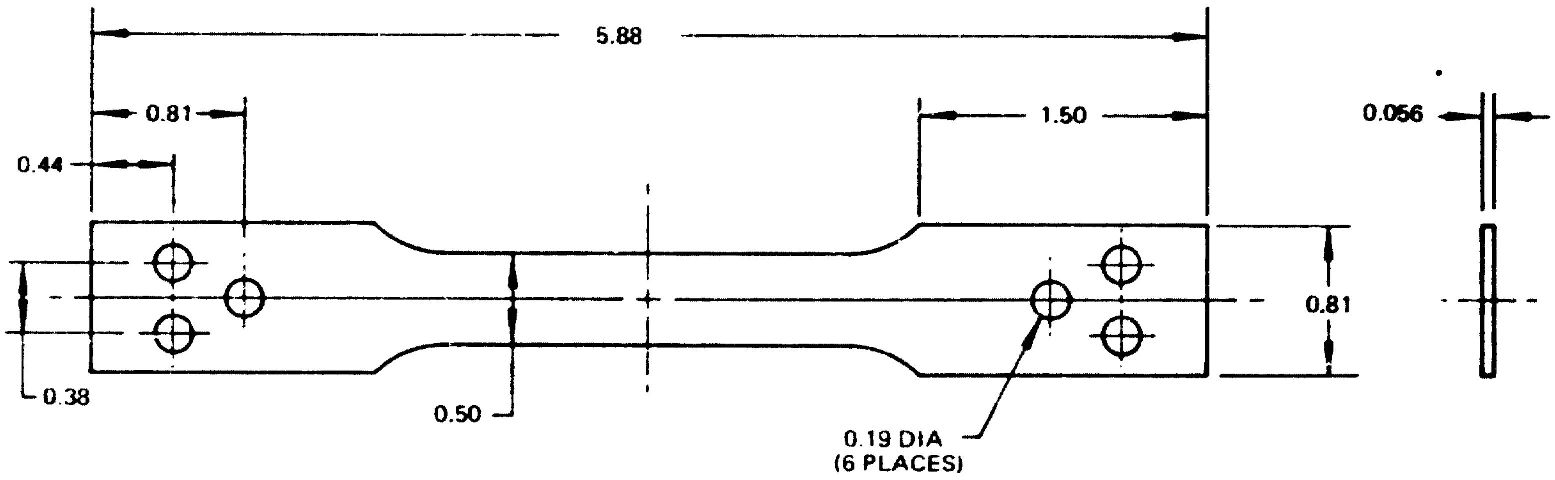
2. Finger, R.W., "Fracture Characteristics of Structural Aerospace Alloys Containing Deep Surface Flaws", to be published, March 1972.

3. Masters, J.N., "Cyclic and Sustained Load Flaw Growth Characteristics of 6Al-4V Titanium", NASA CR-92231, July 1968.

4. Tiffany, C.F., Masters, J.N., and Bixler, W.D., "Investigation of Crack Growth Threshold of Inconel 718 Exposed to High Pressure Oxygen", NASA CR-108485, August 1970.



gure 1: Specimen Configuration

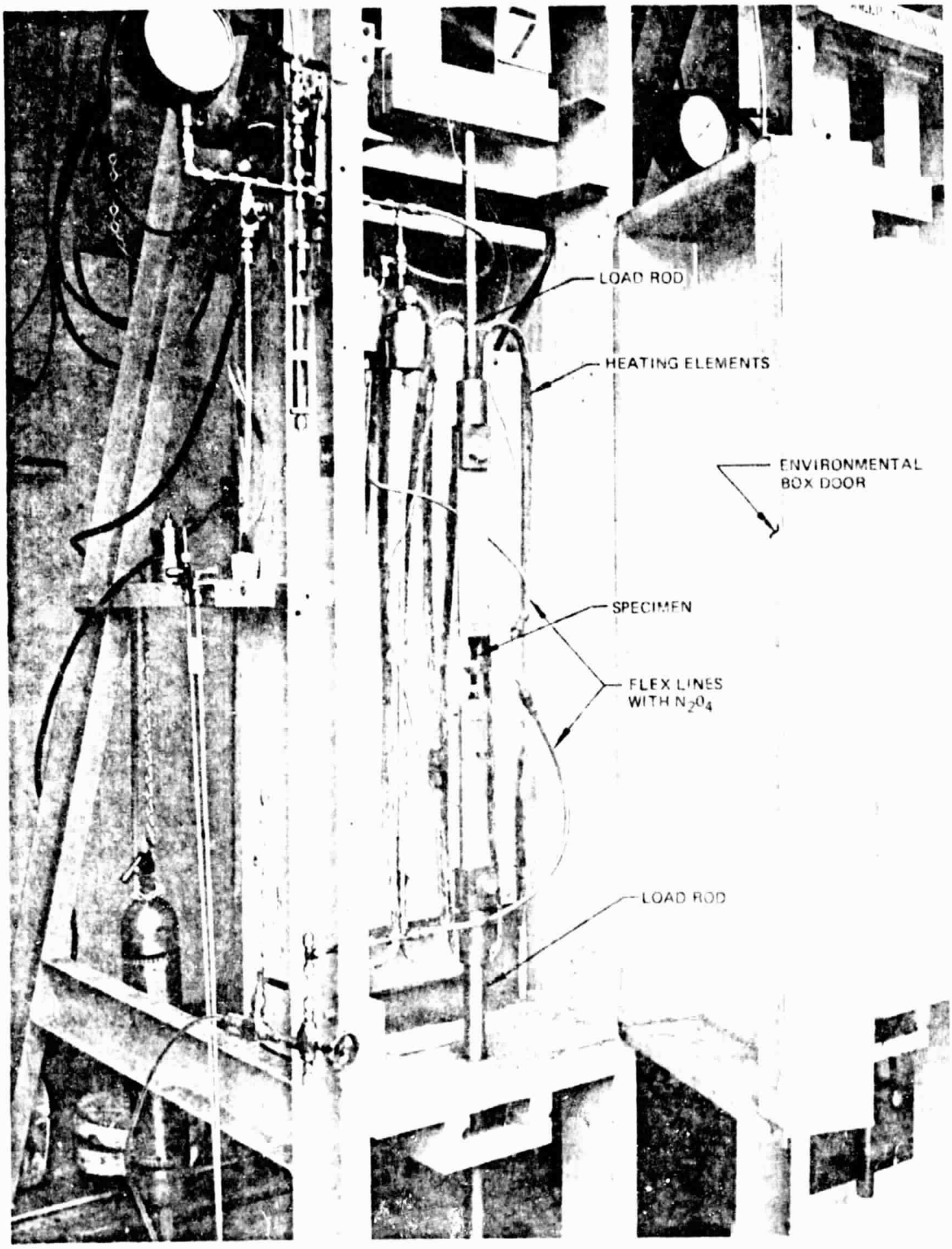


Figure 2: Sustained Load Setup for Liquid Tests

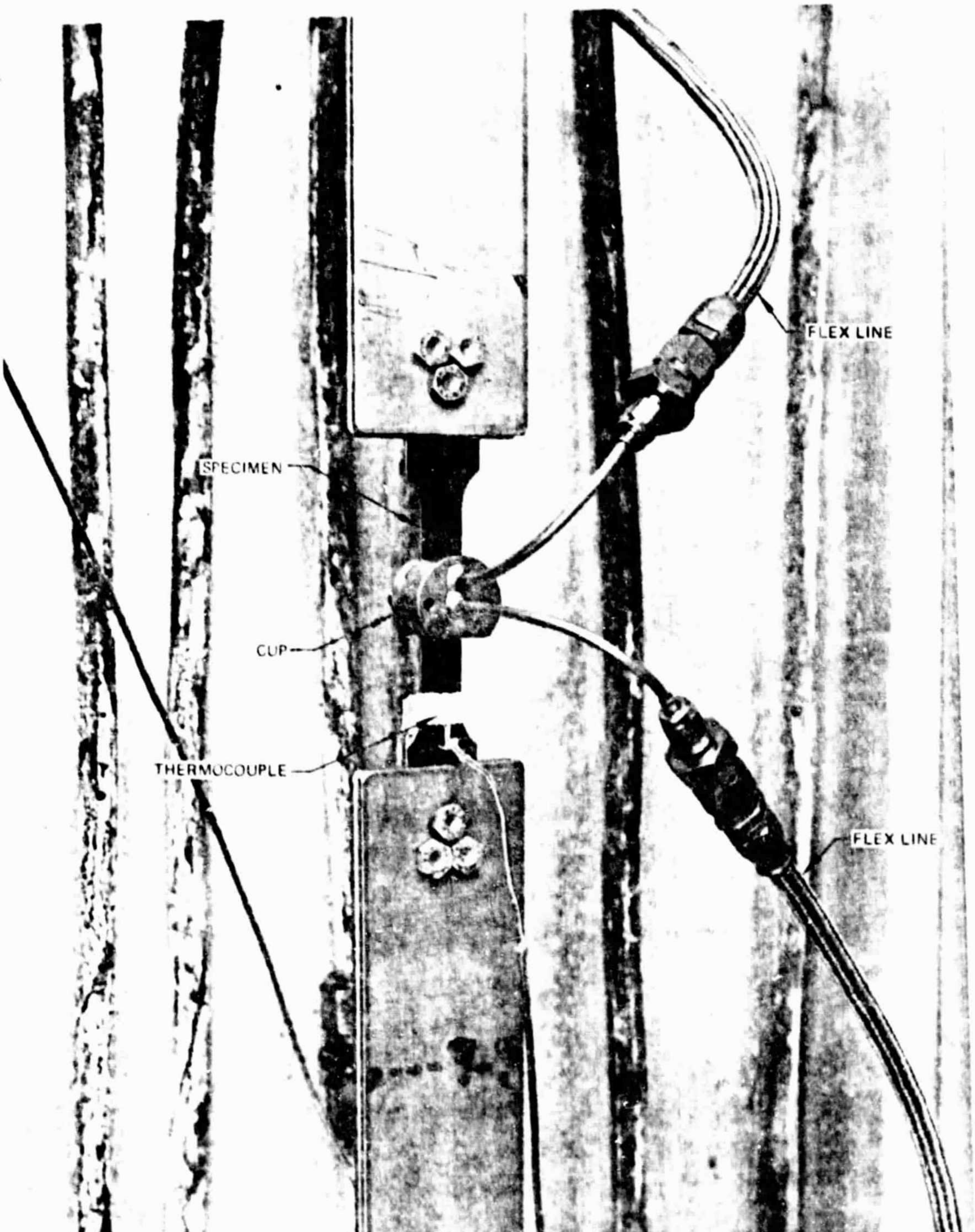
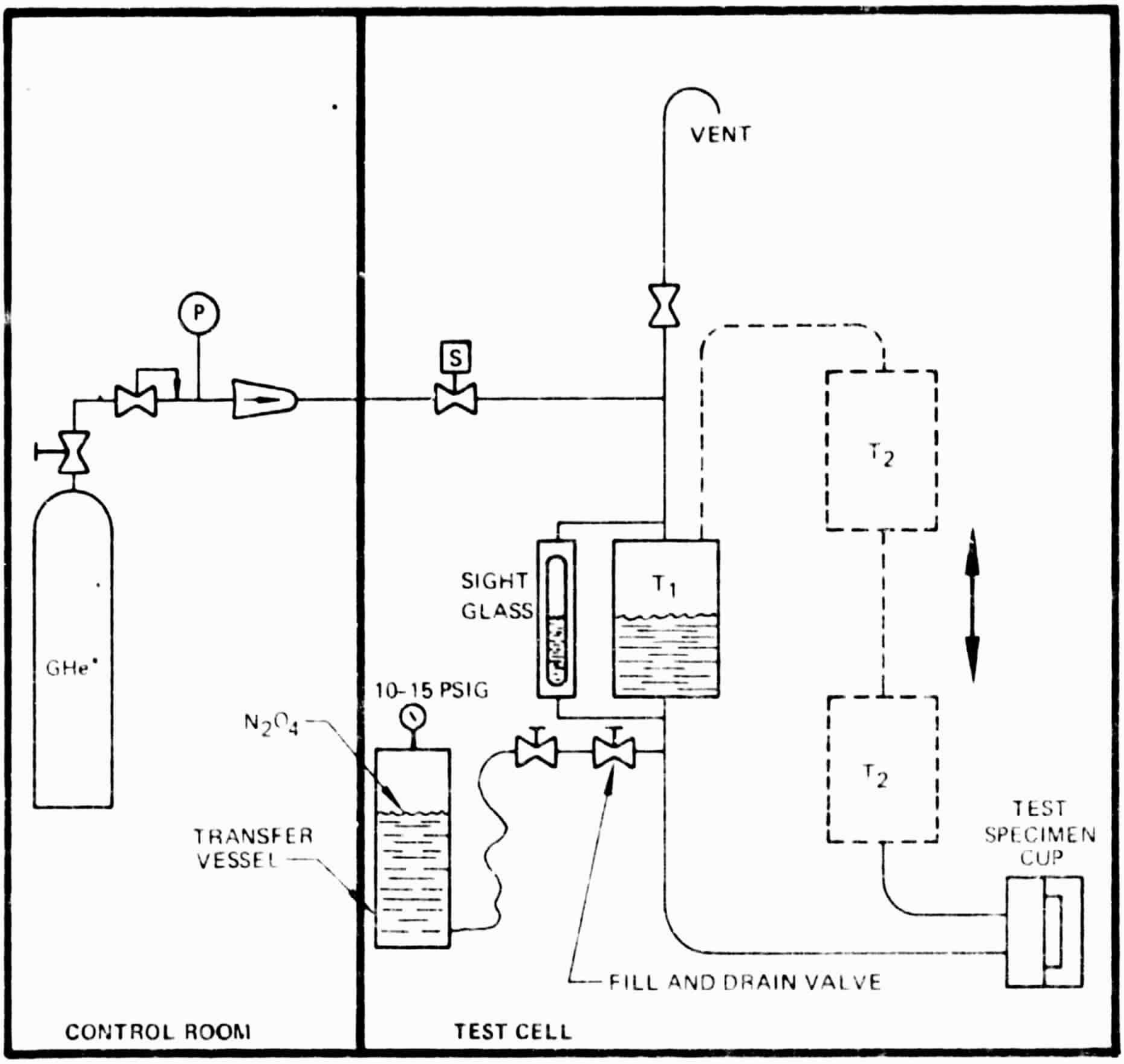


Figure 3: Pressure Cups Mounted on Specimen



T_1 = CIRCULATING TANK - STATIONARY

T_2 = CIRCULATING TANK - CYCLING

P = 150 PSIG

* He SYSTEM ALSO USED FOR PURGING SYSTEM

Figure 4: Fluid and Pressurization System Schematic for Liquid Tests

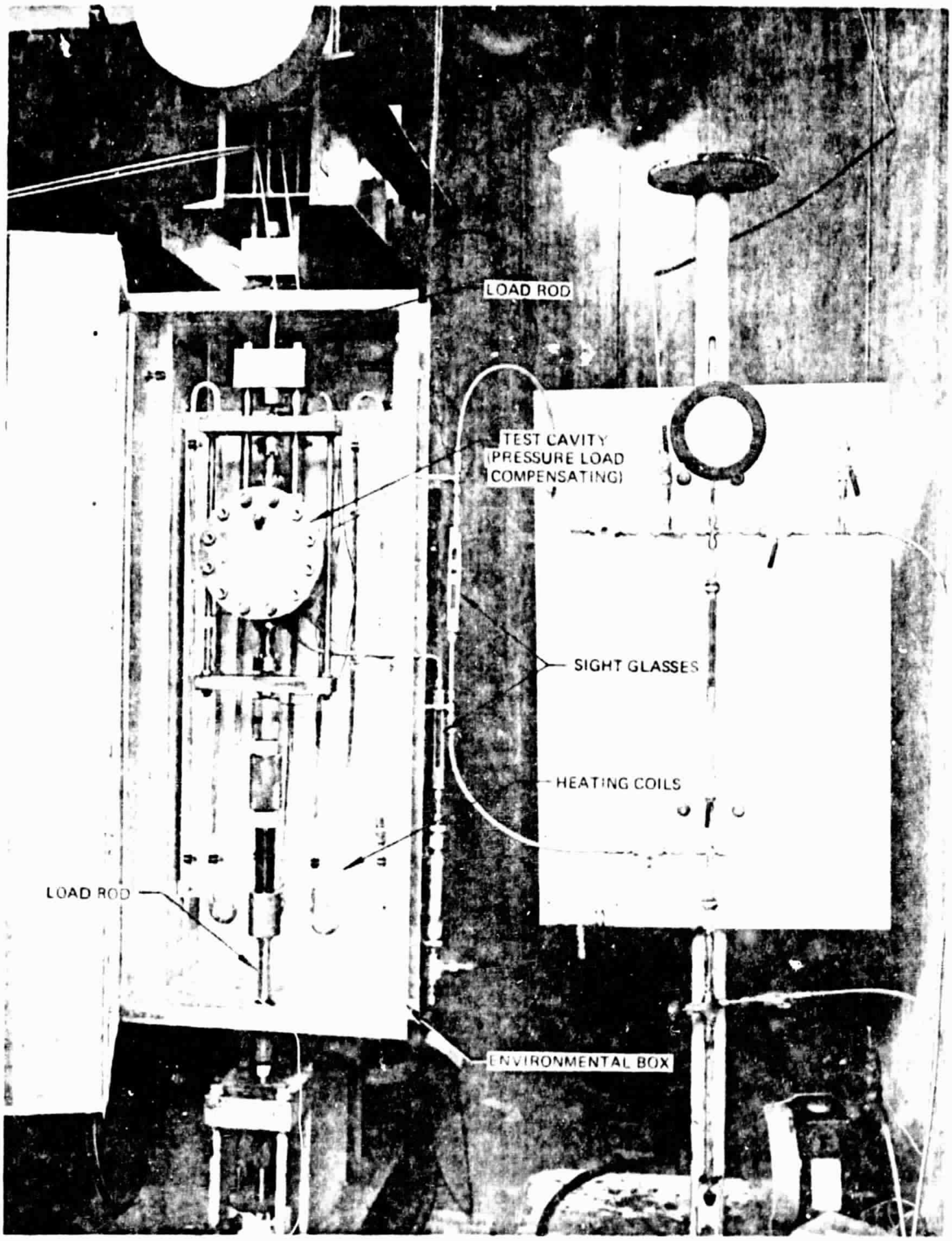


Figure 5: Sustained Load Setup for Vapor Tests

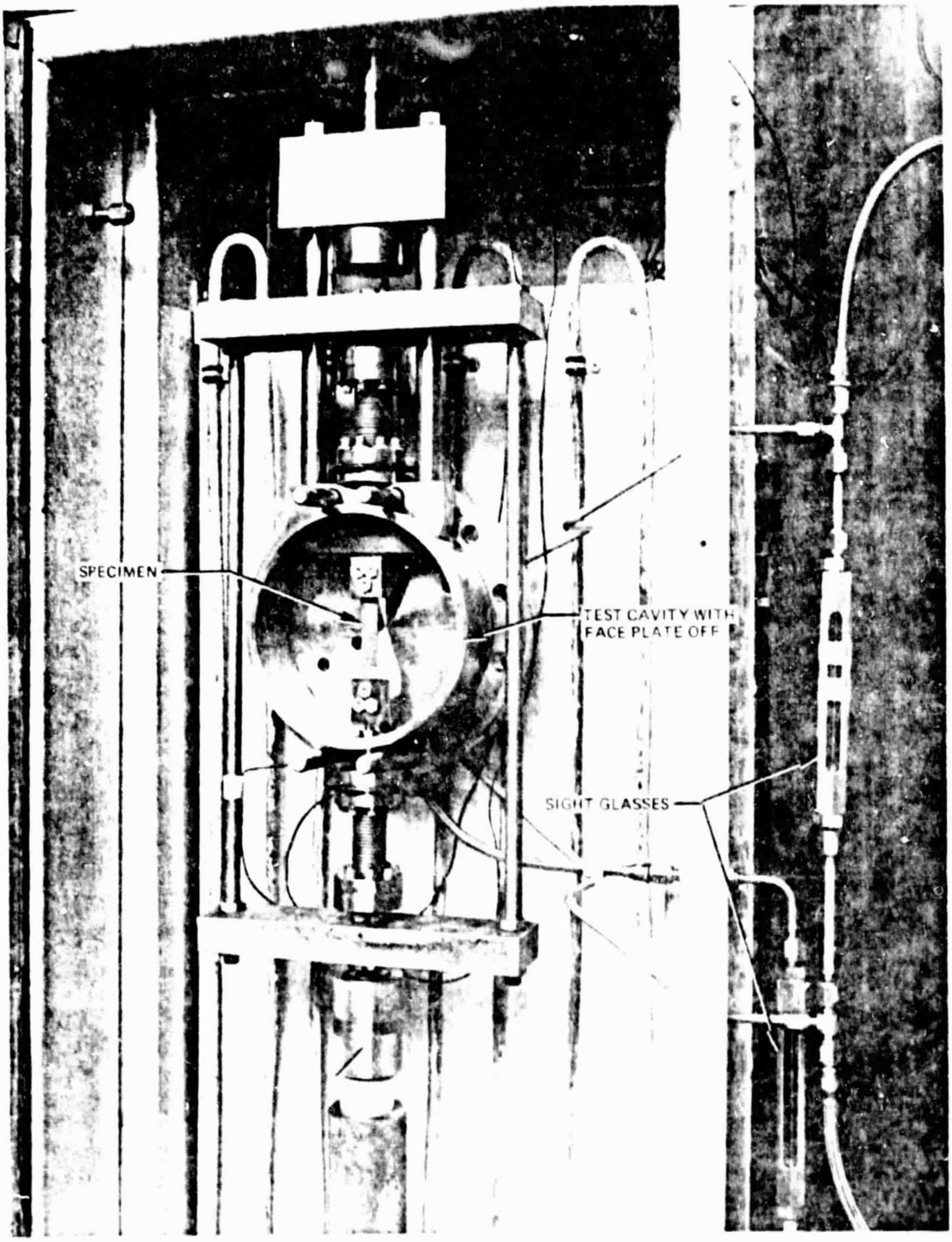
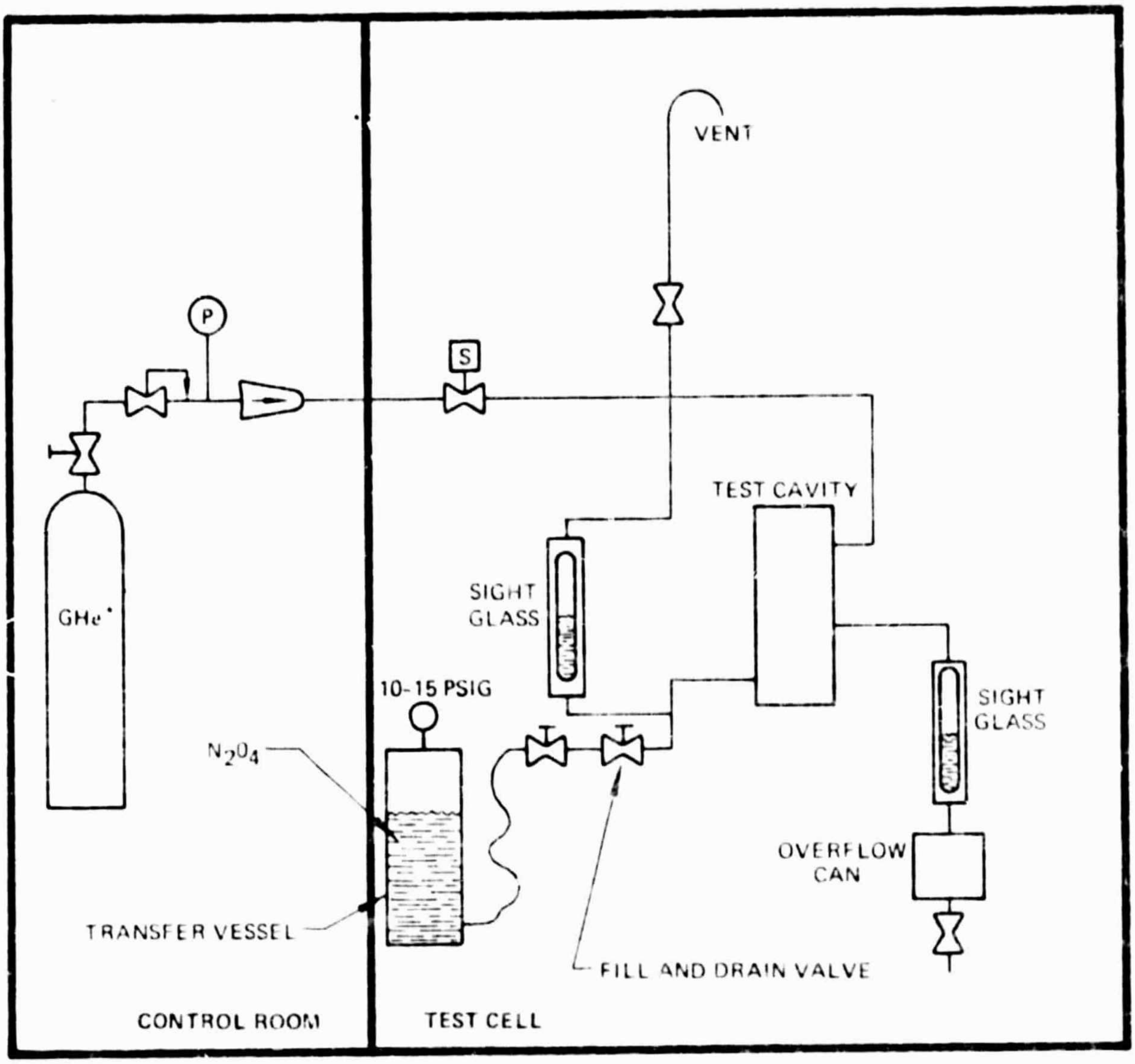


Figure 6. Test Cavity



P = 250 PSIG

* He SYSTEM ALSO USED FOR PURGING SYSTEM

Figure 7: Fluid and Pressurization System Schematic for Vapor Tests

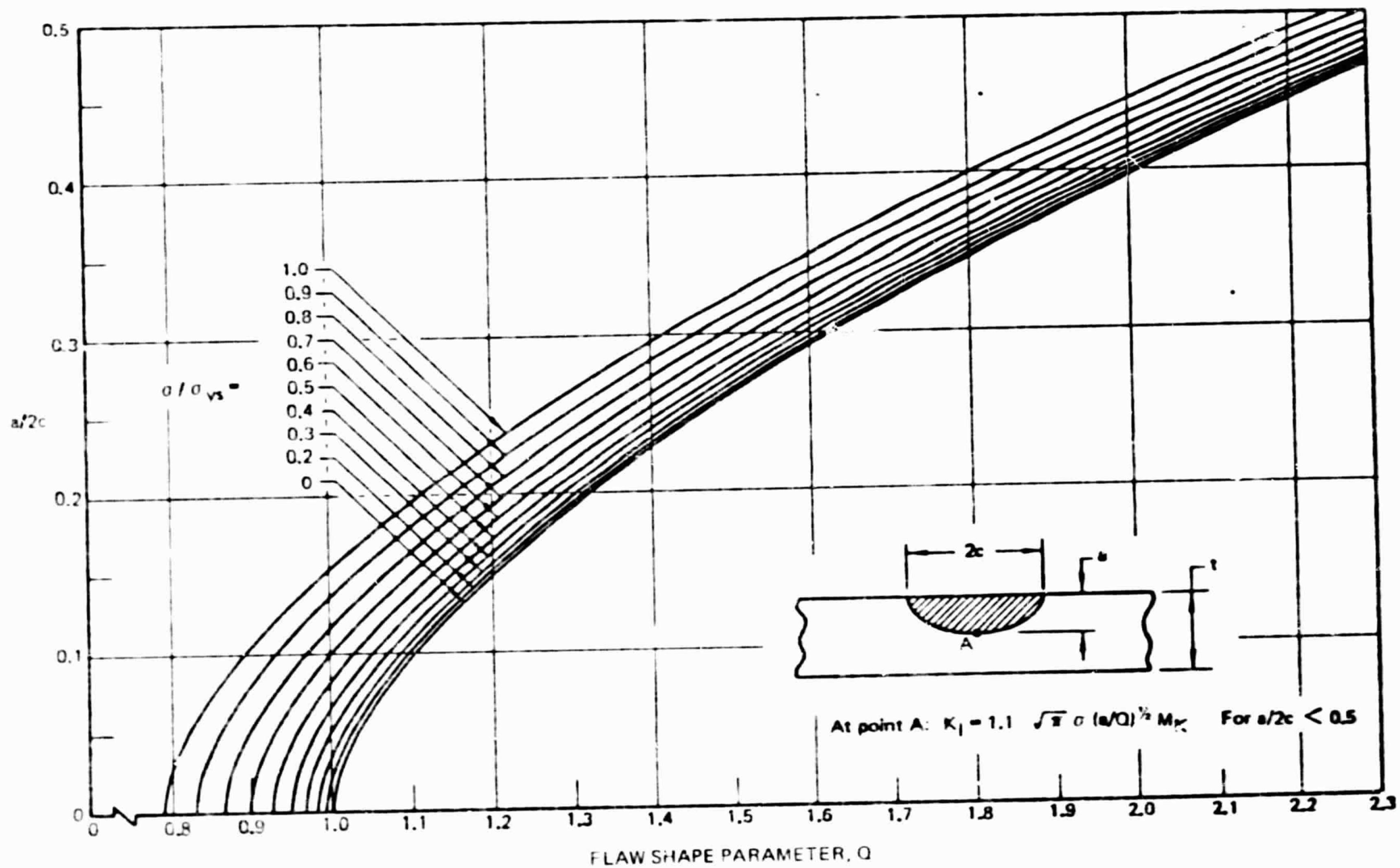


Figure 8: Shape Parameter Curves for Surface and Internal Flaws

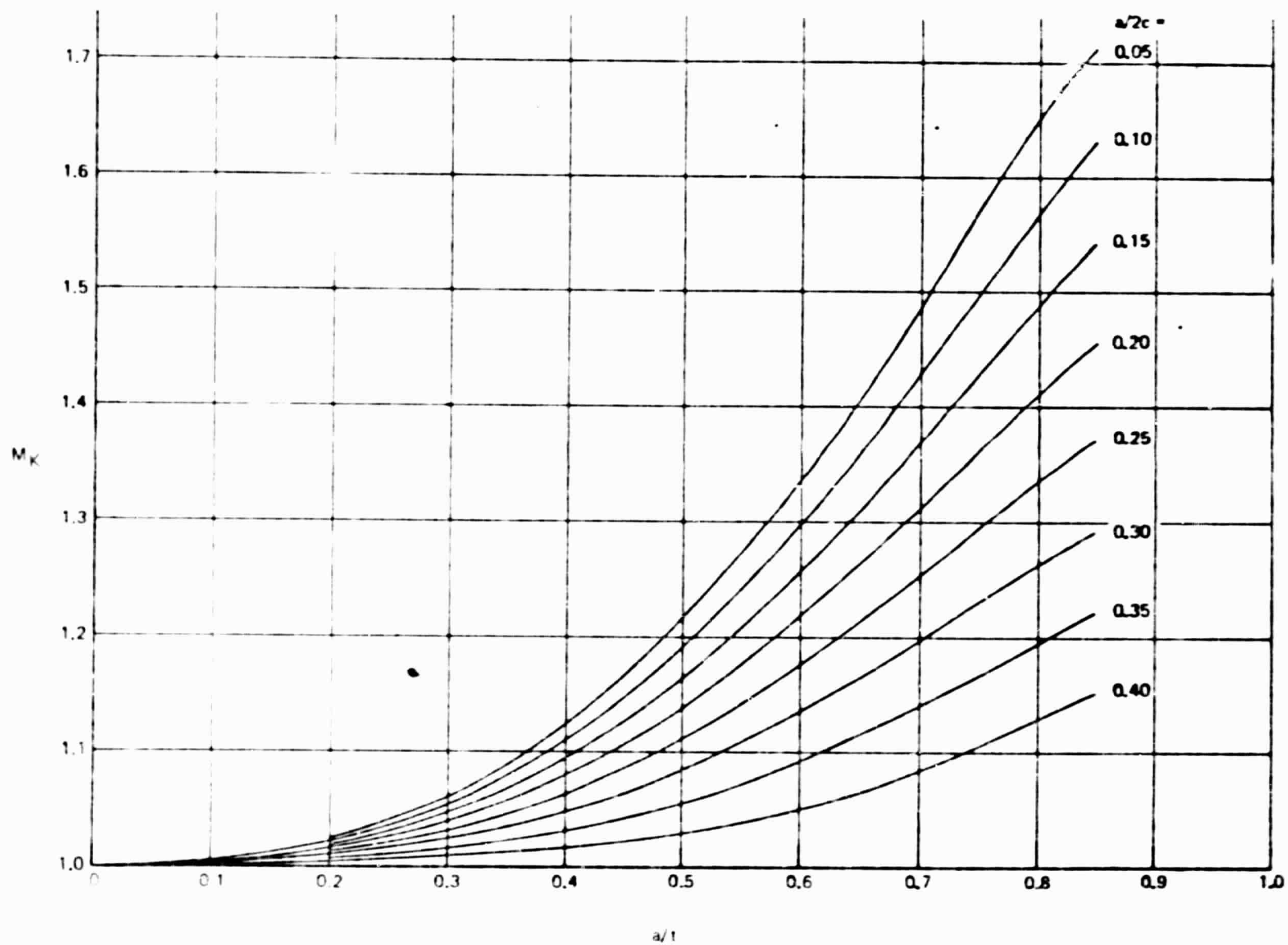


Figure 9. Deep Flaw Magnification Curves (Reference 1)

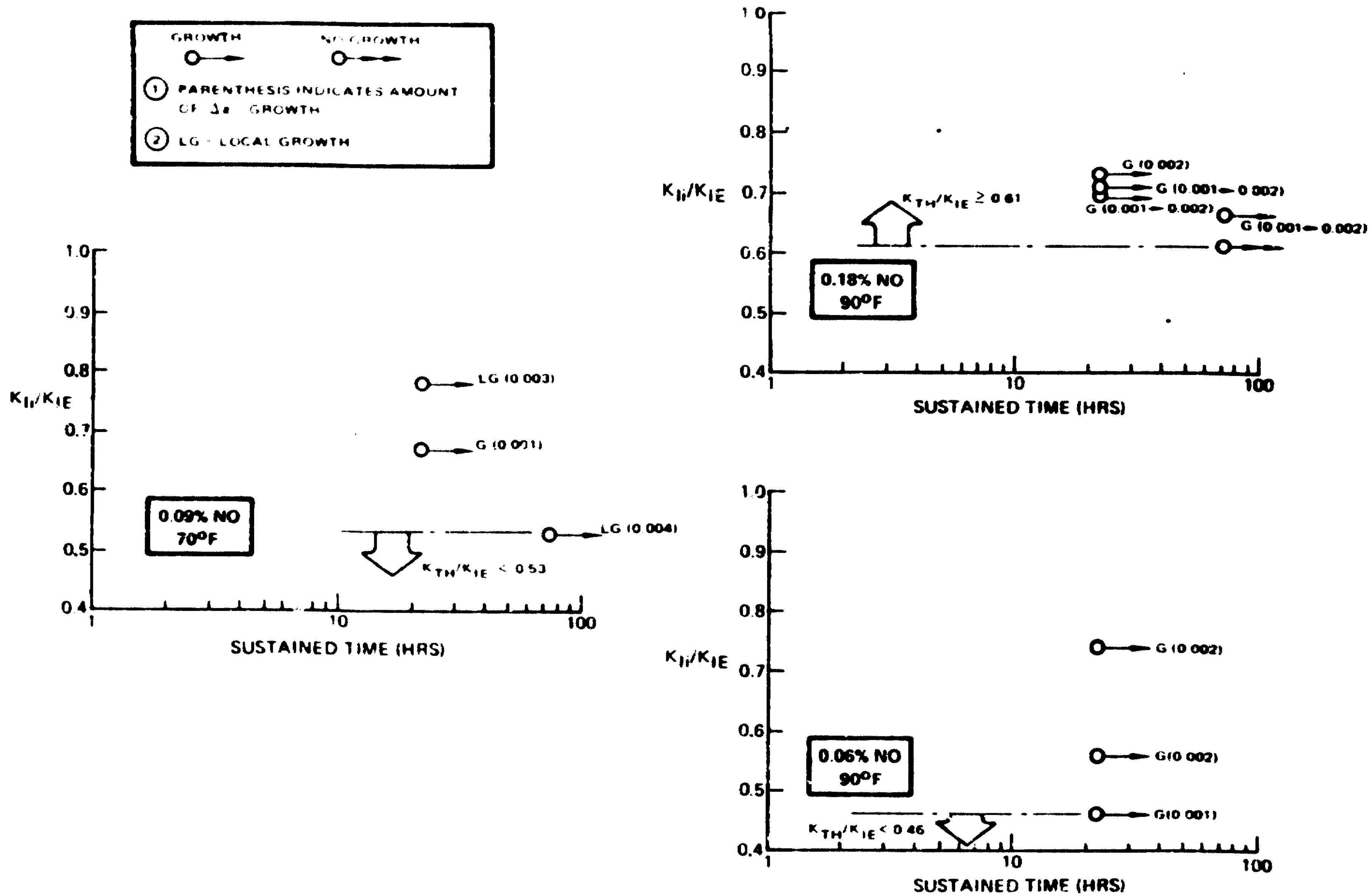


Figure 10. Sustained Load Flaw Growth of 6Al-4V STA Titanium in N_2O_4 At 70°F and 90°F

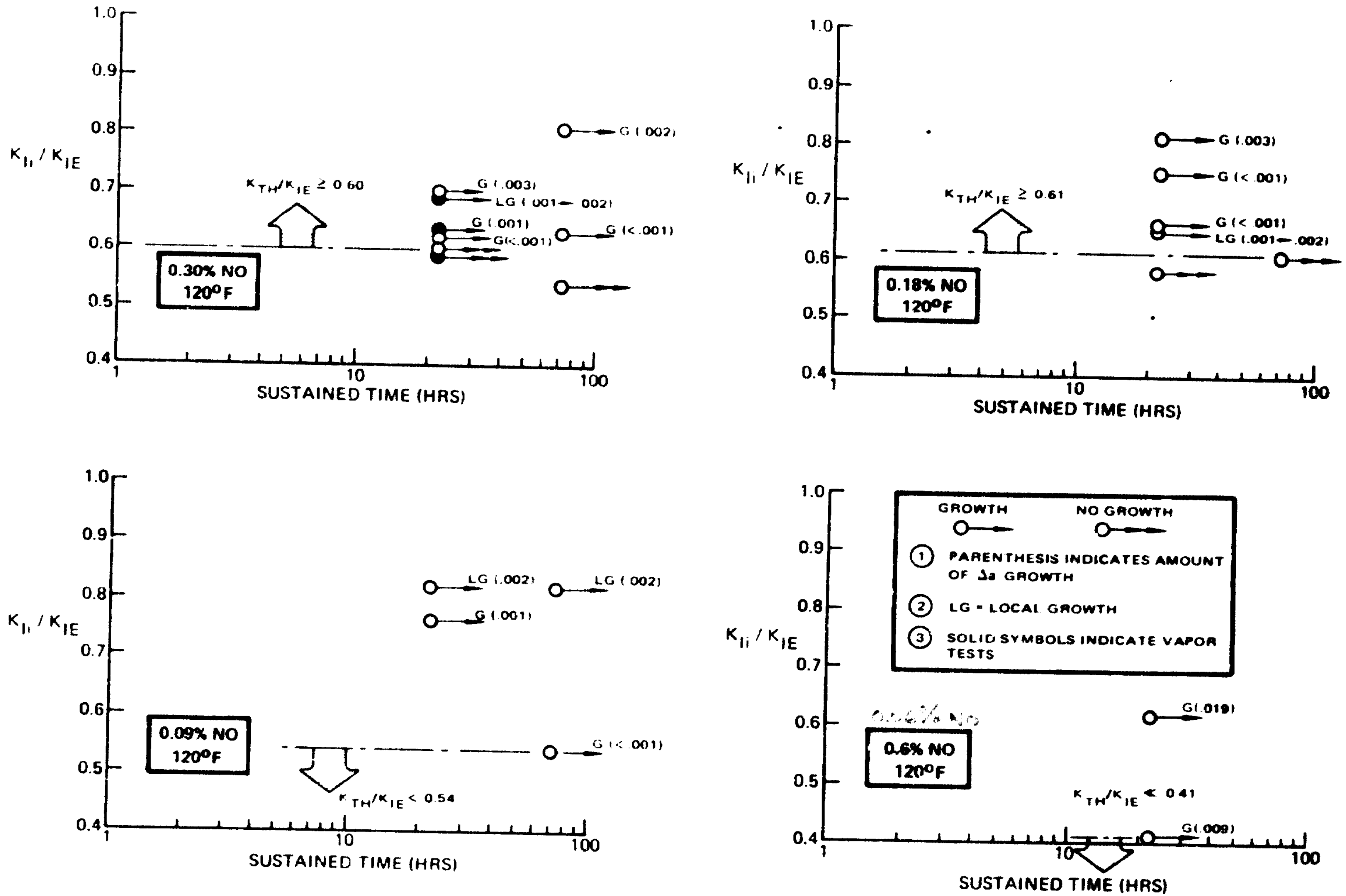


Figure 11: Sustained Load Flaw Growth of 6Al-4V STA Titanium in N_2O_4 At 120°F

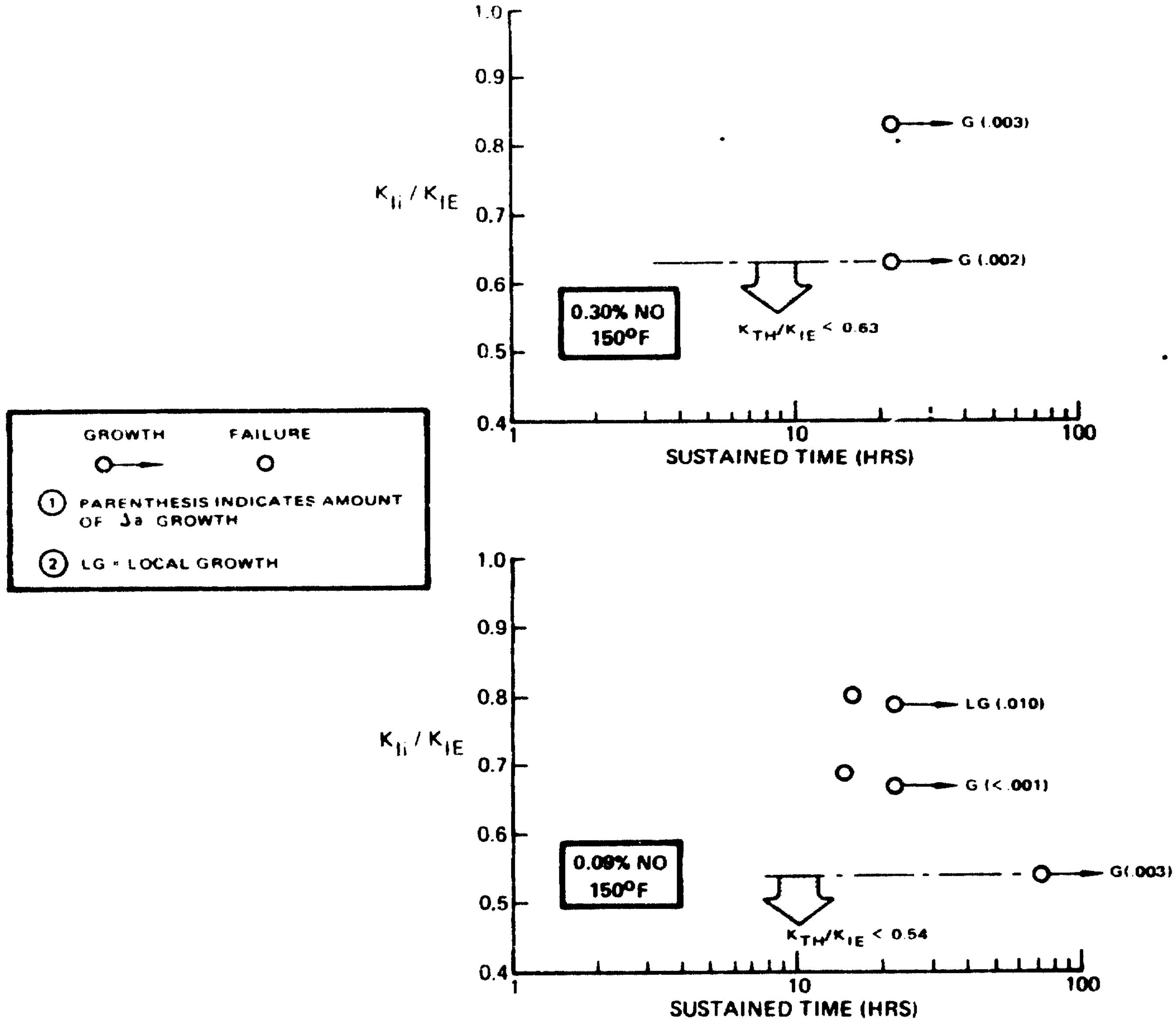


Figure 12: Sustained Load Flaw Growth of 6Al-4V STA Titanium in N_2O_4 At 150°F

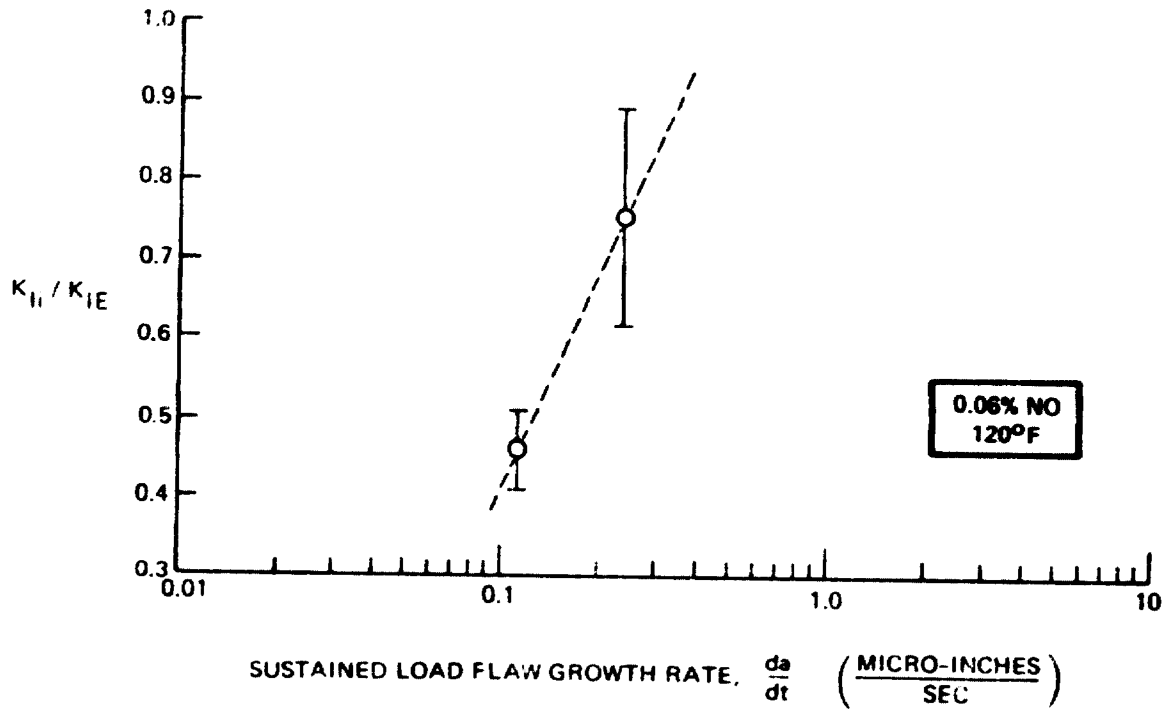


Figure 13: Sustained Load Flaw Growth Rates of 6Al-4V STA Titanium in N_2O_4 (0.06% NO) at 120°F

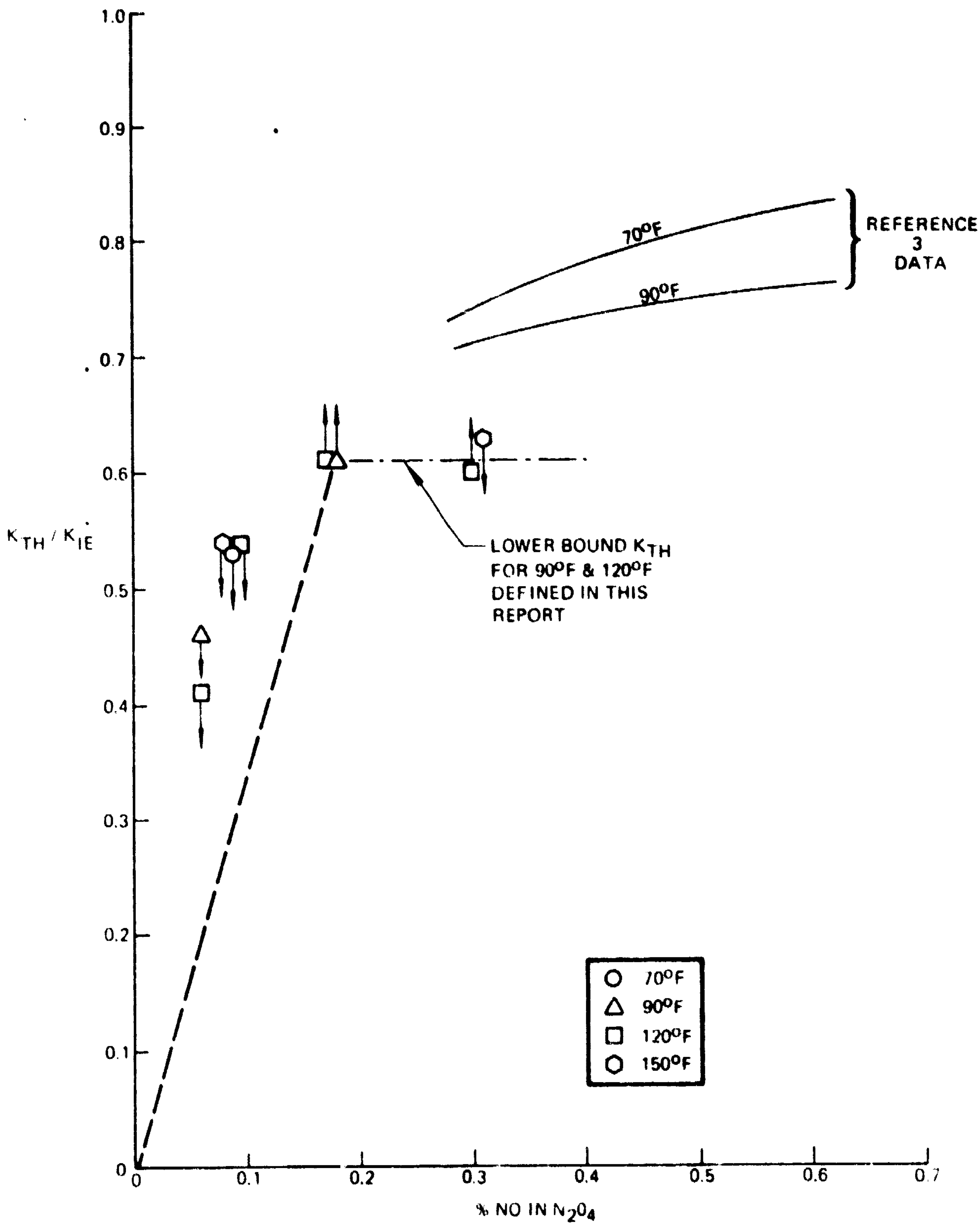


Figure 14: Threshold Summary of 6Al-4V STA Titanium in N_2O_4

Table 1: Chemical Analysis of N_2O_4 [1]
(By Weight)

CYLINDER NUMBER	NITRIC OXIDE (%)	WATER (%)	CHLORIDE (%)
65A916	0.05	0.10	< 0.04
65A1208	0.06	0.05	< 0.04
65A923	0.09	0.10	< 0.04
64A170	0.18	0.07	< 0.04
65A655	0.18	0.10	< 0.04
65A650	0.28	0.10	< 0.04
65A936	0.30	0.09	< 0.04

[1] ANALYSIS BY HERCULES, INC.

Table 2: Static Fracture and Load/Unload Tests

SPECIMEN NUMBER	THICKNESS, t (IN.)	FLAW DEPTH, a (IN.)	FLAW WIDTH, 2c (IN.)	a/2c	STRESS, σ (KSI)	FLAW SHAPE PARAMETER, Q	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST TEMPERATURE, T (°F)	EST ENVIRONMENT	STRESS INTENSITY, K_{Ii} (KSI$\sqrt{IN}$)	K_{Ii}/K_{IE}	REMARKS
PD 51	0.056	0.030	0.146	0.206	117.0	1.22	0.536	1.15	70	AIR	41.1	–	STATIC FRACTURE TESTS $(K_{IE})_{AVG}$ = 43.5 KSI$\sqrt{IN}$
PD 53	0.056	0.029	0.147	0.197	128.0	1.18	0.518	1.16			45.6	–	
PD 140	0.056	0.028	0.152	0.184	127.0	1.14	0.500	1.15			44.6	–	
PD 129	0.056	0.029	0.153	0.190	119.0	1.16	0.518	1.16	120	AIR	42.5	–	
PD 101	0.057	0.029	0.162	0.179	89.0	1.21	0.509	1.16			31.3	0.72	LOAD/UNLOAD GROWTH $\Delta a \leq 0.001''$
PD 141	0.056	0.026	0.152	0.171	84.0	1.18	0.464	1.13			27.5	0.63	LOAD/UNLOAD GROWTH $\Delta a = 0.001'' - 0.002''$

Table 3: Sustained Load Tests in N_2O_4 at 70°F and 90°F

SPECIMEN NUMBER	THICKNESS, t (IN.)	FLAW DEPTH, a (IN.)	FLAW WIDTH, 2c (IN.)	a/2c	STRESS, σ (KSI)	FLAW SHAPE PARAMETER, Q	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST TEMPERATURE, T (°F)	TEST ENVIRONMENT	SUSTAINED TIME (HRS)	STRESS INTENSITY, K_{Ii} (KSI $\sqrt{IN.}$)	K_{Ii}/K_{IE}	REMARKS
PD 109	0.057	0.027	0.146	0.185	88.0	1.23	0.474	1.13			22.0	29.0	0.67	GROWTH Δa = 0.001"
PD 115	0.054	0.027	0.146	0.185	101.0	1.17	0.500	1.15	70	0.09% NO	22.0	34.1	0.78	LOCAL GROWTH Δa = 0.003"
PD 119	0.055	0.027	0.146	0.185	70.0	1.23	0.491	1.14			72.0	23.0	0.53	LOCAL GROWTH Δa = 0.004"
PD 126	0.057	0.029	0.152	0.191	90.0	1.21	0.509	1.15			22.0	31.1	0.71	GROWTH Δa = 0.001" → 0.002" [1]
PD 127	0.056	0.028	0.152	0.184	88.9	1.21	0.500	1.15			22.0	30.3	0.70	GROWTH Δa = 0.001" → 0.002"
PD 133	0.056	0.032	0.150	0.213	73.0	1.33	0.571	1.19	90	0.18% NO	72.0	26.4	0.61	NO GROWTH
PD 134	0.056	0.030	0.150	0.200	82.0	1.25	0.536	1.17			72.0	28.8	0.66	GROWTH Δa = 0.001" → 0.002"
PD 146	0.056	0.027	0.152	0.178	95.0	1.17	0.482	1.14			22.0	31.9	0.73	GROWTH Δa = 0.002"
PD 123	0.056	0.032	0.149	0.215	88.0	1.28	0.571	1.19			22.0	32.0	0.74	GROWTH Δa = 0.002"
PD 124	0.055	0.025	0.150	0.167	76.0	1.19	0.455	1.13	90	0.06% NO	22.0	24.3	0.56	GROWTH Δa = 0.002"
PD 145	0.056	0.031	0.152	0.204	57.0	1.29	0.554	1.18			22.0	20.2	0.46	GROWTH Δa = 0.001"

[1] SPECIMEN PULLED DIRECTLY TO FAILURE AFTER SUSTAIN LOADED; NOT MARKED.

Table 4: Sustained Load Tests in N_2O_4 at 120°F

SPECIMEN NUMBER	THICKNESS, t (IN.)	FLAW DEPTH, a (IN.)	FLAW WIDTH, 2c (IN.)	a/2c	STRESS, σ (KSI)	FLAW SHAPE PARAMETER, Q	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST TEMPERATURE, T (°F)	TEST ENVIRONMENT	SUSTAINED TIME (HRS)	STRESS INTENSITY, K_{Ii} (KSI $\sqrt{IN.}$)	K_{Ii}/K_{IE}	REMARKS
PD 103	0.057	0.030	0.146	0.205	88.0	1.25	0.526	1.16	120	0.30% NO	22.0	30.6	0.70	GROWTH Δa = 0.003"
PD 111	0.057	0.029	0.150	0.193	101.0	1.21	0.509	1.15			72.0	35.1	0.81	GROWTH Δa = 0.002"
PD 118	0.056	0.028	0.153	0.183	70.0	1.22	0.500	1.15			72.0	23.6	0.54	NO GROWTH
PD 130	0.056	0.028	0.150	0.187	84.0	1.22	0.500	1.15			22.0	28.4	0.62	GROWTH $\Delta a \leq$ 0.001"
PD 131	0.056	0.030	0.145	0.207	76.0	1.30	0.536	1.16			22.0	26.3	0.60	NO GROWTH
PD 135	0.057	0.030	0.136	0.221	80.5	1.30	0.526	1.15			72.0	27.2	0.63	GROWTH $\Delta a \leq$ 0.001"
PD 136	0.056	0.028	0.148	0.189	77.0	1.22	0.500	1.15	120	0.30% NO ▷	22.0	25.9	0.60	NO GROWTH
PD 137	0.056	0.028	0.148	0.189	82.0	1.22	0.500	1.15			22.0	27.6	0.63	GROWTH Δa = 0.001"
PD 138	0.055	0.027	0.153	0.176	89.0	1.17	0.491	1.15			22.0	30.0	0.69	LOCAL GROWTH Δa = 0.001" → 0.002"
TBC-1	0.065	0.029	0.142	0.204	88.0	1.26	0.446	1.11	120	0.18% NO	22.0	28.8	0.66	LOCAL GROWTH Δa = 0.001" → 0.002"
PD 102	0.056	0.026	0.148	0.176	88.0	1.18	0.464	1.13			22.0	28.7	0.66	LOCAL GROWTH $\Delta a \leq$ 0.001"
PD 113	0.056	0.029	0.146	0.196	101.0	1.21	0.518	1.16			22.0	35.2	0.81	GROWTH Δa = 0.003"
PD 122	0.056	0.019	0.153	0.124	89.0	1.06	0.339	1.09			22.0	25.1	0.58	NO GROWTH
PD 132	0.056	0.028	0.146	0.192	79.0	1.22	0.500	1.14			72.0	26.5	0.61	NO GROWTH
PD 144	0.056	0.028	0.153	0.183	95.0	1.22	0.500	1.15			22.0	32.6	0.75	GROWTH $\Delta a \leq$ 0.001"

▷ VAPOR TESTS WITH 250 PSIG PRESSURE

Table 4: (Continued) Sustained Load Tests in N_2O_4 at 120°F

SPECIMEN NUMBER	THICKNESS, t (IN.)	FLAW DEPTH, a (IN.)	FLAW WIDTH, 2c (IN.)	a/2c	STRESS, σ (KSI)	FLAW SHAPE PARAMETER, Q	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST TEMPERATURE, T (°F)	TEST ENVIRONMENT	SUSTAINED TIME (HOURS)	STRESS INTENSITY, K_{Ii} (KSI $\sqrt{IN.}$)	K_{Ii}/K_{IE}	REMARKS
PD 73	0.056	0.032	0.160	0.200	88.0	1.23	0.571	1.20	120	0.09% NO	22.0	32.9	0.76	GROWTH $\Delta a = 0.001''$
PD 104	0.056	0.029	0.152	0.191	101.0	1.21	0.518	1.16			22.0	35.5	0.82	LOCAL GROWTH $\Delta a = 0.002''$
PD 110	0.056	0.029	0.152	0.191	101.0	1.21	0.518	1.16			72.0	35.5	0.82	LOCAL GROWTH $\Delta a = 0.002''$
PD 117	0.055	0.028	0.145	0.193	70.0	1.27	0.509	1.15			72.0	23.4	0.54	GROWTH $\Delta a \leq 0.001''$
PD 125	0.055	0.027	0.156	0.173	80.0	1.17	0.491	1.15	120	0.06% NO	22.0	26.9	0.62	GROWTH $\Delta a = 0.019''$, $\Delta 2c = 0.029''$
PD 142	0.056	0.028	0.150	0.187	54.0	1.27	0.500	1.15			22.0	18.0	0.41	GROWTH $\Delta a = 0.009''$, $\Delta 2c = 0.020''$

Table 5: Sustained Load Tests in N_2O_4 at 150°F

SPECIMEN NUMBER	THICKNESS, t (IN.)	FLAW DEPTH, a (IN.)	FLAW WIDTH, 2c (IN.)	a/2c	STRESS, σ (KSI)	FLAW SHAPE PARAMETER, Q	a/t	DEEP FLAW MAGNIFICATION FACTOR, M_K	TEST TEMPERATURE, T (°F)	TEST ENVIRONMENT	SUSTAINED TIME (HRS)	STRESS INTENSITY, K_{Ii} (KSI $\sqrt{IN.}$)	K_{Ii}/K_{IE}	REMARKS
PD 106	0.056	0.024	0.146	0.164	88.0	1.14	0.429	1.11	150	0.30% NO	22.0	27.4	0.63	GROWTH $\Delta a = 0.002''$
PD 107	0.055	0.029	0.155	0.187	101.0	1.21	0.527	1.17			22.0	35.9	0.83	GROWTH $\Delta a = 0.003''$
PD 105	0.056	0.027	0.146	0.185	88.0	1.23	0.482	1.14	150	0.09% NO	22.0	29.1	0.67	GROWTH $\Delta a \leq 0.001''$
PD 108	0.058	0.028	0.147	0.190	101.0	1.22	0.500	1.14			22.0	34.4	0.79	LOCAL GROWTH $\Delta a = 0.010''$
PD 112	0.054	0.028	0.146	0.192	101.0	1.22	0.519	1.16			15.4	34.8	0.80	FAILED $\Delta a = 0.018''$; $\Delta 2c = 0.060''$
PD 114	0.056	0.028	0.152	0.184	88.0	1.22	0.500	1.15			14.9	30.0	0.69	FAILED $\Delta a = 0.019''$; $\Delta 2c = ?$
PD 116	0.055	0.027	0.153	0.176	70.0	1.23	0.491	1.15			72.0	23.3	0.54	GROWTH $\Delta a = 0.003''$