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THE FATIGUE BEHAVIOR OF MATERIALS FOR THE SUPERSONIC TRANSPORT

by M. S. Healy, C. W. Marschall, F. C. Holden, and W. S. Hyler

Prepared under Contract No. NASr-100-(01) *by*
BATTELLE MEMORIAL INSTITUTE
Columbus, Ohio
for

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ABSTRACT

Tests were conducted on sheet specimens of two materials, Ti–8Al–1Mo–1V and AM350 CRT to determine the fatigue lives, rates of fatigue-crack propagation, and residual static strengths at three temperatures, 550°F, –110°F, and room temperature. The effects of prior exposure to 550°F for up to 10 000 hours on the same properties were also studied.

Neither material was significantly degraded by the elevated temperature soak. The fatigue characteristics were found to be comparable to those of contemporary aluminum alloys.

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SUMMARY

This report describes an investigation of the fatigue behavior of two materials considered as skin materials for the supersonic transport. The materials are AM-350 CRT stainless steel and triplex-annealed Ti-8Al-1Mo-1V alloy.

The three aspects of the program are (1) crack propagation behavior, (2) residual static strength, and (3) the base fatigue strength of the two materials. In each case, many variables have been evaluated that are related to the operating conditions of the supersonic transport. This report describes the research accomplished during the second year of the program. However, included in the discussion is information from the first year. This was done so that an over-all view of the results of the program could be obtained.

Based on this investigation it appears that the fatigue behaviors of the two materials are not too different from those of materials currently used in subsonic aircraft. In addition, the studies of the effect of prior stressed exposure on fatigue behavior of the two materials showed that neither material exhibited a significant tendency toward metallurgy instability at an exposure temperature of 550 F after a stressed exposure of about 10,000 hours. This observation agrees with the results of other programs currently in progress at NASA and other organizations on the same materials.

INTRODUCTION

The National Aeronautics and Space Administration is engaged in research programs directed toward the solution of the myriad problems associated with the development of the supersonic transport. One of these problem areas is the selection of suitable skin materials. As with all aircraft, the supersonic transport structure will experience cyclic stresses due to gust and maneuver loads, heating, noise, and other variable loads; thus the fatigue behavior of potential skin materials is an important factor in design considerations.

The skin of the supersonic transport will be subjected to temperatures ranging from well below freezing to approximately 550 F. Actually, a major portion of the flight profile is at cruise condition. Consequently, the skin will be subjected to elevated temperature for appreciable periods of time. It is because of this stressed exposure at elevated temperature over a long period of time that the present program included an evaluation of possible metallurgical instability which could affect static or dynamic behavior of the materials.

This Battelle program has been concerned with the fatigue behavior of two possible skin materials, AM-350 CRT stainless steel and triplex-annealed Ti-8Al-1Mo-1V alloy. The base fatigue and fatigue crack-propagation behavior of these materials, as well as residual static strength, has been examined with respect to the temperatures and stressed exposure to which the supersonic transport skin will be subjected.

Because of the large scope of this research effort, some of the variables were explored to a very limited extent. These studies were intended to cover a wide range of potential problem areas in order to determine those that require further detailed study.

Since the program has covered a 2-year period, generally only experimental data obtained during the second year's research are reported. The data from the first year is presented in NASA CR-28, April 1964 [Reference (1)] . In the discussion and conclusions reference is made to the results of both programs.

EXPERIMENTAL DETAILS

Materials

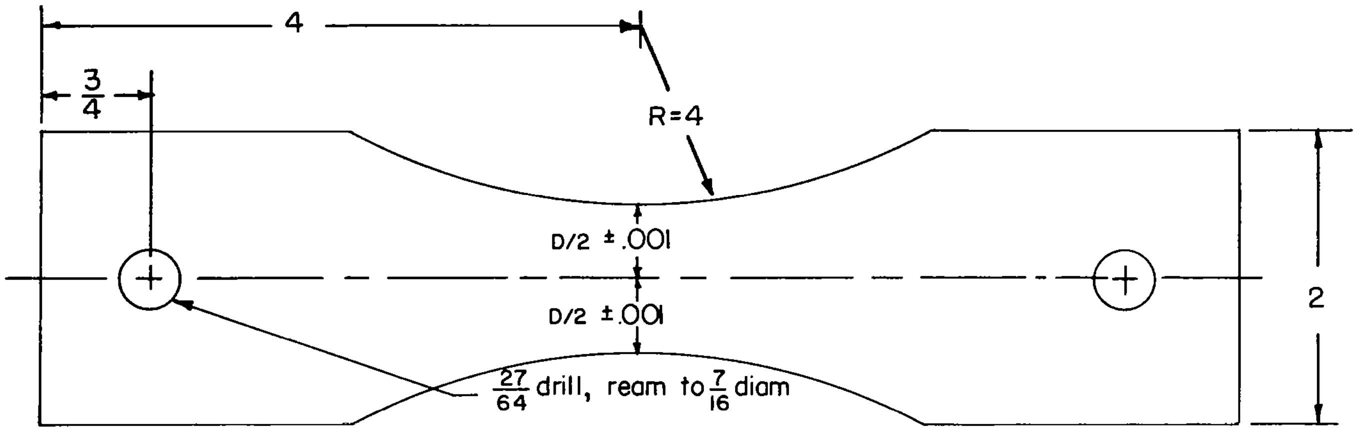
Three sheets of AM-350 CRT stainless steel and of triplex-annealed Ti-8Al-1Mo-1V alloy were provided by Langley Research Center from a large quantity of material specifically obtained for NASA programs. Manufacturer's chemical-analysis and mechanical-property data appear in Appendix A. During the first year of the Battelle program, tensile data were obtained from specimens of each of the three sheets of each material that were provided. A discussion of the results and the detailed data appear in Reference (1). The data are summarized in Table 1, together with tensile data on edge-notched specimens of the same design as the fatigue specimens.

Specimen Design

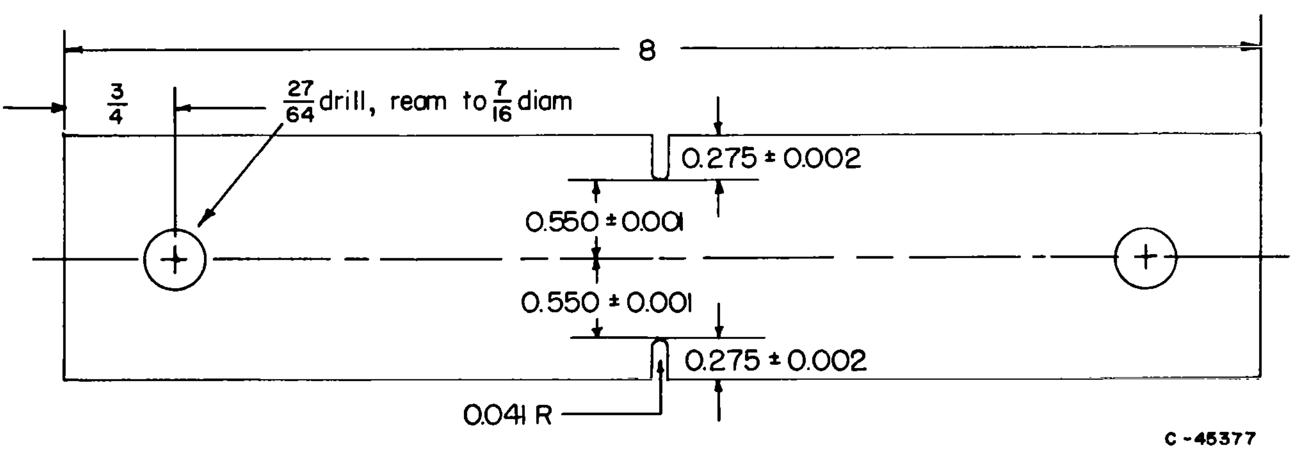
Four types of specimens were employed in the program. These specimens include an unnotched specimen, an edge-notched specimen, a 2-inch-wide center-notched specimen, and a 4-inch-wide center-notched specimen. The latter specimen was made only from the titanium alloy; only a few specimens were made. Drawings of each specimen are shown in Figure 1. Details concerning the fabrication of the specimens are given in Reference (1).

TABLE 1. SUMMARY OF TENSILE DATA FOR AM-350 CRT AND TRIPLEX-ANNEALED Ti-8Al-1Mo-1V SHEET SPECIMENS

Temperature, F	Orientation	0.2 Per Cent Offset Yield Strength, ksi	Ultimate Tensile Strength, ksi	Elongation in 2 Inches, per cent	Modulus of Elasticity, 10^6 psi
		Unnotched-Specimen Data			
AM-350 CRT					
-100	L	221	273	20.2	28.1
RT	L	221	233	21.1	27.8
	T	201	236	13.1	29.5
550	L	184	201	3.7	25.2
Ti-8Al-1Mo-1V					
-100	L	166	179	12.0	20.0
RT	L	140	152	12.9	18.8
	T	132	144	11.8	17.4
550	L	98	125	9.5	16.7
		Notched-Specimen Data, k_t = 4.0			
			Notched Tensile Strength, ksi		
AM-350 CRT					
RT	L	--	242	--	--
550	L	--	200	--	--
Ti-8Al-1Mo-1V					
RT	L	--	166	--	--
550	L	--	125	--	--

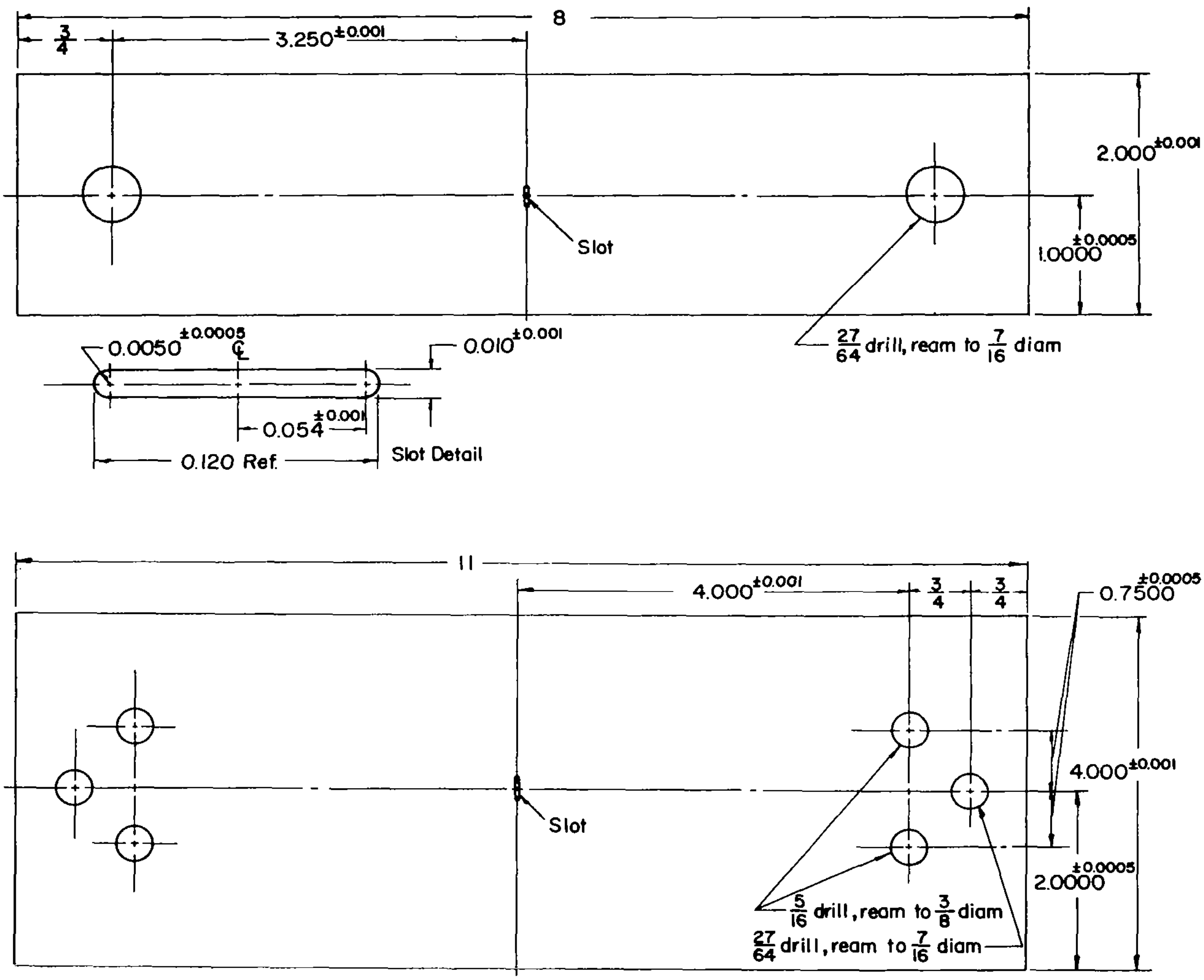


a. Unnotched specimen



b. Edge-notched specimen

FIGURE 1. FATIGUE SPECIMENS



c. Center-Notched Specimens

A-48096

FIGURE 1. (CONTINUED)

Examination of the finished notches showed them to be uniformly good. The edge notches had radii of 0.041 ± 0.002 inch; the center notches had radii of 0.0045 inch and lengths of 0.125 ± 0.005 inch. The theoretical stress-concentration factor for the edge-notched specimen is 4.0, which is the same notch severity as that used in several Battelle and NASA programs.[2,3] Using the relations of Inglis[4] and Dixon[5], as reported by Gerard[6], the stress-concentration factor for the 2-inch-wide center-notched specimens is approximately 7.9. Similarly, K_t is about 8.1 for the 4-inch-wide center-notched specimens.

Equipment

All fatigue testing was conducted in Krouse direct-stress fatigue machines of 5,000 or 10,000-pound capacity. These machines operate at 1725 and 1200 cpm, respectively. The smaller capacity machines are equipped with automatic hydraulic load maintainers that monitor test loads on each specimen. Accuracy of load setting and maintenance is about 3 per cent of the maximum test load.

For specimens that were stressed in compression for a portion of the cycle, antibuckling jigs, similar in design to those used at Langley Research Center, were employed. These jigs consist of graphite plates held in contact with the specimen by steel pressure plates and pressure screws mounted in a rigid frame.

The means of heating the elevated-temperature fatigue specimens has been modified as a consequence of some difficulties experienced occasionally with the antibuckling jig-heater method described in Reference (1). The present equipment consists of two nickel-chromium coiled resistance-wire heating units fixed to opposite sides of a closed section of asbestos pipe. This furnace type of heater encloses the antibuckling jig and specimen grips. The specimen temperature is indicated by a Chromel-Alumel thermocouple located in a hole in the graphite plate of the antibuckling jig. The hole is drilled in the graphite plate on the side away from the specimen. The thermocouple is inserted into this hole to within about 1/32 inch of the specimen surface. The thermocouple is connected to a potentiometer controller which regulates the electrical power to the heating units.

The manner in which the fatigue specimens are cooled to -110 F and the equipment for stress-elevated temperature exposures are discussed in Reference (1).

CRACK PROPAGATION AND RESIDUAL STATIC STRENGTH

The flight profile of the supersonic transport indicates that there are a number of environmental factors that may influence both the manner in which a fatigue crack will propagate and the strength of a structural element that contains a fatigue crack. As a result, a wide variety of variables were studied to determine which ones may have a significant effect upon the crack-propagation behavior and residual static strength of the two materials. The factors that were explored were the following: alternating stress amplitude, cyclic frequency, specimen orientation with respect to principal rolling direction, temperature, and prior stressed exposure at elevated temperature. The studies reported in Reference (1) were devoted to the AM-350 stainless steel. The work that is reported here is primarily concerned with the titanium alloy; however, the behavior of exposed stainless steel specimens has also been examined and is included in this report.

Crack-Propagation Studies

The fatigue-crack propagation studies were conducted in conjunction with the residual-strength investigations. In the latter effort, fatigue-cracked specimens with nominal tip-to-tip crack lengths of 3/16-, 3/8-, 3/4-, and 1-inch were evaluated. Crack-propagation data were obtained from those specimens cracked to 3/4- and 1-inch crack lengths in addition to several specimens in which the cracks were propagated until specimen failure occurred. All of the residual-strength tests were conducted on the 2-inch-wide specimens and therefore the majority of crack-propagation information pertains to the 2-inch-wide specimens. A very limited number of 4-inch-wide Ti-8Al-1Mo-1V specimens were also employed in the crack-propagation studies. Data on the crack-propagation behavior of the titanium alloy were obtained at a mean stress of 25 ksi, and the data for the AM-350 were obtained at a mean stress of 40 ksi.

All of the stainless steel specimens were cracked in a 10,000-pound Krouse fatigue machine at a cyclic rate of 1200 cpm. The titanium-alloy specimens were cracked in a 5000-pound Krouse machine at frequencies of 1725 cpm and 34 cpm; however, the largest stress amplitude employed in the program necessitated the use of the 10,000-pound machine. During cracking, the net-section stresses were held essentially constant with an allowable variation of ±10 per cent for the steel [as in Reference (1)] and 0 to +10 per cent for the Ti-8Al-1Mo-1V alloy. The net-section stresses are based on the uncracked portion, regardless of whether the specimen went into compression or not. A few titanium-alloy specimens were cracked at constant gross-section stress for purposes of comparison with the data obtained under constant net-section stress. Crack-propagation measurements were made by stopping the machine and measuring crack length with a measuring microscope mounted on a traverse. Measurements were taken with the specimen subjected to the maximum stress of the particular test. At -110 F and 550 F, the data were obtained in the same manner by observing the crack through a window in the enclosure.

From the experimental data, total crack length was plotted against total number of cycles. As was indicated in Reference (1), the effect of the ±10 per cent variation in stress is readily apparent in these plots for the steel; however, there seems to be little evidence of the 0 to +10 per cent stress variation in similar curves for the titanium alloy.

In order to determine the effects of the several variables in terms of the crack-propagation behavior, curves were drawn on the crack length versus cycles plots to minimize the small effect of the load changes required to maintain a constant nominal net-section stress. Crack-propagation rates were determined by evaluating the slope of the curves at specific crack lengths of 0.250, 0.350, 0.500, 0.625, 0.750, and 0.950 inch. For purposes of this investigation, "initiation" has been defined as a total crack length of 0.150 inch for the titanium and 0.130 inch for the steel. Although most of the specimen tests were stopped at nominal crack lengths of 3/4 and 1 inch, two specimens, under each set of conditions, were tested to failure from a nominal crack length of 1 inch without further adjustment of the net-section stress. The propagation

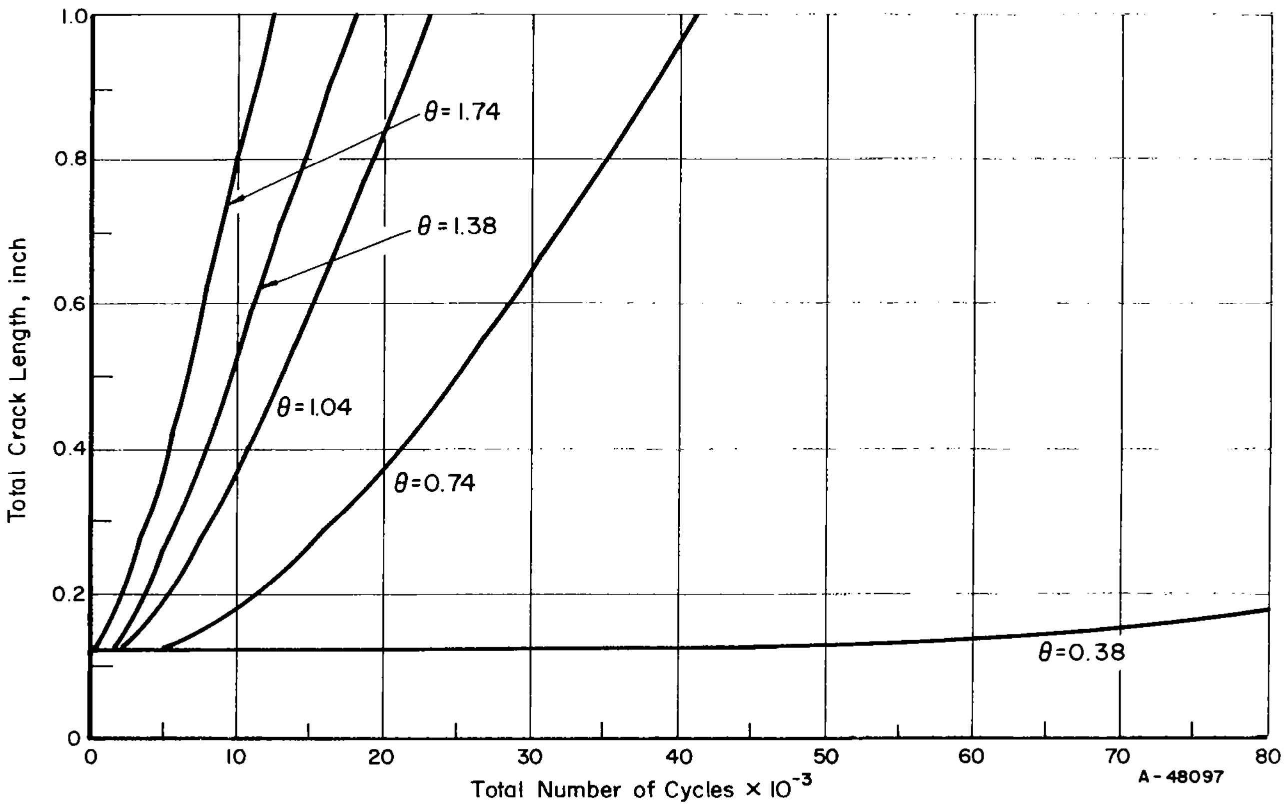


FIGURE 2. TYPICAL FATIGUE-CRACK PROPAGATION CURVES FOR UNEXPOSED, LONGITUDINAL 2-INCH-WIDE Ti-8Al-1Mo-1V ALLOY SHEET SPECIMENS AT ROOM TEMPERATURE AND 1200-1725 CPM

Net-section stresses maintained within 0 to +10 per cent of nominal values.

rates and total number of cycles to propagate a crack to the indicated crack lengths are given in detail in Appendix B. The data from tests of 2-inch-wide titanium alloy specimens at constant net-section stress are summarized in Table 2.

The effects of the variables examined, on crack propagation behavior, are presented and discussed in the following subsections.

Effect of Alternating Stress Amplitude

Alternating stress amplitude has been expressed in Table 2 and in subsequent tables and figures as the ratio, θ, of alternating stress amplitude to 1-g mean stress. The effect of θ is illustrated by conditions A, B, G, K, N, and Q in Table 2.

As would be expected, θ does have a significant influence upon crack propagation behavior. Figure 3, on which are stress-lifetime curves for various crack-length criteria, shows how the number of cycles to a given crack length is affected by θ. Figure 4 illustrates the increase in crack-propagation rates with increasing θ for three values of crack length. Figure 2 and Table 2 show that following initiation, crack-propagation rate increases with increasing crack length for an initial portion of total crack growth. After this portion of crack growth has taken place, the propagation rate becomes virtually constant with a further increase in crack length, to a nominal 1-inch crack length. This appears to be consistent with other observations[7,8] of crack propagation behavior under constant net-section stresses.

As a guide to determine the value of θ at which a crack will not initiate in the starter notch in 10^7 cycles, a specimen was tested at a θ of 0.25. After the specimen had accumulated 10^6 cycles without any visible sign of a crack, the test was continued on the same specimen at $\theta = 0.30$. Following a period of crack initiation and growth at $\theta = 0.30$, it was decided to determine the value of θ at which the crack would cease to propagate. The value of θ was decreased successively in steps with sufficient cycles added at each θ to insure that crack growth occurred and that some measure of the propagation rate was obtained. The results from this test appear in Table 3. As is indicated, the test was stopped after a crack failed to propagate at $\theta = 0.05$ in 80,000 cycles.

The initiation curve in Figure 3 indicates that the fatigue limit, at 10^7 cycles, for a 2-inch-wide center-notched Ti-8Al-1Mo-1V alloy specimen, with a K_t of approximately 7.9, will be at a θ of about 0.20. However, the data from the single specimen points out that once a crack has initiated, cracks will propagate at values of θ which are considerably lower than the fatigue limit for the starter notch. It is recognized[9,10,11] that the θ at which a fatigue crack will cease propagating also is a function of the crack length, but the results of this test illustrate that a crack will propagate at stresses below the fatigue limit. This adds to the complexity of cumulative damage assessment since both initiation and propagation behavior of a crack must be accounted for, and some of the lower stresses for propagation should be included in an analysis. To provide comparable information for both materials, a similar test was conducted on a single specimen of AM-350 stainless steel. During this test the same values of θ were employed, and every effort was made to have initial and final crack lengths for each condition identical to those in the titanium specimen test. The results are given in Table 4. From a comparison of the two sets of data, it is apparent that the same observations apply to the behavior of the stainless steel.

TABLE 2. SUMMARY OF DATA FROM CRACK-PROPAGATION TESTS OF 2-INCH-WIDE Ti-8Al-1Mo-1V ALLOY SHEET SPECIMENS AT CONSTANT NET-SECTION STRESS

Center-notched, triplex-annealed specimens.
Constant net-section mean stress of 25 ksi.

			Crack-Propagation Rate, μin./cycle, at Indicated Crack Length[a], inch						Total Thousands of Cycles to Indicated Crack Length[a], inch								
Condition	Test Series Value	Number Tested	0.250	0.350	0.500	0.625	0.750	0.950	0.150 (Initiation)	0.250	0.350	0.500	0.625	0.750	0.950	1.000	Failure[b]
			θ[c] = 0.26, Room Temperature, 1725 CPM, Longitudinal, Unexposed.														
A	Minimum		1.3	2.2	2.8	3.3	3.4	3.4	635	853	915	973	1013	1045	1095	1107	1181
	Mean	2	1.4	2.2	2.9	3.4	3.7	3.7	858	1041	1103	1161	1199	1234	1289	1300	1380
	Maximum		1.4	2.2	2.9	3.4	4.0	4.0	1080	1229	1291	1349	1385	1422	1481	1492	1578
			θ = 0.38, Room Temperature, 1725 CPM, Longitudinal, Unexposed														
B	Minimum		4.2	5.3	7.2	8.1	8.7	8.7	53.0	92.5	105	127	141	156	177	181	228
	Mean	5	4.3	5.8	8.1	8.8	9.4	9.0	61.2	93.7	115	136	151	165	186	192	234
	Maximum		4.5	6.7	8.6	9.6	10	9.6	67.2	101	123	146	161	176	199	205	240
			θ = 0.38, Room Temperature, 1725 CPM, Transverse, Unexposed														
C	Minimum		3.6	4.5	5.8	7.4	7.4	8.0	77.3	119	146	165	180	195	217	222	269
	Mean	4	4.0	4.7	6.4	7.9	8.1	8.4	86.6	129	153	178	196	212	236	241	291
	Maximum		4.5	4.9	7.2	8.3	9.2	9.2	103	151	179	206	224	239	264	271	312
			θ = 0.38, 550 F, 1725 CPM, Longitudinal, Unexposed														
D	Minimum		3.0	3.8	4.6	5.5	5.2	5.2	57.3	90.2	117	149	174	195	229	239	298
	Mean	2	3.4	3.9	4.8	5.5	5.7	5.3	57.4	99.6	128	162	187	209	247	256	316
	Maximum		3.8	4.0	4.9	5.5	6.1	5.3	57 5	109	139	175	199	223	264	273	333
			θ = 0.74, -110 F, 1725 CPM, Longitudinal, Unexposed														
E	Minimum		20	23	[illegible]	34	34	33	8.3	14.7	19.1	24.7	28.0	31.4	36.2	37.4	45.9
	Mean	4	22	24	36	36	37	38[d]	9.2	15.7	20.0	25.5	29.0	32.5	38.2[d]	39.6[d]	48.3
	Maximum		23	26	38	38	42	42	11.1	17.6	22.0	27.5	31.1	34.8	40.1	41.7	50.7
			θ = 0.74, Room Temperature, 34 CPM, Longitudinal, Unexposed														
F	Minimum		19	26	33	36	36	38	6.0	11.7	15.4	20.3	23.7	26.9	32.0	32.9	39.4
	Mean	4	23	28	34	38	38	39[d]	6.5	12.3	16.4	21.3	24.8	28.1	32.7[d]	33.8[d]	41.0
	Maximum		24	29	35	40	40	39	7.8	12.9	16.7	21.9	25.4	28.9	33.4	34.7	42.6
			θ = 0.74, Room Temperature, 1725 CPM, Longitudinal, Unexposed														
G	Minimum		17	22	27	30	30	31	6.7	11.7	16.3	22.2	26.3	30.2	36.2	37.7	45.1
	Mean	10	20	24	29	31	32	32[e]	7.1	13.5	18.4	24.3	28.5	32.3	38.4[e]	39.8[e]	47.3
	Maximum		22	25	31	33	36	34	7.5	14.3	19.3	25.4	29.7	33.7	40.2	41.9	50.0

						θ = 0.74, Room Temperature, 1725 CPM, Longitudinal, 8,000 Hours' Exposure										
H	Minimum		21	23	32	34	37	38	5.3	10.9	17.1	19.3	22.2	25.0	32.7	34.0	41.5
	Mean	7	23	28	34	38	39	38[d]	6.5	11.9	16.8	21.3	24.1	27.4	33.7[d]	35.0[d]	42.3[d]
	Maximum		24	33	37	45	45	39	7.7	13.1	15.0	22.1	25.9	29.3	34.6	36.0	43.0
						θ = 0.74, Room Temperature, 1725 CPM, Transverse, Unexposed										
I	Minimum		16	21	25	26	26	31	7.3	14.7	19.2	25.4	29.9	33.9	40.0	41.6	51.1
	Mean	6	18	22	27	29	30	31[e]	8.2	15.0	20.1	26.7	31.1	35.4	40.8[e]	42.4[e]	51.5
	Maximum		20	23	28	31	31	33	8.8	16.2	21.8	28.5	33.3	38.1	41.7	43.1	51.8
						θ = 0.74, 550 F, 1725 CPM, Longitudinal, Unexposed										
J	Minimum		12	14	17	17	17	18	6.5	15.6	23.0	31.9	38.6	44.9	54.9	57.4	74.3
	Mean	4	13	15	18	18	18	19[d]	7.6	17.0	24.4	33.7	40.6	47.4	57.4[d]	59.8[d]	76.5
	Maximum		14	17	19	20	20	20	8.7	18.0	25.5	35.0	42.1	49.2	59.9	62.2	78.7
						θ = 1.04, Room Temperature, 1725 CPM, Longitudinal, Unexposed										
K	Minimum		35	36	43	47	47	47	3.4	6.8	9.5	13.2	15.8	18.3	22.4	23.4	30.2
	Mean	3	36	41	47	50	50	50	3.7	7.2	10.0	13.7	16.3	18.7	22.7	23.7	30.4
	Maximum		36	43	52	52	52	52	4.4	7.9	10.6	14.1	16.6	19.1	23.3	24.3	30.5
						θ = 1.38, -110 F, 1725 CPM, Longitudinal, Unexposed										
L	Minimum		57	63	82	82	82	82	1.8	4.2	5.7	7.6	9.0	10.4	12.6	13.1	15.8
	Mean	2	58	67	83	86	86	86	1.9	4.2	5.8	7.8	9.2	10.7	13.0	13.6	16.4
	Maximum		58	71	83	89	89	89	1.9	4.2	5.8	7.9	9.4	10.9	13.4	14.0	17.0
						θ = 1.38, Room Temperature, 34 CPM, Longitudinal, Unexposed										
M	Minimum		49	58	71	71	76	78	1.2	3.7	5.4	7.5	9.1	10.7	13.3	13.8	16.5
	Mean	4	54	62	77	77	78	77[d]	1.4	3.9	5.7	7.9	9.5	11.1	13.7[d]	14.2[d]	17.0
	Maximum		56	63	79	79	79	76	1.8	4.3	6.2	8.5	10.1	11.7	14.0	14.6	17.5
						θ = 1.38, Room Temperature, 1725 CPM, Longitudinal, Unexposed										
N	Minimum		44	50	59	59	59	56	1.8	4.3	6.2	8.8	10.7	12.6	15.7	16.5	21.0
	Mean	3	46	53	62	62	62	60	2.2	4.8	6.9	9.5	11.6	13.6	16.9	17.8	22.[illegible]
	Maximum		50	56	64	64	64	64	2.4	5.3	7.4	10.1	12.2	14.2	17.8	18.8	23.[illegible]
						θ = 1.38, Room Temperature, 1725 CPM, Transverse, Unexposed										
O	Minimum		38	46	52	52	52	50	1.3	4.7	7.0	9.9	12.0	14.2	17.5	18.3	22.2
	Mean	4	42	47	58	58	60	55	2.2	5.2	7.5	10.4	12.6	14.8	18.3	19.2	23.7
	Maximum		44	48	61	61	70	61	2.5	5.6	8.2	11.3	13.7	16.1	20.0	21.0	25.1
						θ = 1.38, 550 F, 1725 CPM, Longitudinal, Unexposed										
P	Minimum		30	39	44	44	44	44	1.6	5.3	8.4	11.9	14.7	17.2	21.6	22.7	26.0
	Mean	2	31	41	45	45	49	45	1.7	5.4	8.5	12.0	14.8	17.5	21.9	23.0	27.1
	Maximum		31	42	45	45	53	45	1.8	5.5	8.6	12.1	14.9	17.7	22.2	23.3	28.2

TABLE 2. (Continued)

Condition	Test Series Value	Number Tested	Crack Propagation Rate, μ in./cycle, at Indicated Crack Length(a), inch 0.250	0.350	0.500	0.625	0.750	0.950	Total Thousands of Cycles to Indicated Crack Length(a), inch 0.150 (Initiation)	0.250	0.350	0.500	0.625	0.750	0.950	1.000	Failure(b)
								θ = 1.74, Room Temperature, 1200 CPM, Longitudinal, Unexposed									
Q	Minimum		50	61	71	75	75	63	1.1	2.2	4.7	6.5	8.0	9.5	11.8	12.4	15.1
	Mean	4	57	68	81	82	82	75	1.3	3.3	5.1	7.2	8.7	10.3	12.8	13.5	16.6
	Maximum		61	71	85	85	85	83	1.5	4.0	5.7	8.1	9.8	11.5	14.5	15.3	15.5

(a) Tip-to-tip crack length.
(b) Two specimens under each set of conditions cycled to failure from 1-inch nominal crack length without further adjustment of net-section stress.
(c) θ= net-section alternating-stress amplitude/1-g mean stress of 25 ksi.
(d) Only two specimens tested to indicated crack length.
(e) Only four specimens tested to indicated crack length.

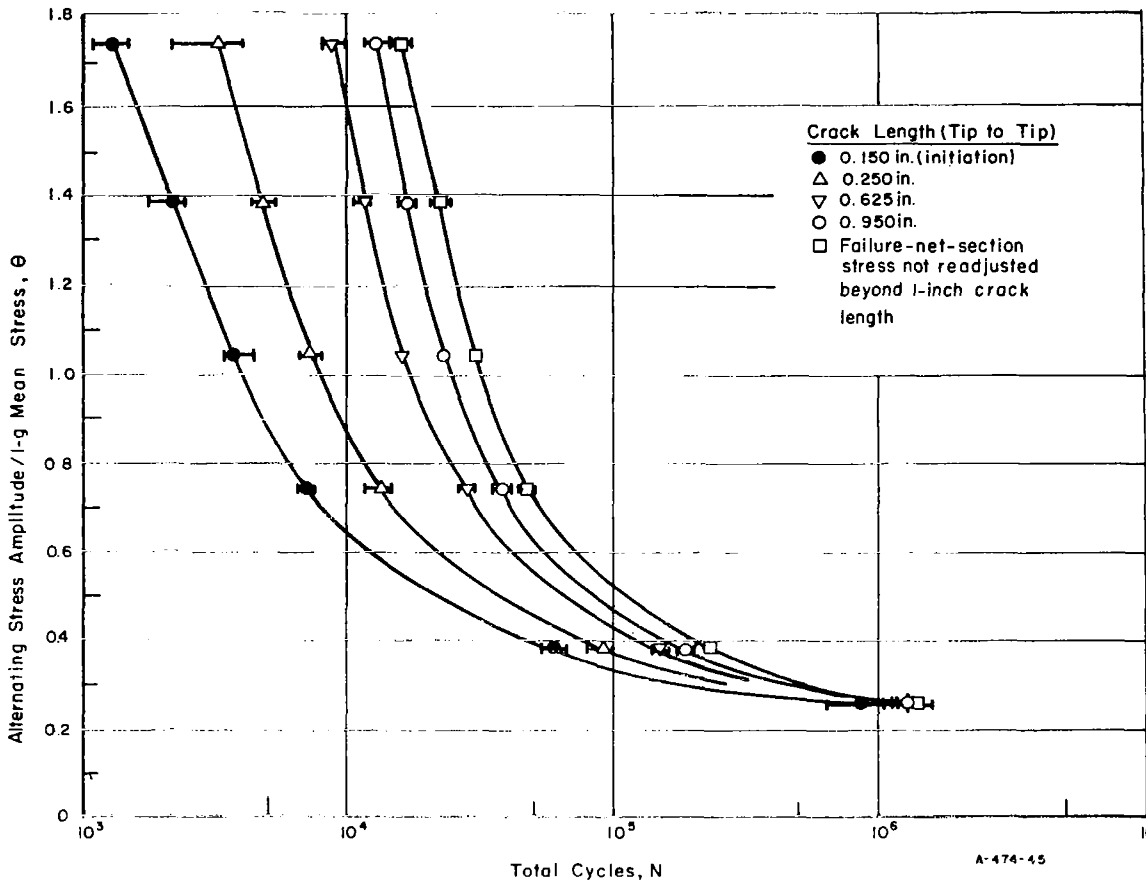


FIGURE 3. EFFECT OF THE RATIO θ ON THE CRACK-PROPAGATION BEHAVIOR OF Ti-8Al-1Mo-1V ALLOY SHEET SPECIMENS

Specimens: Unexposed, 2 inches wide, longitudinal.

Conditions: Room temperature, 1200-1725 cpm, constant net-section 1-g mean stress of 25 ksi.

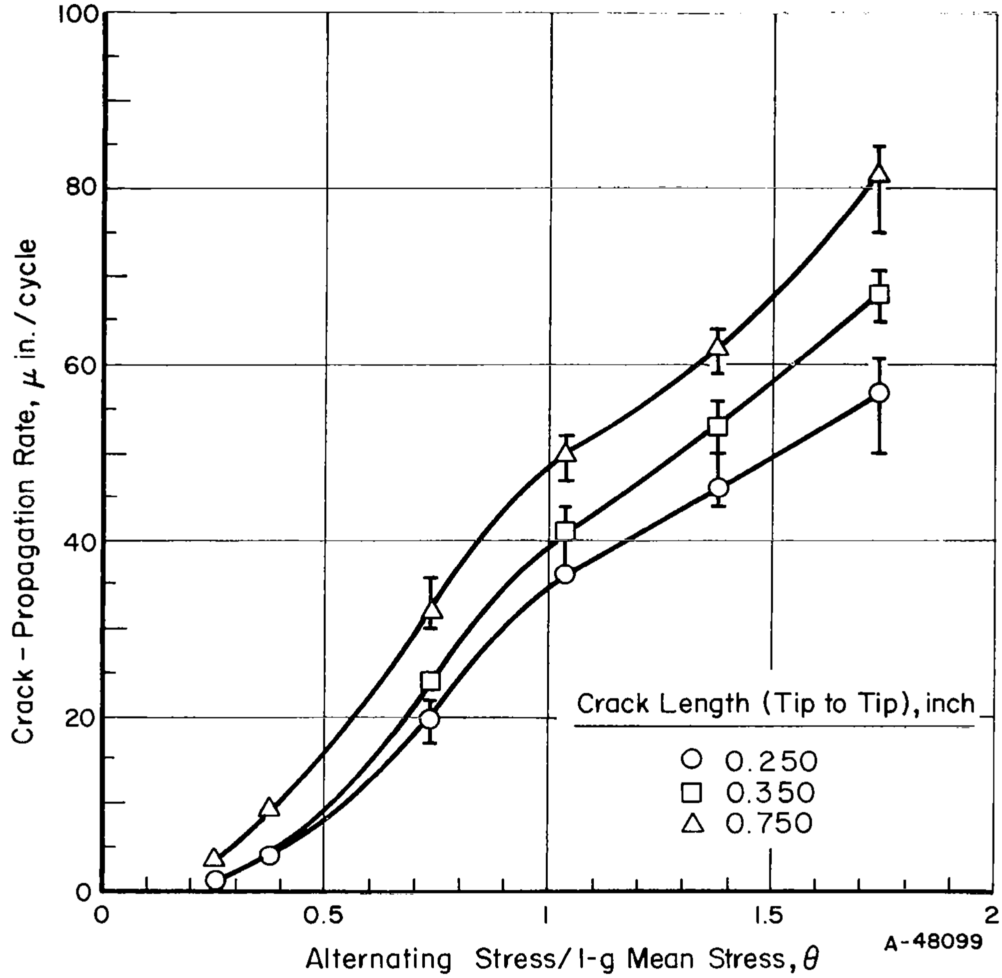


FIGURE 4. EFFECT OF THE RATIO θ ON CRACK-PROPAGATION RATE IN Ti-8Al-1Mo-1V ALLOY SHEET SPECIMENS

Specimens: Unexposed, 2 inches wide, longitudinal.

Conditions: Room temperature, 1200-1725 cpm, constant net-section stress.

TABLE 3. CRACK-PROPAGATION DATA FOR A 2-INCH-WIDE Ti-8Al-1Mo-1V ALLOY SHEET SPECIMEN AT SEVERAL ALTERNATING STRESS AMPLITUDES AND CRACK LENGTHS

25-ksi mean stress, room temperature, unexposed, longitudinal, and 1725 cpm

Condition	ASA	θ	ℓ_i	ℓ_f	N	$\Delta\ell/\Delta N$
1	6.25	0.25	0.1218	0.1218	1000	0
2	7.50	0.30	0.1218	0.2880	320	2.5(a)
3	7.00	0.28	0.2880	0.3433	30	1.8
4	6.50	0.26	0.3433	0.3922	30	1.6
5	6.00	0.24	0.3922	0.4463	30	1.8
6	5.00	0.20	0.4463	0.4965	40	1.3
7	4.50	0.18	0.4965	0.5371	50	0.8
8	3.75	0.15	0.5371	0.5568	40	0.5
9	3.00	0.12	0.5568	0.5936	130	0.3
10	2.00	0.08	0.5936	0.6072	150	0.09
11	1.25	0.05	0.6072	0.6072	80	0.00

ASA – alternating stress amplitude in ksi.
θ – alternating stress amplitude/mean stress.
ℓ_i – initial tip-to-tip crack length at indicated condition.
ℓ_f – final tip-to-tip crack length at indicated condition.
N – number of cycles (x 10^{-3}) under given condition.
$\Delta\ell/\Delta N$ – average crack propagation rate, μin./cycle.

(a) Represents average crack-propagation rate over the final portion of this condition.

TABLE 4. CRACK-PROPAGATION DATA FOR A 2-INCH-WIDE AM-350 STAINLESS STEEL SHEET SPECIMEN AT SEVERAL ALTERNATING STRESS AMPLITUDES AND CRACK LENGTHS

40 ksi mean stress, room temperature, unexposed, longitudinal, and 1725 cpm

Condition	ASA	θ	ℓ_i	ℓ_f	N	$\Delta\ell/\Delta N$
1	10.0	0.25	0.1234	0.1234	1000	0
2	12.0	0.30	0.1234	0.287	84	5.0(a)
3	11.2	0.28	0.287	0.363	16	4.7
4	10.4	0.26	0.363	0.390	6	4.5
5	9.6	0.24	0.390	0.445	14	3.9
6	8.0	0.20	0.445	0.4935	17.5	2.8
7	7.2	0.18	0.4935	0.542	22.5	2.2
8	6.0	0.15	0.542	0.554	10	1.2
9	4.8	0.12	0.554	0.594	45	0.9
10	3.2	0.08	0.594	0.612	67	0.3
11	2.0	0.05	0.612	0.6205	108	0.08
12	1.2	0.03	0.6205	0.6205	110	0.00

ASA – alternating stress amplitude in ksi.
θ – alternating stress amplitude/mean stress.
ℓ_i – initial tip-to-tip crack length at indicated condition.
ℓ_f – final tip-to-tip crack length at indicated condition.
N – number of cycles (X 10^{-3}) under given condition.
$\Delta\ell/\Delta N$ – average crack propagation rate, μin./cycle.

(a) Represents average crack-propagation rate over the final portion of this condition.

A very limited study was made of the differences in crack-propagation behavior of the titanium alloy between tests conducted under constant net-section stress and those under constant gross-section stress. One specimen under the latter stress condition was tested at each value of θ employed in the program. The crack-propagation behavior of the material under the two stress conditions is illustrated in Figures 5 and 6.

It has been proposed that the rate at which a crack propagates under constant gross-section stress is given by

$$\frac{d\ell}{dN} = c\,\ell^m S_G^n \quad ,$$

where

ℓ = total crack length

S_G = gross section stress amplitude

c, m, and n are constants.

In the analysis of the present data, the exponent m was taken equal to 1.0, after Frost and Dugdale(12) and Liu(13). This assumption implies a linear relationship between log ℓ and N over a limited range. The exponent n was found to be 1.7 from Figure 5 for these specimens tested at S_{mean} = 25 ksi. From Figure 6 it can be seen that the linear relationship between log ℓ and N did exist for ℓ/w values up to at least 0.4 for the constant gross-section stress tests. On much wider specimens than used in the present program, this linear relation was reported by Frost and Dugdale to be valid for ℓ/w values of 0.125 or less, with the exponent n = 3.0 for all materials that they tested.

Figures 5 and 6 show that specimens tested with constant net-section stress do not follow the above expression. Careful examination of Figure 5 and Table 2 shows for specimens tested in this manner, that the rate of crack propagation became almost constant at some crack length in the range 0.500 to 1.000 inch. In some cases the propagation rate decreased after reaching some maximum value. In this respect, there was a major difference in the two types of crack-propagation tests.

Another way of considering the data is by means of the form suggested by McEvily and Illg,(14) as shown in Figure 7.

In this figure, the parameter, $K_N S_{net}$, was evaluated for the constant gross-section stress tests by using the simplifying assumption that the effective crack-tip radius, ρ_e, was approximately equal to the Neuber constant, ρ', and thus

$$K_N = [\,1 + 1/2\,(K_H - 1)\,(\ell/2\rho')^{1/2}\,] \quad ,$$

where

ℓ = total crack length

K_H = theoretical stress-concentration factor for a hole of diameter ℓ.

The value of ρ' was evaluated from Figure 5c of Reference (15) and was found to be approximately equal to 0.0049 inch. The term S_{net} is defined as the maximum nominal net-section stress to which the remaining uncracked area of the specimen is subjected.

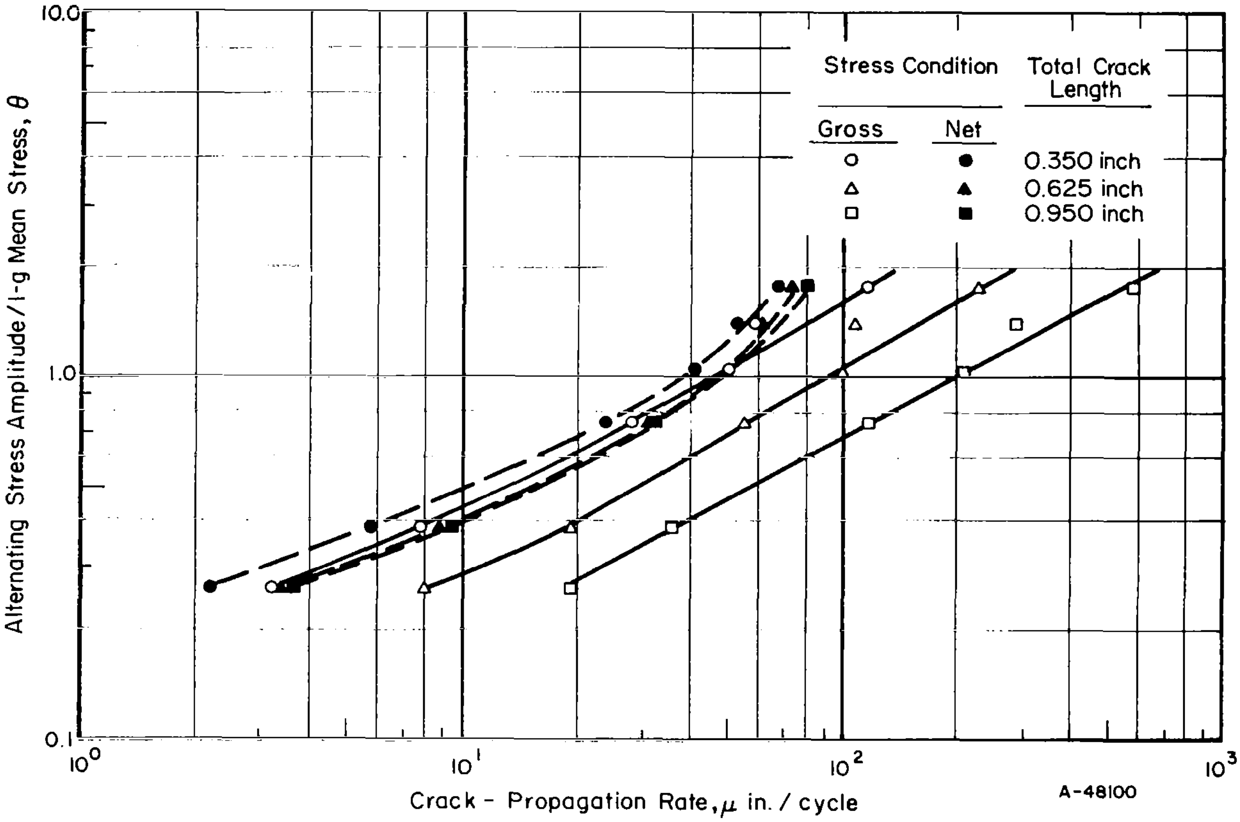


FIGURE 5. EFFECT OF STRESS CONDITION ON CRACK-PROPAGATION RATE IN 2-INCH-WIDE, LONGITUDINAL Ti-8Al-1Mo-1V ALLOY SHEET SPECIMENS

Room temperature, 1200-1725 cpm, and 25-ksi mean stress.

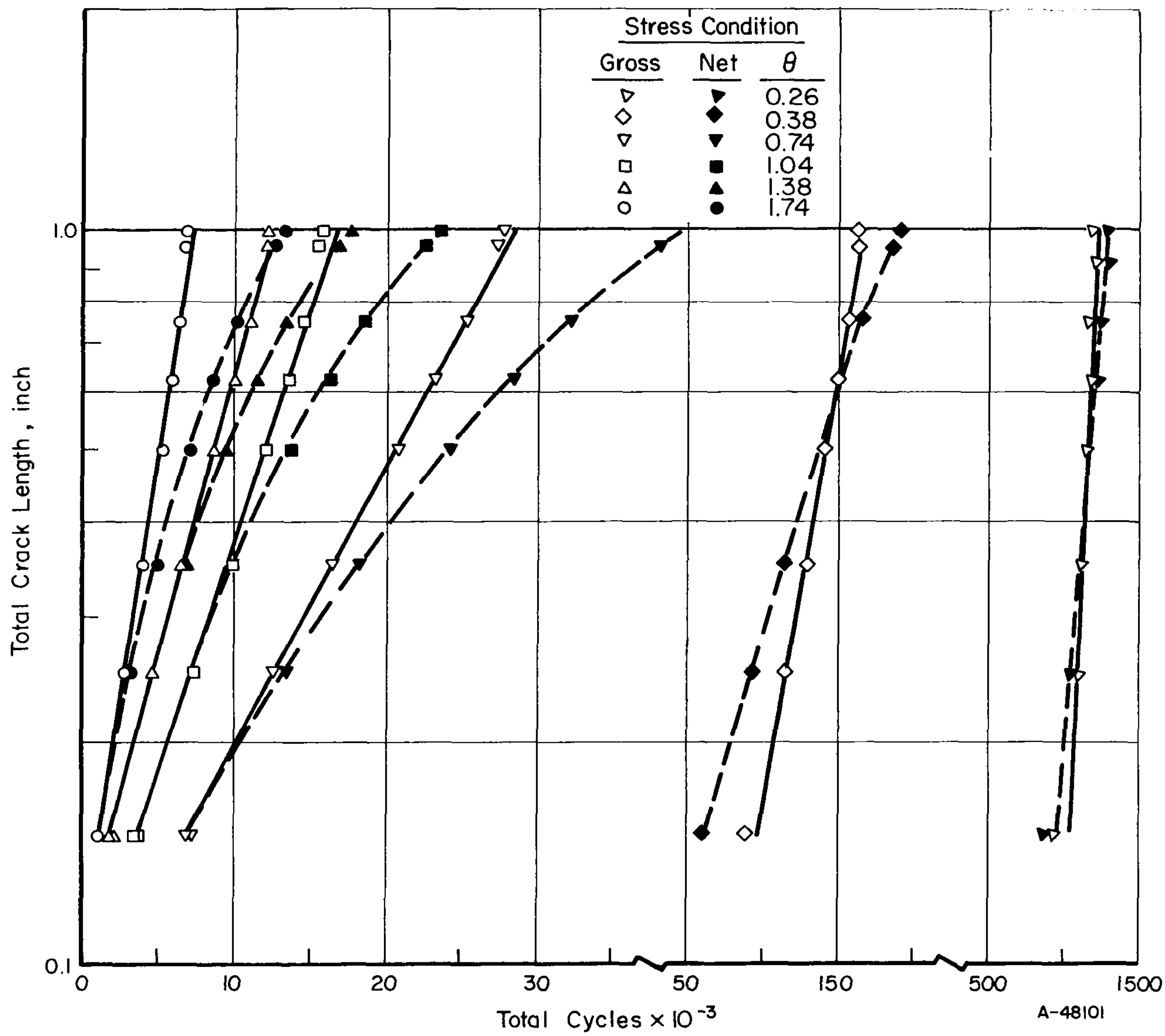


FIGURE 6. EFFECT OF STRESS CONDITION ON THE NUMBERS OF CYCLES TO A PARTICULAR CRACK LENGTH IN 2-INCH-WIDE, LONGITUDINAL Ti-8Al-1Mo-1V ALLOY SHEET SPECIMENS

Room temperature, 1200-1725 cpm, and 25-ksi mean stress.

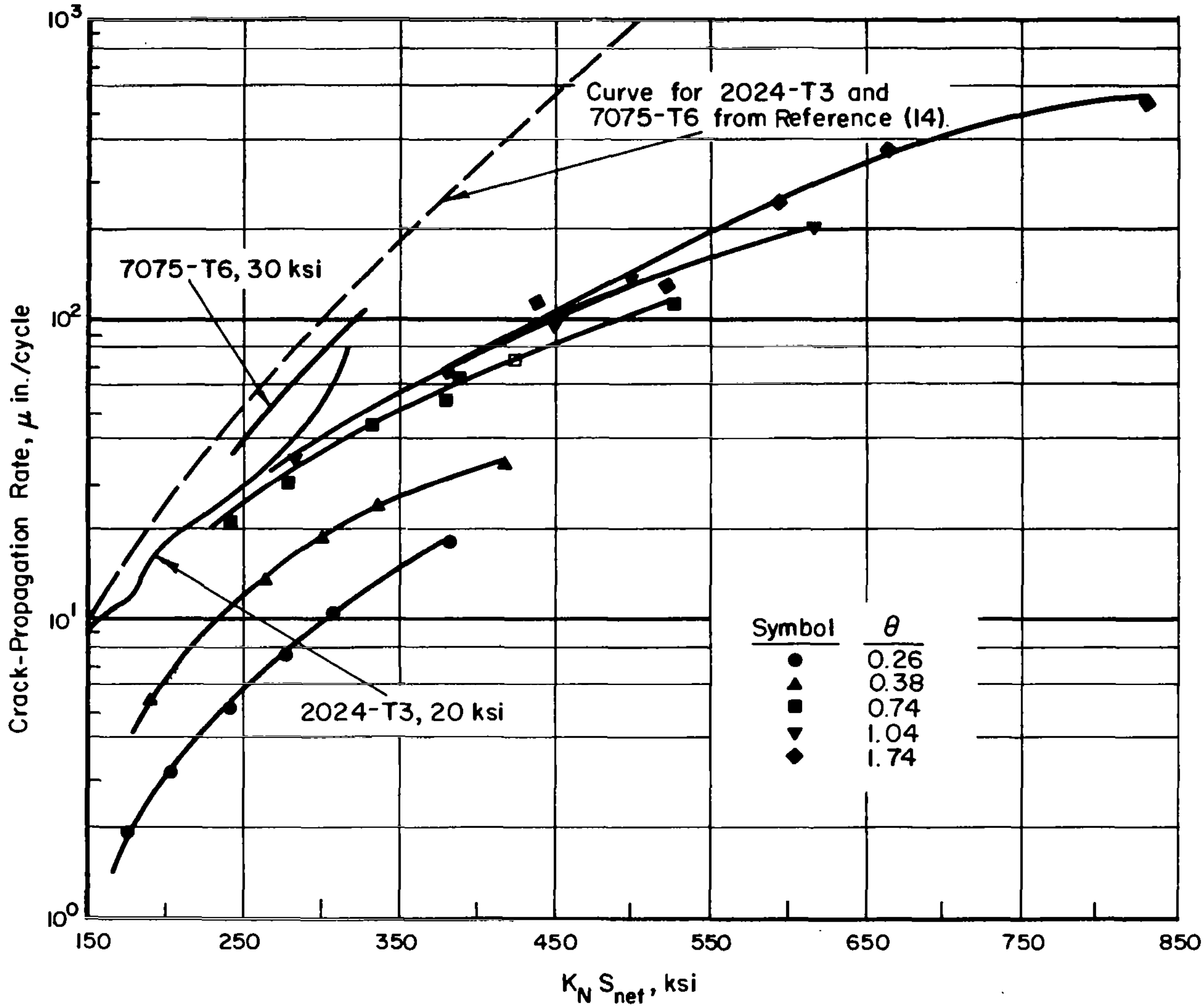


FIGURE 7. CRACK-PROPAGATION RATE AS A FUNCTION OF K_NS_{net} FOR 2-INCH-WIDE, LONGITUDINAL Ti-8Al-1Mo-1V ALLOY SHEET SPECIMENS TESTED UNDER CONSTANT GROSS-SECTION STRESS CONDITION

Room temperature, 1200-1725 cpm, and 25-ksi mean stress.

Also shown on the figure are three additional curves from Reference (14). The dashed curve is plotted from an empirical expression relating crack-propagation rate with $K_N S_{net}$ for 2- and 12-inch-wide center-cracked specimens of 2024-T3 and 7075-T6 aluminum alloys. All tests were run essentially at R = 0, and the dashed curve fit all of the data reasonably well. To provide for a comparison of the results from the tests on Ti-8Al-1Mo-1V alloy and the aluminum alloys, two individual curves were singled out (one for each alloy) and are plotted in Figure 7. These were selected because the ratio of the mean test stress to tensile strength of each aluminum alloy was about equivalent to that of the titanium alloy. Thus, the latter two curves can be compared with the curve for titanium for $\theta = 1.04$. This limited comparison showed that for equal values of $K_N S_{net}$, the rate of crack propagation of the titanium was less than that of the aluminum alloys.

Also shown in Figure 7 is the fact that the titanium data cannot be represented conveniently by a single curve. Further evaluation, particularly at low θ values, would be required to establish a functional relationship between crack-propagation rate, R or A and $K_N S_{net}$.

Another limited study concerned the manner in which specimen width affects the propagation behavior of a cracked titanium specimen. Two 4-inch-wide specimens were cracked at each of two values of θ under constant net-section stress. The results are summarized in Table 5 and are illustrated in Figure 8. In general, the number of cycles to propagate a crack to a particular length and the rate of crack propagation at a particular crack length are markedly different for the two specimen widths at the same value of θ. These effects of specimen width are similar to those observed by McEvily and Illg(16), Rolfe and Munse(8), and Weibull(7). Again employing the parameter $K_N S_{net}$, Figure 9 shows that the difference between the propagation rates for the two specimen widths seems to be reasonably accounted for for crack lengths up to an ℓ/ω of about 0.30.

TABLE 5. DATA ON CRACK-PROPAGATION BEHAVIOR OF LONGITUDINAL Ti-8Al-1Mo-1V ALLOY AT ROOM TEMPERATURE AND 1725 CPM FOR TWO SPECIMEN WIDTHS AND TWO STRESS AMPLITUDES

Total Crack Length, inch	Mean Crack-Propagation Rate, μin./cycle, for Indicated Specimen Width: 2 Inches	4 Inches
	$\theta = 0.38$	
0.250	4.3	5.9
0.350	5.8	8.8
0.500	8.1	13
0.625	8.8	16
0.750	9.4	17
0.950	9.0	21
1.250	--	23
1.500	--	23
1.750	--	23
1.900	--	23
	$\theta = 0.74$	
0.250	20	24
0.350	24	32
0.500	29	39
0.625	31	45
0.750	32	51
0.950	32	60
1.250	--	66
1.500	--	68
1.750	--	68
1.900	--	68

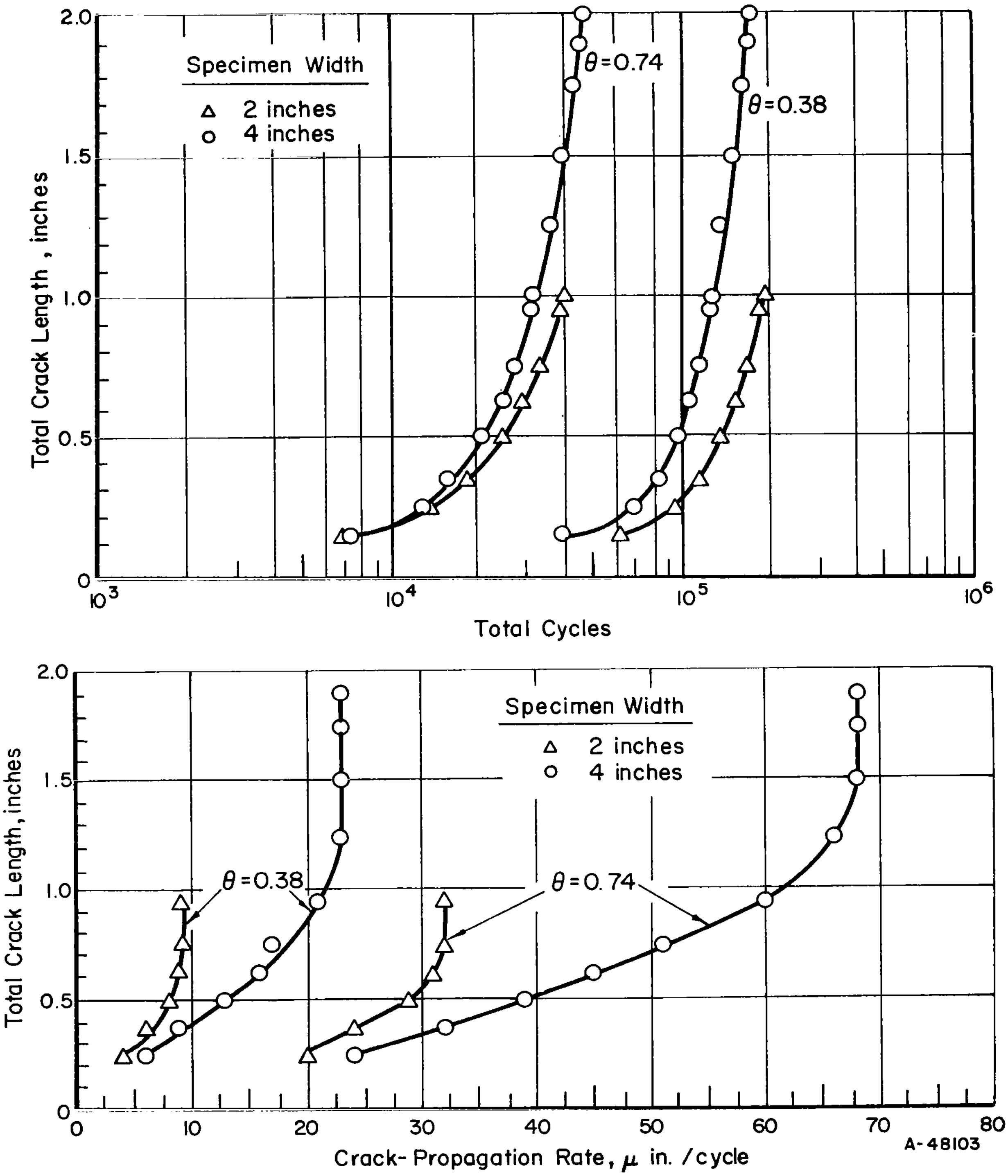


FIGURE 8. EFFECT OF SPECIMEN WIDTH ON THE CRACK-PROPAGATION BEHAVIOR OF LONGITUDINAL Ti-8Al-1Mo-1V ALLOY SHEET SPECIMENS UNDER CONSTANT NET-SECTION STRESS

Room temperature, 1200-1725 cpm, and 25-ksi mean stress.

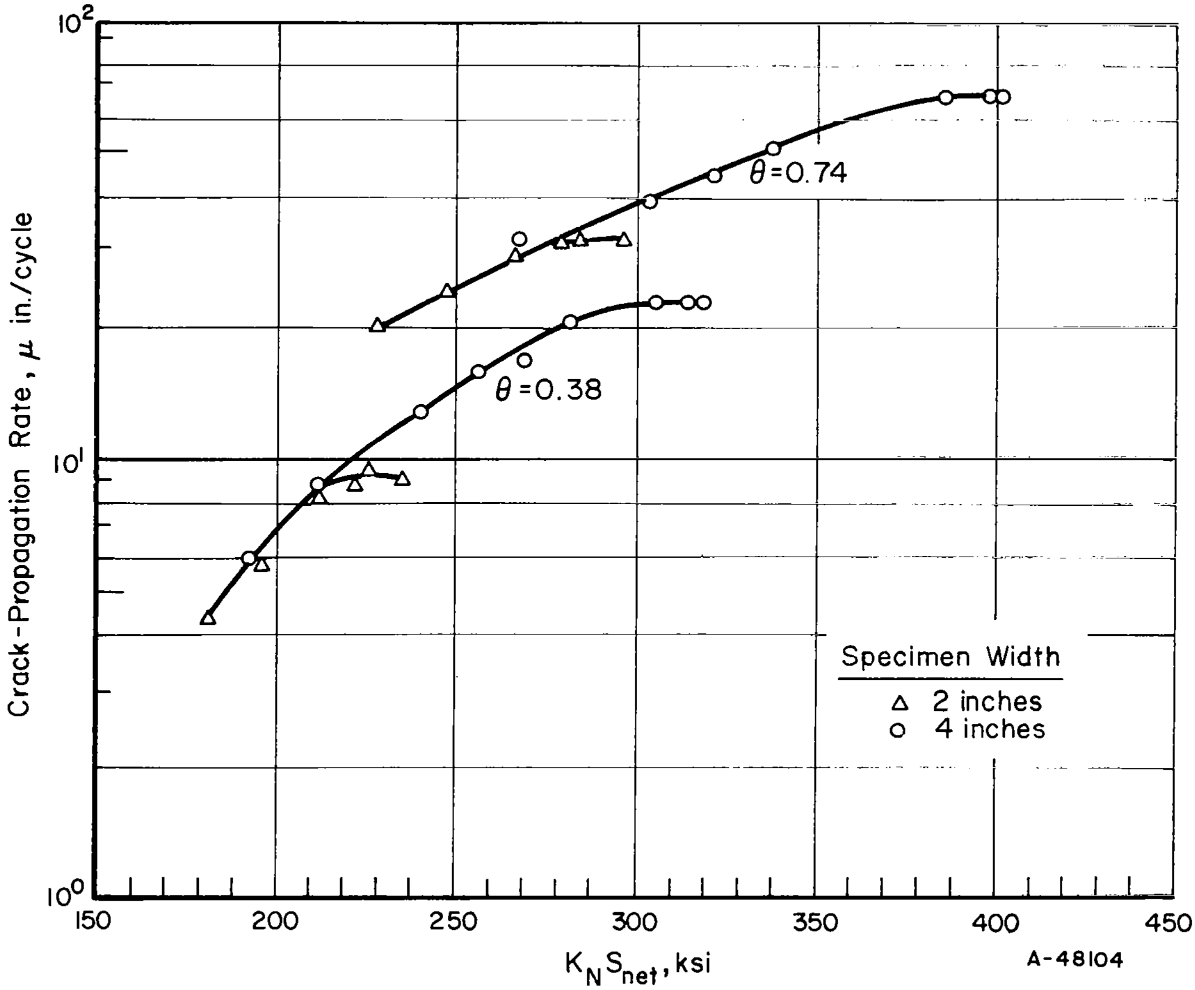


FIGURE 9. CRACK-PROPAGATION RATE AS A FUNCTION OF $K_N S_{net}$ FOR TWO SHEET SPECIMEN WIDTHS OF LONGITUDINAL Ti-8Al-1Mo-1V ALLOY UNDER CONSTANT NET-SECTION STRESS

Room temperature, 1200-1725 cpm, and 25-ksi mean stress.

Effect of Orientation

The effect of the orientation of the specimen with respect to principal rolling direction is summarized in Table 6. Represented here are data from Table 2, Conditions B, C, G, I, N and O. There appears to be some difference between propagation rates of the longitudinal and transverse specimens at θ values of 0.38, 0.74, and 1.38. These differences are consistent with the lifetime-to-failure data indicated in Table 6. In each comparison, the total lifetime-to-failure and the crack-propagation-rate data suggest that longitudinal specimens have slightly faster crack-growth characteristics than do transverse specimens.

TABLE 6. DATA ON CRACK-PROPAGATION BEHAVIOR AT THREE ALTERNATING STRESS AMPLITUDES FOR 2-INCH-WIDE Ti-8Al-1Mo-1V ALLOY SHEET SPECIMENS

Room temperature and 1725 cpm

Total Crack Length, inch	Mean Crack-Propagation Rate, μin./cycle, for Indicated Specimen Orientation	
	Longitudinal	Transverse
	$\theta = 0.38$	
0.250	4.3	4.0
0.350	5.8	4.7
0.500	8.1	6.4
0.625	8.8	7.9
0.750	9.4	8.1
0.950	9.0	8.4
Failure (cycles)	234,000	291,000
	$\theta = 0.74$	
0.250	20	18
0.350	24	22
0.500	29	27
0.625	31	29
0.750	32	30
0.950	32	31
Failure (cycles)	47,300	51,500
	$\theta = 1.38$	
0.250	46	42
0.350	53	47
0.500	62	58
0.625	62	58
0.750	62	60
0.950	60	55
Failure (cycles)	22,400	23,700

Effect of Cyclic Rates

Data illustrating the effect of cyclic rate on crack propagation were obtained at θ values of 0.74 and 1.38. The testing frequencies evaluated were 34 and 1725 cpm. These data are listed in Table 2 and include conditions F, G, M, and N. Figure 10 shows that if the cyclic rate decreases there is an increase in the rate of crack propagation. In this figure data are illustrated for specimens with crack lengths of 0.250 inch and 0.750 inch. On the basis of the data, it appears that there is a small but significant effect of cycling rate on the rate of crack propagation and that this effect appears more important at high values of alternating stress amplitude and for longer cracks. For the limited conditions evaluated, increases in crack-propagation rate in the range 15 to 25 per cent were observed when testing speed was reduced from 1725 cpm to 34 cpm.

Effect of Temperature

To examine the effects of temperature on crack growth in the titanium alloy, specimens were tested at several values of θ at -110 F and at 550 F. The behavior of these specimens was compared with the behavior of specimens evaluated at room temperature. The high- and low-temperature data correspond to Conditions D, E, J, L, and P in Table 2. Figure 11 shows the influence of temperature on the rate of crack propagation at a crack length of 0.750 inch. Similar observations apply to shorter cracks. From this figure it is seen that at a given alternating stress the crack growth is more rapid the lower the temperature. Table 7 contains a summary of lifetime data for the points in Figure 11. The lifetime values for $\theta = 0.38$ can be considered to be on S-N curves for the starter notch at the three temperatures in the vicinity of the fatigue limit. From the data in Table 7, the S-N curves would be ordered in the long-life region as were the S-N curves for notched specimens with $K_t = 4.0$ [Figure 21 in Reference (1)].

Effect of Prior Stressed Exposure

Specimens of AM-350 CRT stainless steel and triplex-annealed Ti-8Al-1Mo-1V alloy were statically subjected to the appropriate 1-g mean stress while the specimens were at 550 F. The steel specimens were exposed at 40 ksi for 10,000 hours; the titanium specimens at 25 ksi for 8,000 hours. The specimens then were fatigue cracked, and crack-growth measurements were made. Table 8 is a summary of data obtained on exposed and unexposed specimens. Two cases are illustrated: (1) where the starter crack has grown to 0.250 inch and (2) where the crack has grown to 0.625 inch. The summary for stainless steel shows that the rate of crack propagation is not affected by 10,000 hours of stressed exposure. This is consistent with observations made at 1000 hours' exposure. The titanium specimens show some increase in propagation rate with exposure.

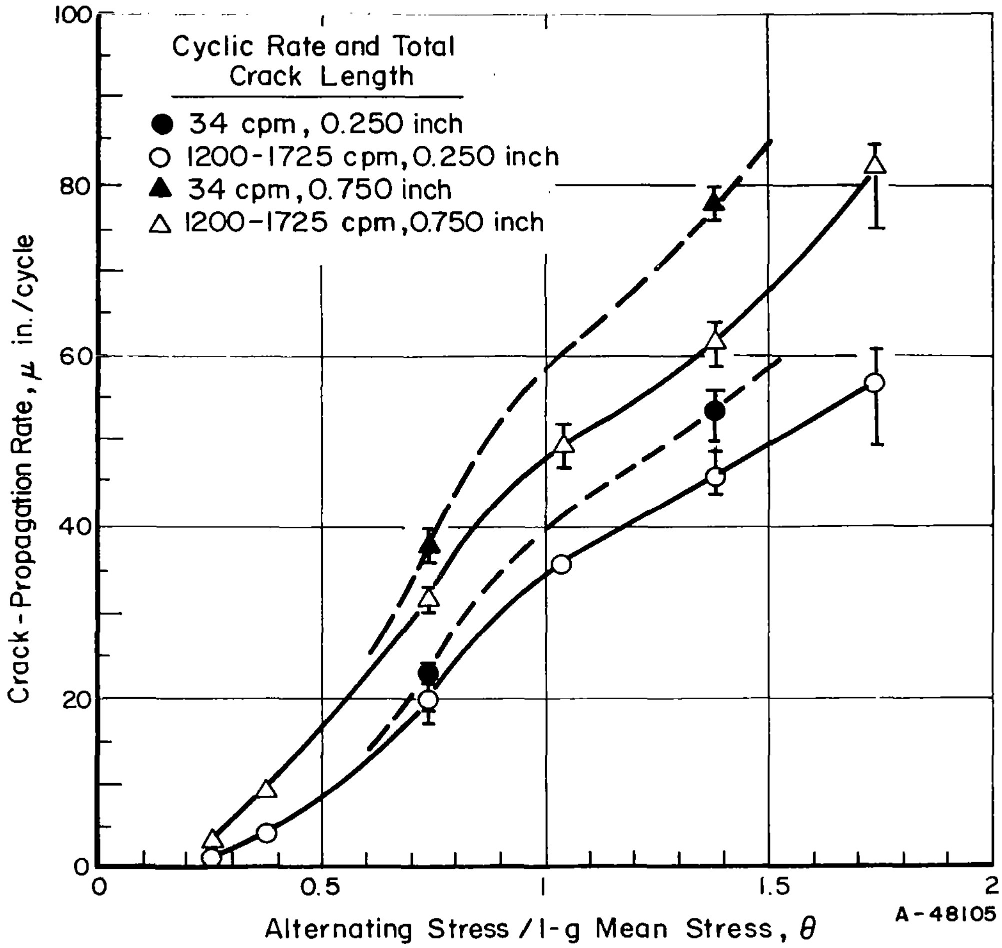


FIGURE 10. EFFECT OF CYCLIC RATE ON CRACK-PROPAGATION RATE IN 2-INCH-WIDE, LONGITUDINAL Ti-8Al-1Mo-1V ALLOY SHEET SPECIMENS AT ROOM TEMPERATURE

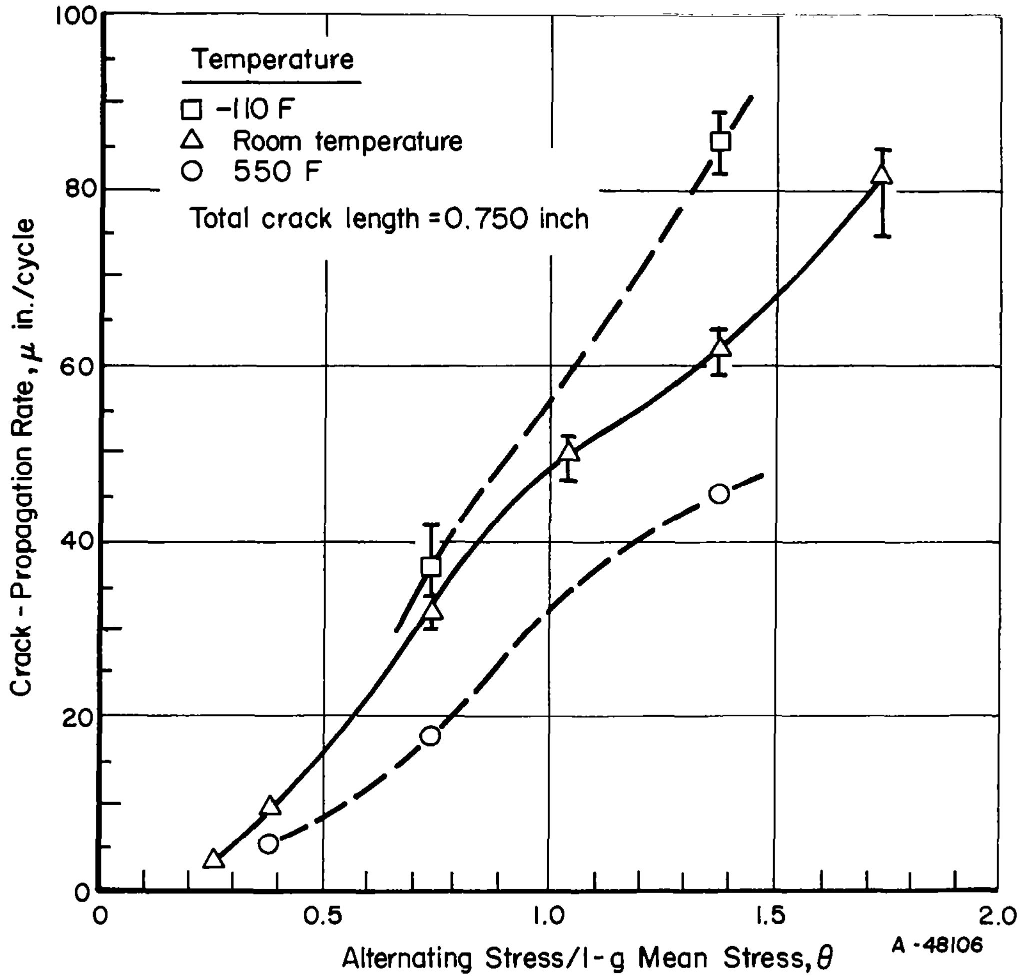


FIGURE 11. EFFECT OF TEMPERATURE ON CRACK-PROPAGATION RATE IN 2-INCH-WIDE, LONGITUDINAL Ti-8Al-1Mo-1V ALLOY SHEET

Specimens at 1200-1725 cpm.

TABLE 7. DATA ON CRACK-PROPAGATION BEHAVIOR AT THREE ALTERNATING STRESS AMPLITUDES AND THREE TEMPERATURES FOR Ti-8Al-1Mo-1V ALLOY SHEET

2-inch-wide longitudinal specimens at 1725 cpm.

Temperature, F	Mean Total Cycles to Indicated Crack Length x 10^{-3}: 0.150 Inch (Initiation)	Failure
	θ = 0.38	
-110	No initiation in 750,000 cycles	--
RT	61.2	234
550	57.4	315
	θ = 0.74	
-110	9.2	48.3
RT	7.1	47.3
550	7.6	76.5
	θ = 1.38	
-110	1.9	16.4
RT	2.2	22.4
550	1.7	27.1

TABLE 8. DATA ON CRACK-PROPAGATION BEHAVIOR OF AM-350 STAINLESS STEEL AND Ti-8Al-1Mo-1V ALLOY SHEET AT ROOM TEMPERATURE SUBJECTED TO PRIOR STRESSED EXPOSURE

2-inch-wide longitudinal specimens at 1200-1725 cpm.

Total Crack Length, inch		Crack-Propagation Rate, μin./cycle, for Indicated Exposure Time: Zero	8,000 Hours	10,000 Hours
		AM-350 at θ = 0.75		
0.250	Minimum	14	--	19
	Mean	21	--	20
	Maximum	29	--	20
0.625	Minimum	30	--	29
	Mean	36	--	34
	Maximum	40	--	38
		Ti-8Al-1Mo-1V at θ = 0.74		
0.250	Minimum	17	21	--
	Mean	20	23	--
	Maximum	22	24	--
0.625	Minimum	30	34	--
	Mean	31	38	--
	Maximum	33	45	--

Residual-Static-Strength Studies

Procedures and Equipment

To determine the residual static strength and its dependence on several variables, center-cracked sheet specimens, 2 inches wide by 8 inches long, were tested in tension. The specimen geometry was identical to that employed in fatigue crack-propagation experiments (see Figure 1), except for slight modifications in the grip section. To alleviate difficulty with failures near the loading pin, stiffeners were spot welded to the grip section of the specimen and 3/4-inch-diameter loading-pin holes were drilled.

In conducting the tension tests, a constant head speed of approximately 0.02 inch/minute was used. Low-temperature tests were conducted in a mixture of dry ice and alcohol with the specimen completely immersed. Tests at 550 F were conducted in a cylindrical furnace that completely enclosed the specimen. Test temperatures were measured by thermocouples in contact with the specimen near the center crack.

The variables investigated for their effect on the residual static strength of Ti-8Al-1Mo-1V were crack length, test temperature, orientation with respect to the rolling direction, fatigue conditions employed to introduce the crack, and prior exposure to 1-g stress at 550 F.

In addition, the effect at 10,000 hours' exposure was examined for the AM-350 stainless steel. The residual-strength studies of unexposed steel and the steel after intermediate exposure are given in Reference 1.

Effect of Crack Length

Nominal crack lengths of 3/16, 3/8, 3/4, and 1 inch were examined for their effect on residual static strength. In Figure 12, residual strength at three test temperatures is shown as a function of crack length; Table 9 contains all the pertinent data.

The data presented in Figure 12 and Table 9 show that the residual strength (both net section and gross section) decreases with increasing crack length, with one exception: specimens having crack lengths of 3/4 inch, when tested at 550 F, exhibited greater net-section strengths than those having crack lengths of 3/16 or 3/8 inch. At room temperature and -110 F, residual strength decreases continuously with increasing crack length.

Effect of Test Temperature

Residual strength was determined at test temperatures of -110, 75, and 550 F. In Figure 13 residual strength is shown as a function of test temperature for various crack lengths. Included for comparison is a curve showing the variation of the ultimate tensile strength with temperature.

Examination of Figure 13 and Table 9 shows that the residual strength decreases continuously with increasing test temperature for all the crack lengths investigated. However, the decrease in strength between room temperature and 550 F of specimens containing 3/4-inch cracks is considerably less than that of specimens with smaller cracks.

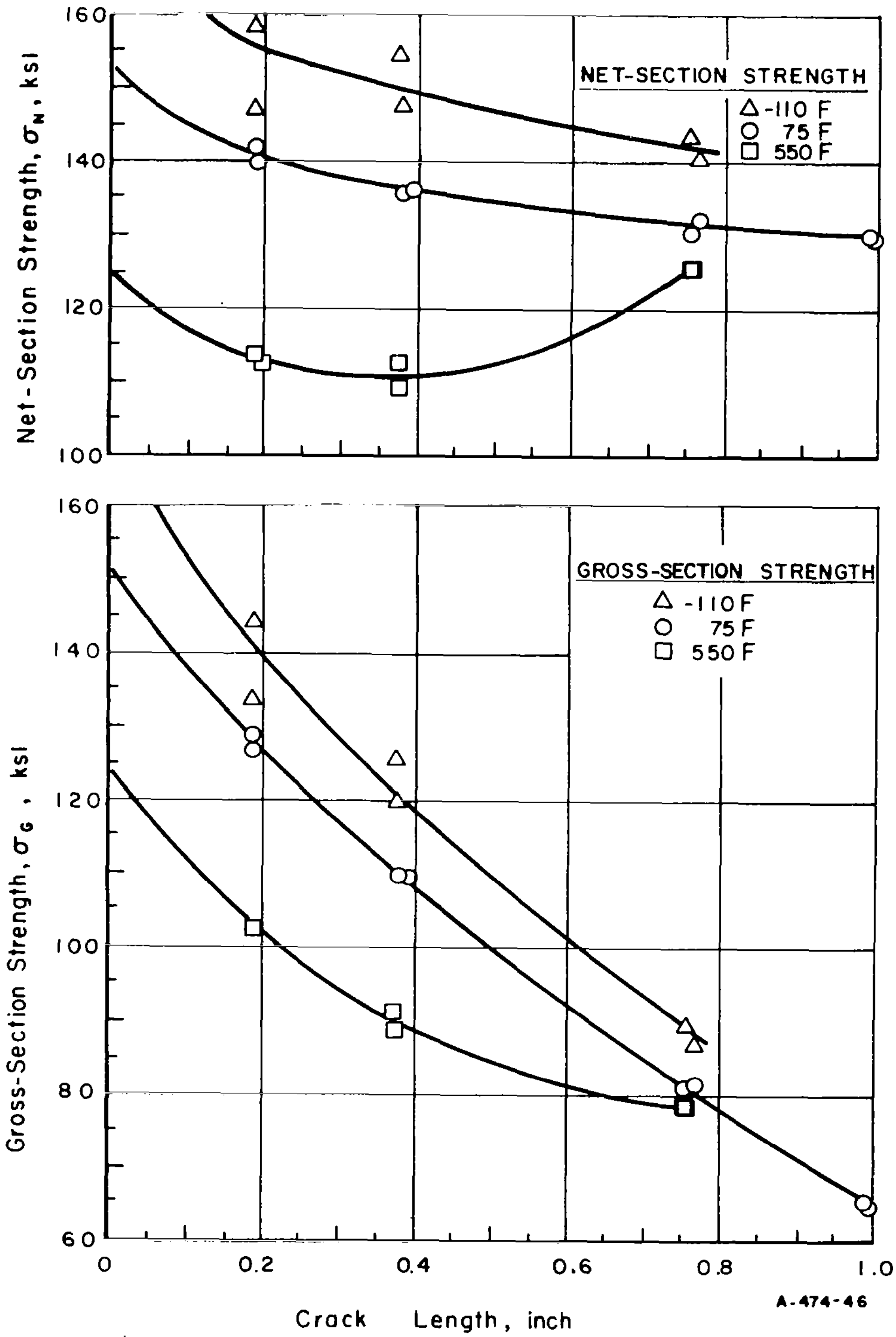


FIGURE 12. EFFECT OF CRACK LENGTH, AT THREE TEST TEMPERATURES, ON NET-SECTION STRENGTH AND GROSS-SECTION STRENGTH OF CENTER-CRACKED Ti-8Al-1Mo-1V SHEET SPECIMENS

Longitudinal specimens, 2 inches wide.

TABLE 9. RESULTS OF TENSILE TESTS ON CENTER-CRACKED Ti-8Al-1Mo-1V SHEET SPECIMENS FATIGUE CRACKED AT ROOM TEMPERATURE

2-inch-wide specimens 25-ksi mean stress, 18.5-ksi alternating stress amplitude (θ = 0.74) and 1725 cpm.

Specimen	Orientation	Test Temperature, F	Initial Crack Length, inches	Thickness, inches	σ_N(a), ksi	σ_G(b), ksi
8325	L	75	0.188	0.042	139.9	126.9
6345	L	75	0.186	0.047	142.2	129.0
6348	L	75	0.379	0.047	135.9	110.1
8169	L	75	0.390	0.042	136.2	109.6
7338	L	75	0.754	0.0445	130.4	81.2
8175	L	75	0.767	0.0405	132.2	81.5
8328	L	75	0.959	0.0433	130.1	65.7
7337	L	75	0.997	0.044	130.0	65.3
7329	L	-110	0.186	0.044	158.6	143.8
7326	L	-110	0.186	0.045	147.1	133.3
8176	L	-110	0.372	0.040	154.2	125.6
7349	L	-110	0.376	0.0442	147.7	119.9
6335	L	-110	0.763	0.0465	140.5	86.9
8167	L	-110	0.752	0.042	143.6	89.6
6351	L	550	0.191	0.0465	113.0	102.3
8170	L	550	0.188	0.0417	113.6	102.9
7331	L	550	0.371	0.0435	112.6	91.5
6338	L	550	0.374	0.0465	109.3	88.8
7333	L	550	0.752	0.0435	125.8	78.5
6337	L	550	0.752	0.0465	125.9	78.5
8229	T	75	0.195	0.0425	132.3	119.4
6206	T	75	0.198	0.048	130.1	117.2
6208	T	75	0.373	0.0475	126.2	102.6
8228	T	75	0.370	0.0425	128.5	104.7
6209	T	75	0.753	0.0475	121.6	75.8
8227	T	75	0.752	0.0415	123.1	76.8
8225	T	75	1.000	0.042	121.5	60.7
7227	T	75	1.001	0.043	123.8	61.9

(a) Net-section strength: $\sigma_N = \frac{\text{maximum load}}{\text{thickness x (width - crack length)}}$.

(b) Gross-section strength: $\sigma_G = \frac{\text{maximum load}}{\text{thickness x width}}$.

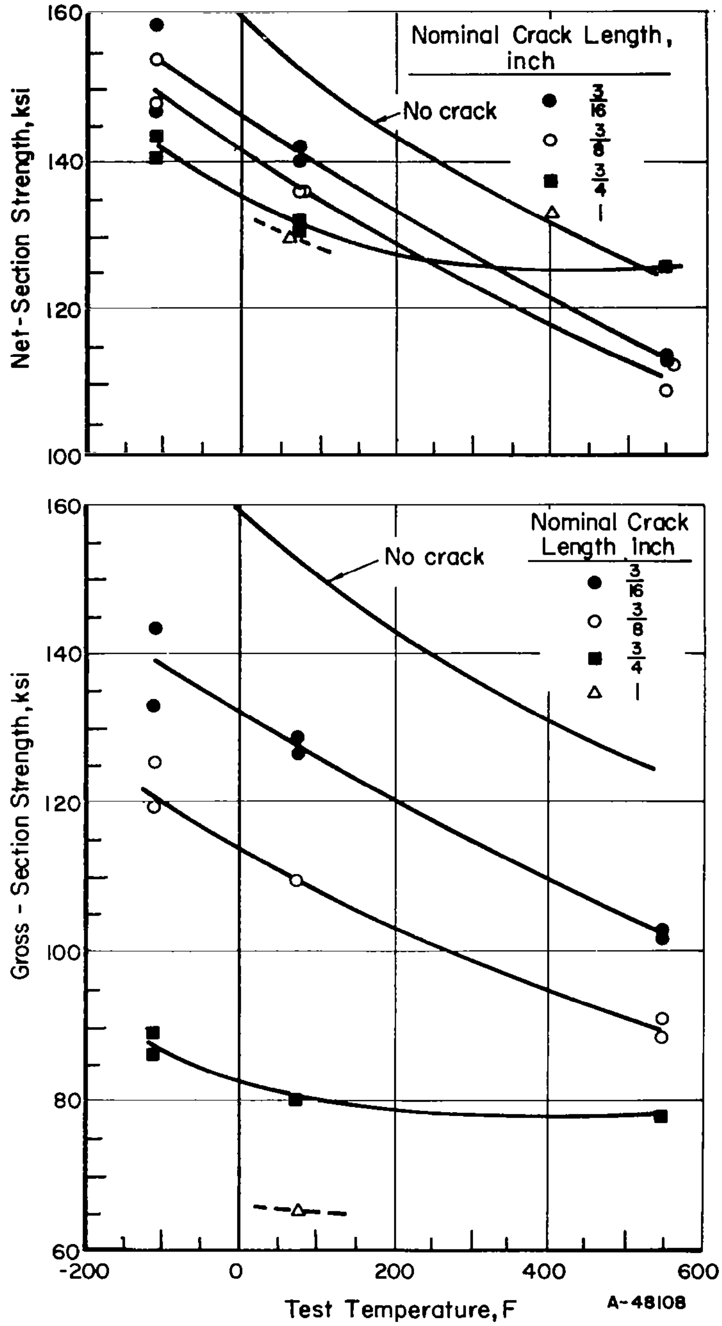


FIGURE 13. EFFECT OF TEST TEMPERATURE AT SEVERAL CRACK LENGTHS ON NET-SECTION STRENGTH AND GROSS-SECTION STRENGTH OF CENTER-CRACKED Ti-8Al-1Mo-1V SHEET SPECIMENS

2-inch-wide longitudinal specimens.

Effect of Orientation With Respect to the Rolling Direction

Specimens containing nominal 3/16-, 3/8-, 3/4-, and 1-inch cracks were tested at room temperature, both parallel and perpendicular to the rolling direction, to determine the effect of specimen orientation on residual strength. The results are shown in Figure 14 and Table 9. At all crack lengths investigated, transverse specimens (i. e., those with the specimen axis perpendicular to the rolling direction) exhibited a lower residual strength than did longitudinal specimens. The difference in the strength levels between the two specimen orientations is about the same to crack lengths up to ℓ/ω = 0.500.

Effect of Fatigue Conditions Used to Introduce Cracks

To determine whether or not the residual strength of fatigue-cracked Ti-8Al-1Mo-1V is influenced by the manner in which the crack is introduced, experiments were performed in which the fatigue-stress amplitude, fatigue temperature, and cycling speed were varied.

Effect of Fatigue-Stress Amplitude. Four different stress amplitudes were employed to introduce fatigue cracks in Ti-8Al-1Mo-1V. These were 9.5-, 18.5-, 34.5- and 43.5-ksi (θ values of 0.38, 0.74, 1.38, and 1.74, respectively), all superposed upon a mean stress of 25 ksi. In Section C of Table 10, the net-section and gross-section strengths are given for several values of stress amplitudes (and θ) at several crack lengths and for both longitudinal and transverse specimen orientations. It is apparent that fatigue-stress amplitude, in the range studied, has virtually no effect on residual strength.

Effect of Fatigue-Cracking Temperature. Fatigue cracks 3/4-inch long were introduced at temperatures of -110, 75, and 550 F, prior to determination of residual strength at room temperature. An examination of Section A of Table 10 shows that there is no appreciable effect of fatigue-cracking temperature on the residual strength of the 8Al-1Mo-1V titanium alloy.

Effect of Cyclic Frequency. Two different cyclic frequencies, 1725 and 34 cycles per minute, were used to introduce 3/4-inch fatigue cracks in Ti-8Al-1Mo-1V sheet specimens. As shown in Section B of Table 10, no effect of cyclic speed upon residual strength was observed.

Effect of Exposure to 1-g Stress at 550 F

Center-notched Ti-8Al-1Mo-1V sheet specimens were exposed in air to a 1-g (25.0 ksi) net-section stress at 550 F for 8000 hours prior to introducing fatigue cracks. Center-cracked specimens then were tested at -110, 75, and 550 F, with the results shown in Table 11 and Figure 15. The results indicate that an 8000-hour exposure weakens the titanium alloy slightly if long cracks are present (3/4 inch in a 2-inch-wide specimen). The data are somewhat inconsistent in this regard, with reference to

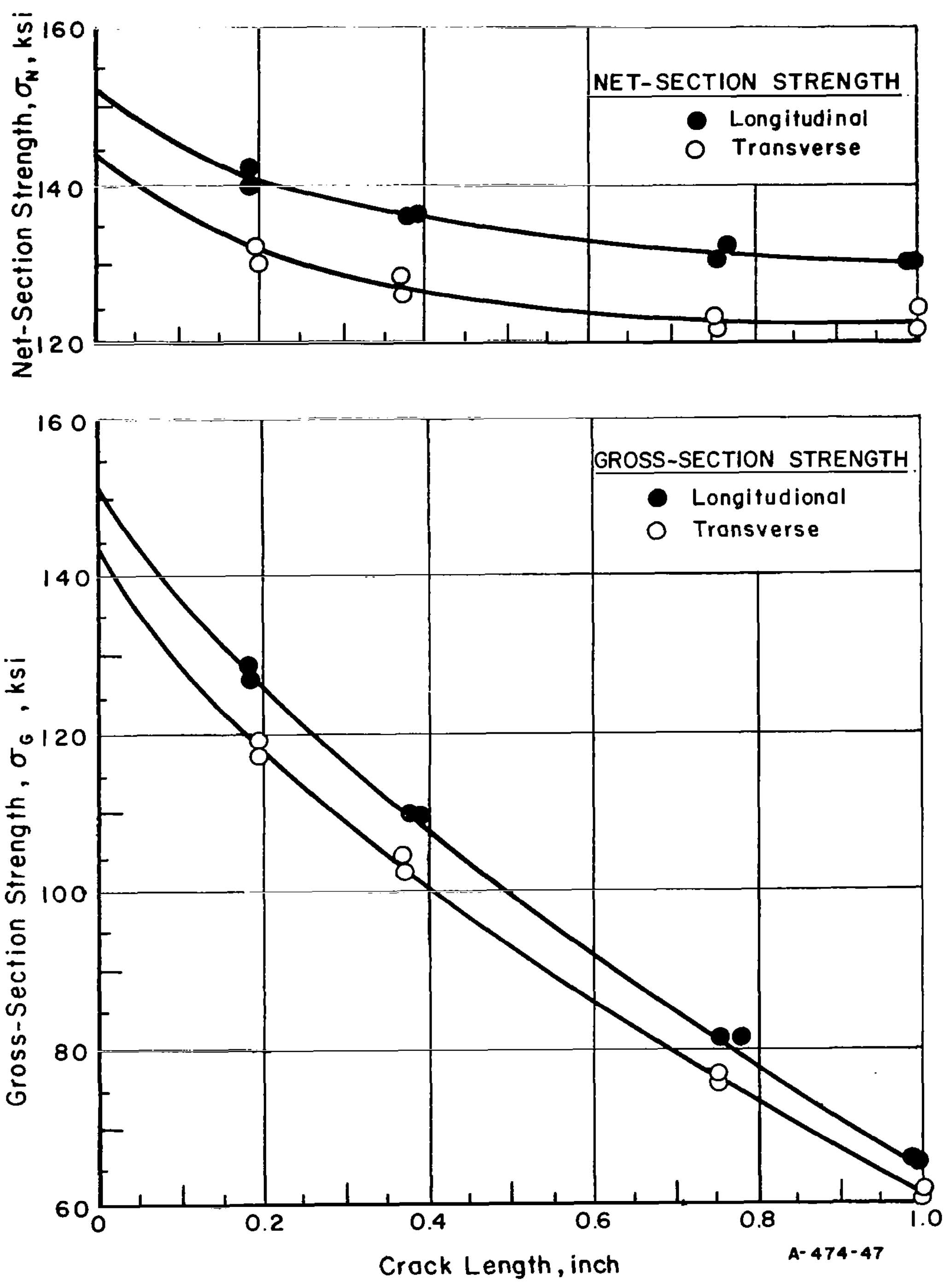


FIGURE 14. EFFECT OF SPECIMEN ORIENTATION ON NET-SECTION STRENGTH AND GROSS-SECTION STRENGTH OF 2-INCH-WIDE, CENTER-CRACKED Ti-8Al-1Mo-1V SHEET SPECIMENS AT ROOM TEMPERATURE

TABLE 10. RESULTS OF ROOM-TEMPERATURE TENSILE TESTS ON 2-INCH WIDE, CENTER-CRACKED, Ti-8Al-1Mo-1V SHEET SPECIMENS, FATIGUE-CRACKED AT VARIOUS TEMPERATURES, CYCLIC FREQUENCIES, AND ALTERNATING STRESS AMPLITUDES

Specimen	Orientation	Crack Length, inches	Thickness, inch	Fatigue-Cracking Conditions: Temperature, F	Frequency, cpm	σ_{mean}, ksi	σ_{alt}, ksi	θ	σ_N(a), ksi	σ_G(b), ksi
				Section A. Effect of Fatigue Temperature						
8162	L	0.766	0.041	-110	1725	25	18.5	0.74	131.3	81.0
8174	L	0.768	0.0405	-110	1725	25	18.5	0.74	134.0	82.6
6354	L	0.752	0.046	-110	1725	25	18.5	0.74	130.3	81.2
7338	L	0.754	0.0445	75	1725	25	18.5	0.74	130.4	81.2
8175	L	0.767	0.0405	75	1725	25	18.5	0.74	132.2	81.5
7336	L	0.748	0.044	550	1725	25	18.5	0.74	131.9	82.4
6344	L	0.749	0.047	550	1725	25	18.5	0.74	131.2	82.2
				Section B. Effect of Cyclic Frequency						
7343	L	0.750	0.0445	75	34	25	18.5	0.74	130.6	81.5
8163	L	0.752	0.0415	75	34	25	18.5	0.74	130.6	81.4
7338	L	0.754	0.0445	75	1725	25	18.5	0.74	130.4	81.2
8175	L	0.767	0.0405	75	1725	25	18.5	0.74	132.2	81.5
				Section C. Effect of Alternating Stress Amplitude						
7343	L	0.750	0.0445	75	34	25	18.5	0.74	130.6	81.5
8163	L	0.752	0.0415	75	34	25	18.5	0.74	130.6	81.4
8168	L	0.779	0.042	75	34	25	34.5	1.38	132.9	81.0
7347	L	0.755	0.044	75	34	25	34.5	1.38	130.7	81.3
6353	L	1.000	0.046	75	1725	25	9.5	0.38	127.1	63.5
8332	L	1.000	0.042	75	1725	25	9.5	0.38	129.8	64.9
8328	L	0.989	0.0433	75	1725	25	18.5	0.74	130.1	65.7
7337	L	0.997	0.044	75	1725	25	18.5	0.74	130.0	65.3
7332	L	1.004	0.044	75	1200	25	43.5	1.74	127.8	63.7
8330	L	0.999	0.042	75	1200	25	43.5	1.74	128.9	64.6
7225	T	0.999	0.0435	75	1725	25	9.5	0.38	122.4	61.2
8230	T	0.998	0.042	75	1725	25	9.5	0.38	122.2	61.2
8225	T	1.000	0.042	75	1725	25	18.5	0.74	121.5	60.7
7227	T	1.001	0.043	75	1725	25	18.5	0.74	123.8	61.9
6207	T	1.008	0.048	75	1725	25	34.5	1.38	119.0	59.0
7353	T	0.997	0.044	75	1725	25	34.5	1.38	124.0	62.3

(a) Net-section strength; $\sigma_N = \frac{\text{maximum load}}{\text{thickness x (width - crack length)}}$.

(b) Gross-section strength; $\sigma_G = \frac{\text{maximum load}}{\text{thickness x width}}$.

very small cracks (3/16 inch). Even with the slight weakening observed in the presence of long cracks, however, the material behaves in a ductile fashion at all three test temperatures studied. The ratio of net-section strength to the 1-g stress remains well in excess of 4.0 for all crack lengths and test temperatures.

TABLE 11. EFFECT OF EXPOSURE TO 1-g STRESS (25-KSI) AT 550 F ON RESIDUAL STATIC STRENGTH OF 2-INCH-WIDE CENTER-CRACKED LONGITUDINAL Ti-8Al-1Mo-1V SHEET SPECIMENS

Specimen	Exposure Time, hours	Test Temperature, F	Initial Crack Length, inch	σ_N, ksi	σ_G, ksi
7329	--	-110	0.186	158.6	143.8
7326	--	-110	0.186	147.1	133.3
7430	8000	-110	0.185	156.3	141.9
6335	--	-110	0.763	140.5	86.9
8167	--	-110	0.752	143.6	89.6
7403	8000	-110	0.740	136.7	86.1
8325	--	75	0.188	139.9	126.9
6345	--	75	0.186	142.2	129.0
7434	8000	75	0.188	139.8	126.5
7419	8000	75	0.189	134.2	121.8
7338	--	75	0.754	130.4	81.2
8175	--	75	0.767	132.2	81.5
7427	8000	75	0.752	127.1	79.3
7404	8000	75	0.750	128.0	80.0
6351	--	550	0.191	113.0	102.3
8170	--	550	0.188	113.6	102.9
7422	8000	550	0.183	116.3	105.7
7426	8000	550	0.183	118.8	107.9
7333	--	550	0.752	125.8	78.5
6337	--	550	0.752	125.9	78.5
7417	8000	550	0.741	120.9	76.3
7402	8000	550	0.752	109.2	67.6

As mentioned previously, the residual strength of fatigue-cracked AM-350 was the subject of an earlier investigation. However, tests were conducted in the present study to evaluate the effect of long-time (10,000 hours) exposure to stress at 550 F.

Center-notched AM-350 sheet specimens were exposed in air at a net-section stress of 40 ksi at 550 F prior to introducing fatigue cracks. Center-cracked specimens then were tested at -110, 75, and 550 F, with the results shown in Table 12 and

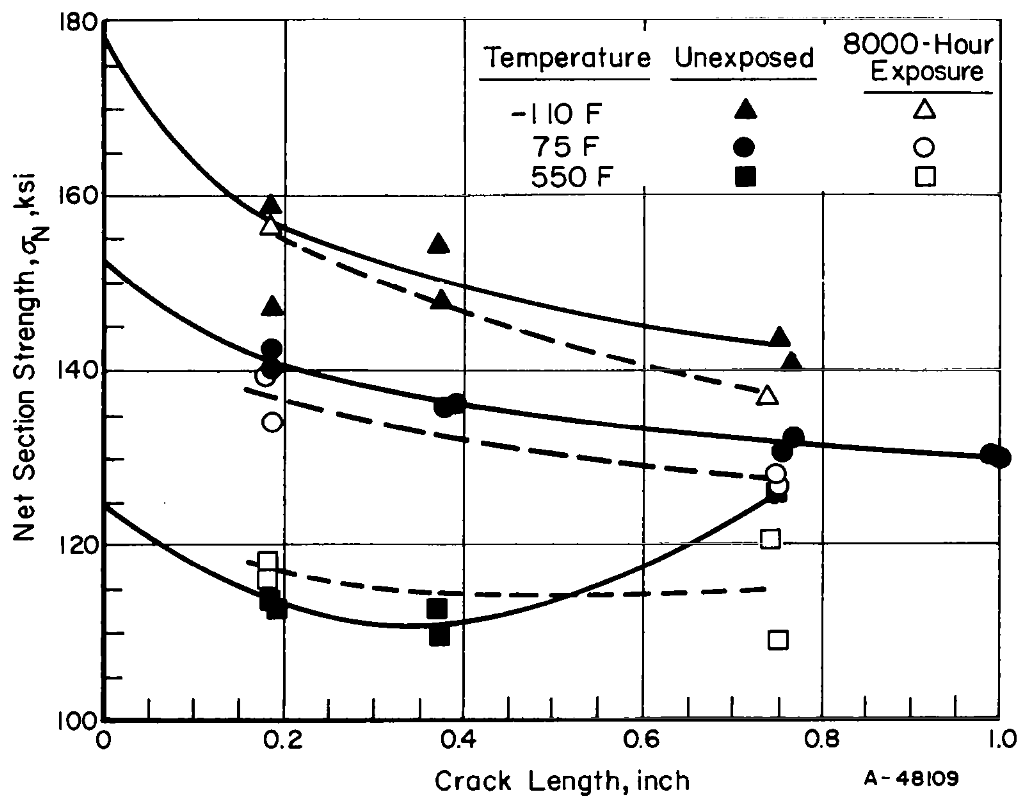


FIGURE 15. EFFECT OF 8000-HOUR EXPOSURE TO 1-G STRESS OF 25-KSI AT 550 F ON NET-SECTION STRENGTH OF 2-INCH-WIDE CENTER-CRACKED LONGITUDINAL Ti-8Al-1Mo-1V SHEET SPECIMENS

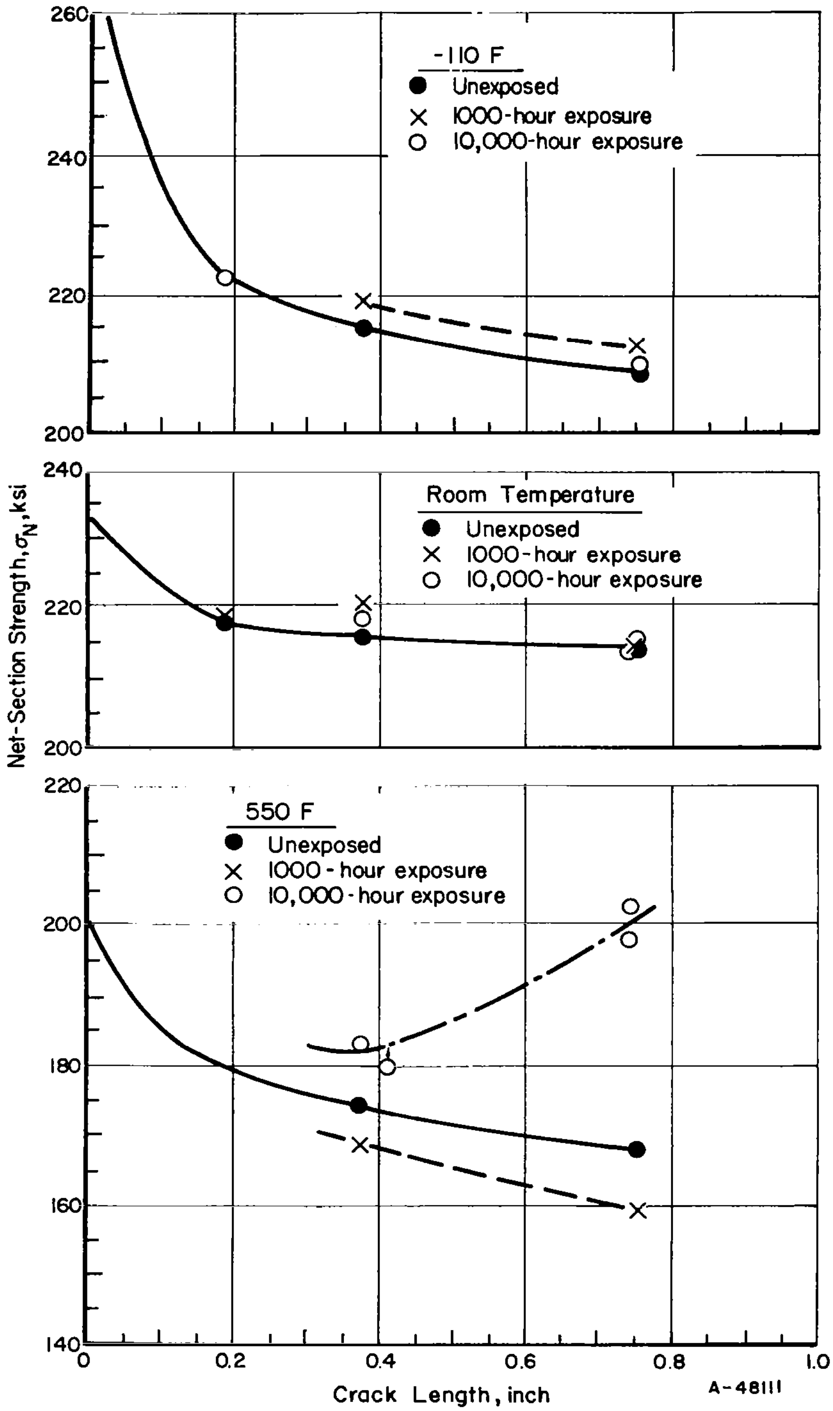


FIGURE 16. EFFECT OF 10,000-HOUR EXPOSURE TO 1-G STRESS OF 40-KSI AT 550 F ON NET-SECTION STRENGTH OF 2-INCH-WIDE CENTER-CRACKED LONGITUDINAL AM-350 SHEET SPECIMENS

TABLE 12. EFFECT OF EXPOSURE TO 1-G STRESS OF 40-KSI AT 550 F ON RESIDUAL STATIC-STRENGTH OF 2-INCH-WIDE, CENTER-CRACKED, LONGITUDINAL AM-350 SHEET SPECIMENS

Specimen	Exposure Time, hours	Test Temperature, F	Initial Crack Length, inches	σ_N, ksi	σ_G, ksi
634	--	-110	0.183	(a)	(a)
832	1,000	-110	0.190	(a)	(a)
6320	10,000	-110	0.182	222.3	202.0
6311	--	-110	0.375	215.4	175.0
7317	1,000	-110	0.374	218.9	177.9
6316	--	-110	0.752	209.0	130.4
8317	1,000	-110	0.749	212.8	133.1
838	10,000	-110	0.753	209.5	131.0
6310	--	75	0.188	217.5	197.1
834	1,000	75	0.188	(a)	(a)
831	1,000	75	0.186	218.4	198.0
7314	10,000	75	0.178	(a)	(a)
631	10,000	75	0.191	(a)	(a)
6313	--	75	0.375	216.0	175.5
8320	1,000	75	0.375	220.8	179.4
8318	10,000	75	0.376	218.5	177.5
6317	--	75	0.751	214.1	133.7
8311	1,000	75	0.747	214.4	134.3
6314	10,000	75	0.739	213.7	134.8
731	10,000	75	0.750	215.5	134.8
638	--	550	0.181	(a)	(a)
8316	1,000	550	0.189	(a)	(a)
6318	10,000	550	0.201	(a)	(a)
635	10,000	550	0.180	(a)	(a)
6312	--	550	0.373	174.7	142.2
835	1,000	550	0.375	168.9	137.3
8315	10,000	550	0.376	183.4	149.0
7312	10,000	550	0.412	>179.8[a]	>142.7[a]
8319	--	550	0.753	168.2	104.9
8313	1,000	550	0.758	159.5	99.0
6319	10,000	550	0.746	203.0	127.4
739	10,000	550	0.744	198.3	124.4

(a) Specimen failed in grips.

Figure 16. There appears to be little effect of exposure at test temperatures of -110 and 75 F, but a significant effect is apparent when testing at 550 F. A 1000-hour exposure leads to a loss in net-section strength at 550 F, whereas a 10,000-hour exposure raises the net-section strength to a level substantially greater than that observed for unexposed specimens. The reason for this marked improvement in net-section strength at 550 F after 10,000 hours exposure to stress at 550 F is not apparent. No difference in Rockwell hardness was discernible at room temperature when comparing exposed with unexposed specimens.

These results, combined with those of the previous investigation, indicate that AM-350 behaves in a ductile fashion at all temperatures and crack lengths studied, and is not adversely affected by long-time exposure to a 1-g stress at 550 F. As was the case for Ti-8Al-1Mo-1V, the AM-350 exhibits ratios of net-section strength to 1-g stress in excess of 4.0.

FATIGUE BEHAVIOR

The stress-lifetime behavior of unnotched and notched ($K_t = 4.0$) AM-350 stainless steel specimens and Ti-8Al-1Mo-1V alloy specimens were evaluated. The behavior of the two materials at -110 F, room temperature, and 550 F and at their respective 1-g mean stresses of 40 ksi and 25 ksi is summarized in Reference (1). The current program has been concerned with the base fatigue strength of the steel alloy at room temperature and 550 F and at mean stresses of zero, 20, and 100 ksi and for the titanium alloy at the same temperatures and mean stresses of zero and 60 ksi. These data have permitted stress-range diagrams for room temperature and 550 F to be constructed. In addition, the effect of notched-specimen orientation at room temperature has been explored. The effects of prior stressed exposure on notched specimens were investigated for exposure times of 10,500 hours at 40 ksi and 550 F for AM-350 and 10,000 hours at 25 ksi and 550 F for Ti-8Al-1Mo-1V. The tabular stress-lifetime data are given in Appendix C.

S-N curves that illustrate the base fatigue behavior of the two alloys at room temperature and at 550 F are shown in Figures 17 through 25. With these figures and appropriate ones from Reference (1), the stress-range diagrams of Figures 26 through 29 have been constructed. These figures show that the unnotched fatigue behavior of the two materials generally decreased with an increase in temperature. The notched behavior of both materials as shown in the next section seems consistent with experience on high-strength aluminum alloys used extensively in aircraft in the past 30 years. The AM-350 steel with higher static strength also shows higher fatigue strengths.

Figures 30 and 31 illustrate the results of the limited study of notched-specimen orientation. The evaluation was made at room temperature and for each material at the appropriate 1-g mean stress. From the figures it is seen that orientation of the specimen does not influence the behavior in fatigue of the two materials.

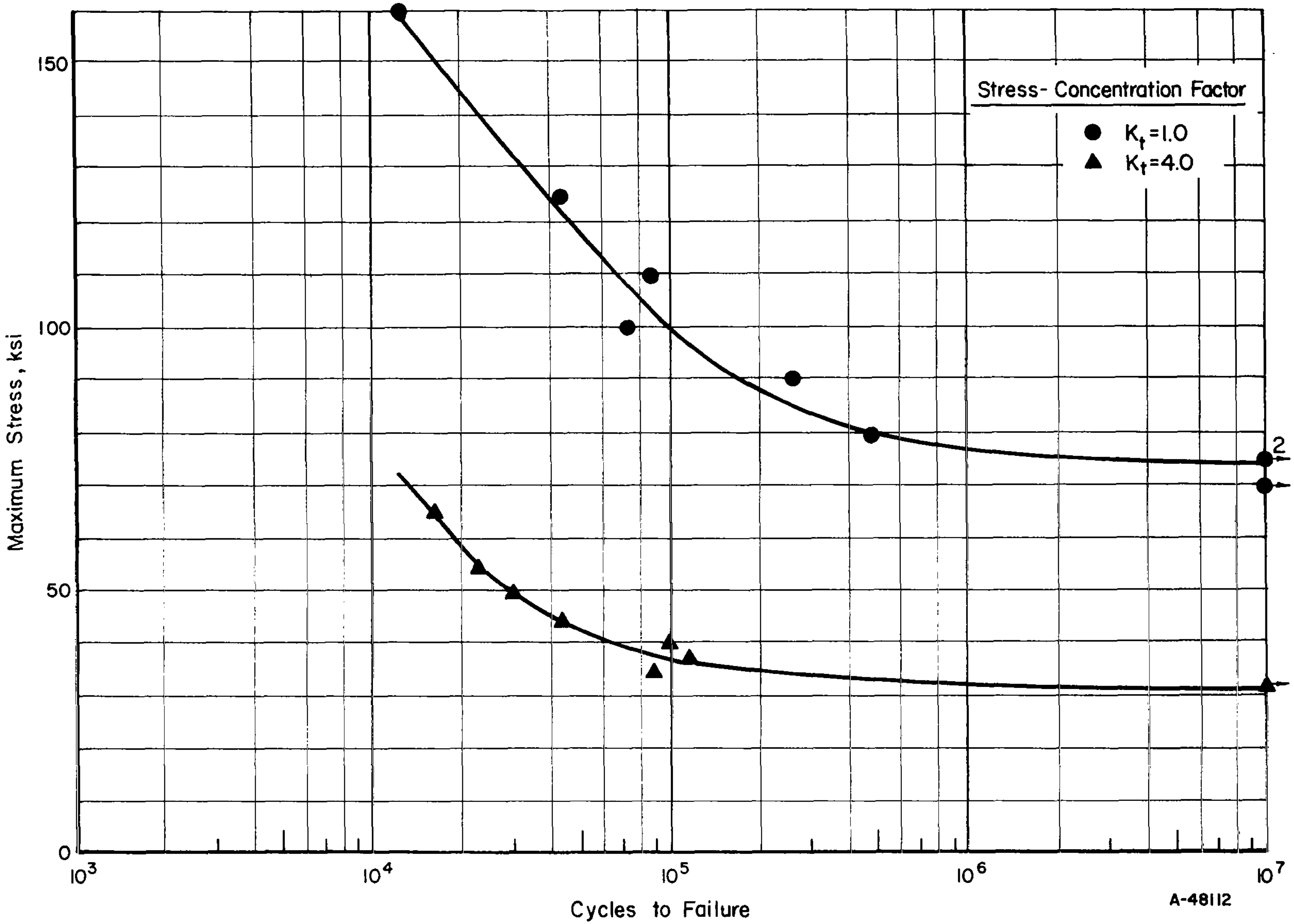


FIGURE 17. FATIGUE BEHAVIOR OF UNEXPOSED LONGITUDINAL AM-350 STAINLESS STEEL SPECIMENS AT ROOM TEMPERATURE AND ZERO MEAN STRESS

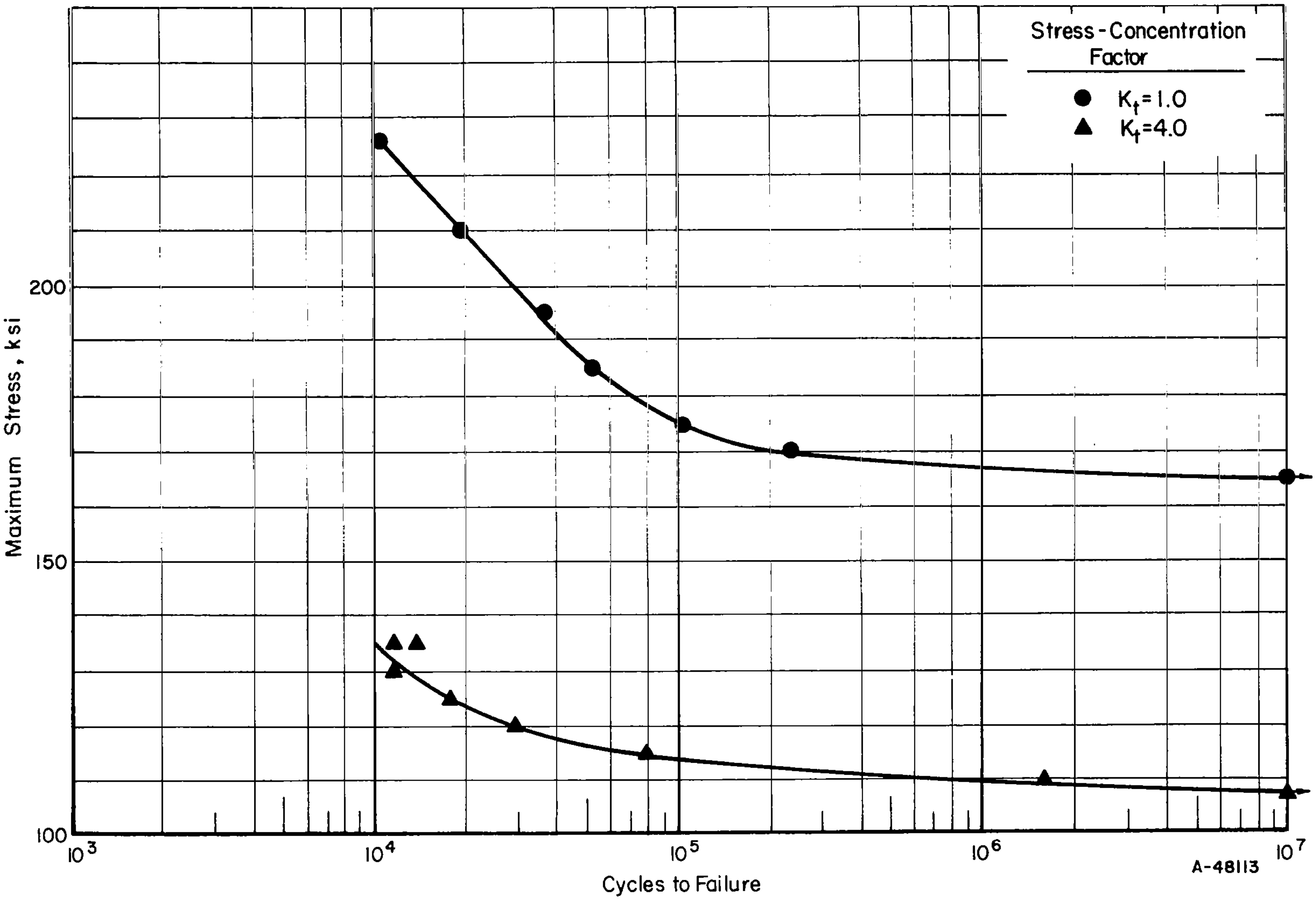


FIGURE 18. FATIGUE BEHAVIOR OF UNEXPOSED LONGITUDINAL AM-350 STAINLESS STEEL SPECIMENS AT ROOM TEMPERATURE AND 100-KSI MEAN STRESS

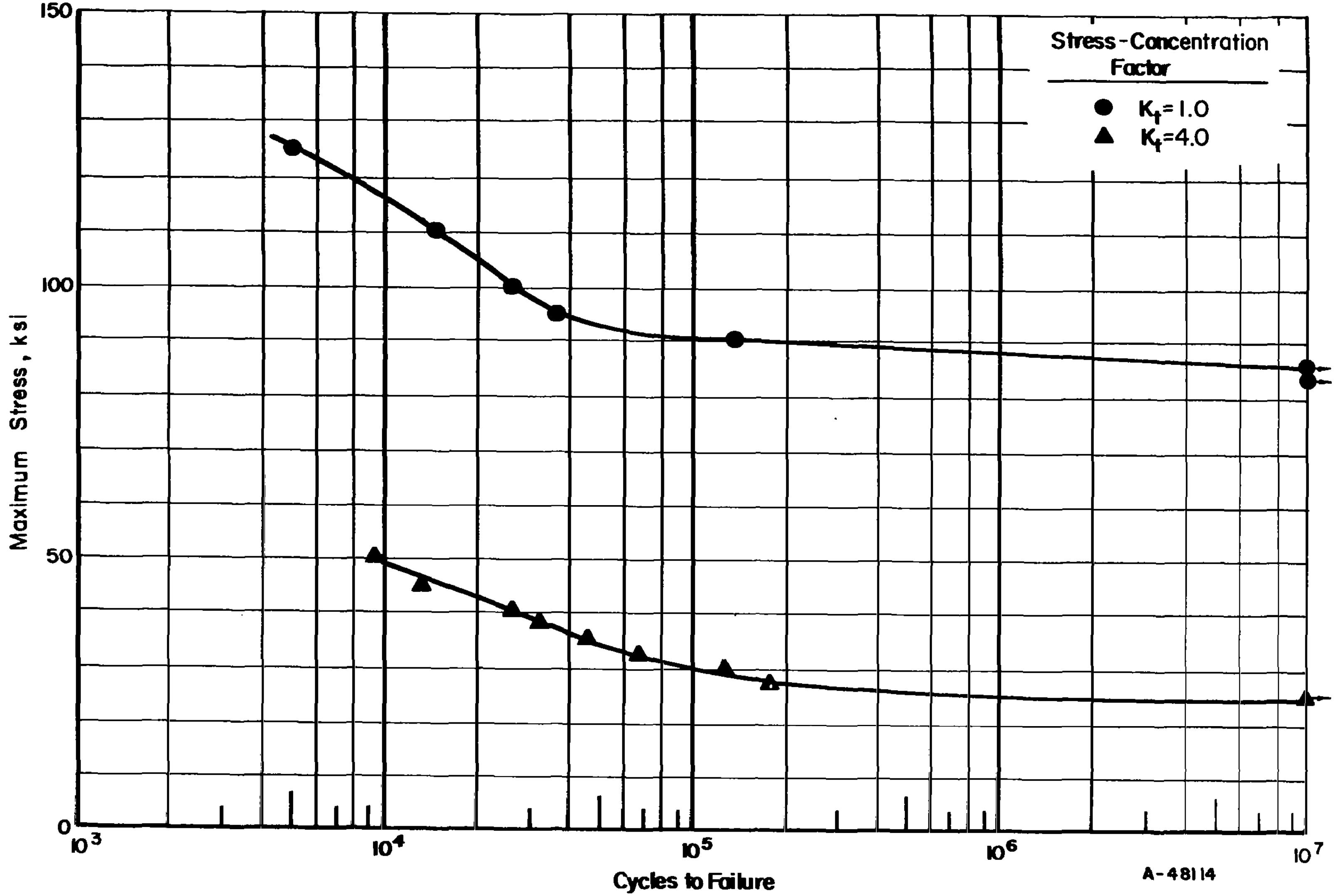


FIGURE 19. FATIGUE BEHAVIOR OF UNEXPOSED LONGITUDINAL AM-350 STAINLESS STEEL SPECIMENS AT 550 F AND ZERO MEAN STRESS

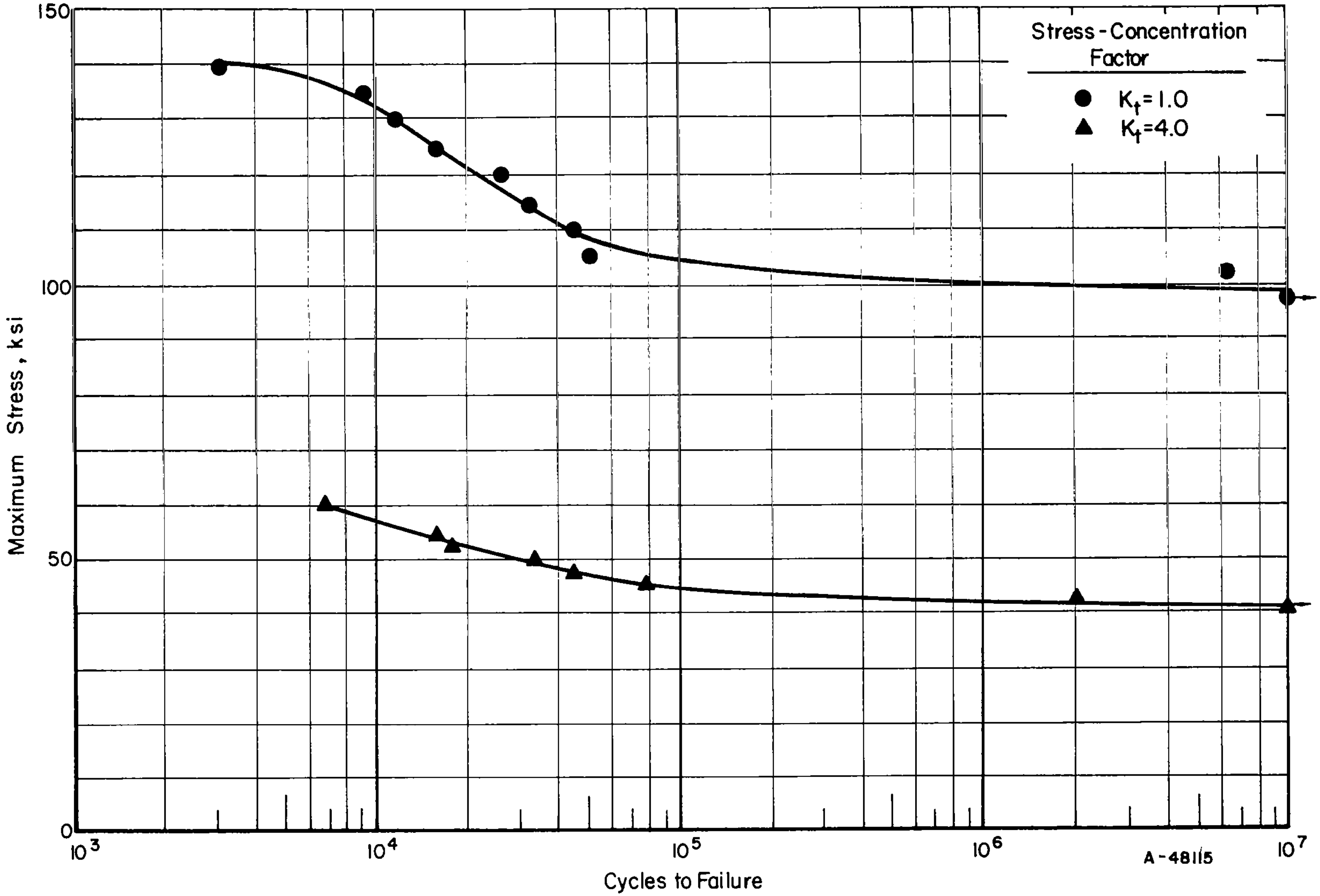


FIGURE 20. FATIGUE BEHAVIOR OF UNEXPOSED LONGITUDINAL AM-350 STAINLESS STEEL SPECIMENS AT 550 F AND 20-KSI MEAN STRESS

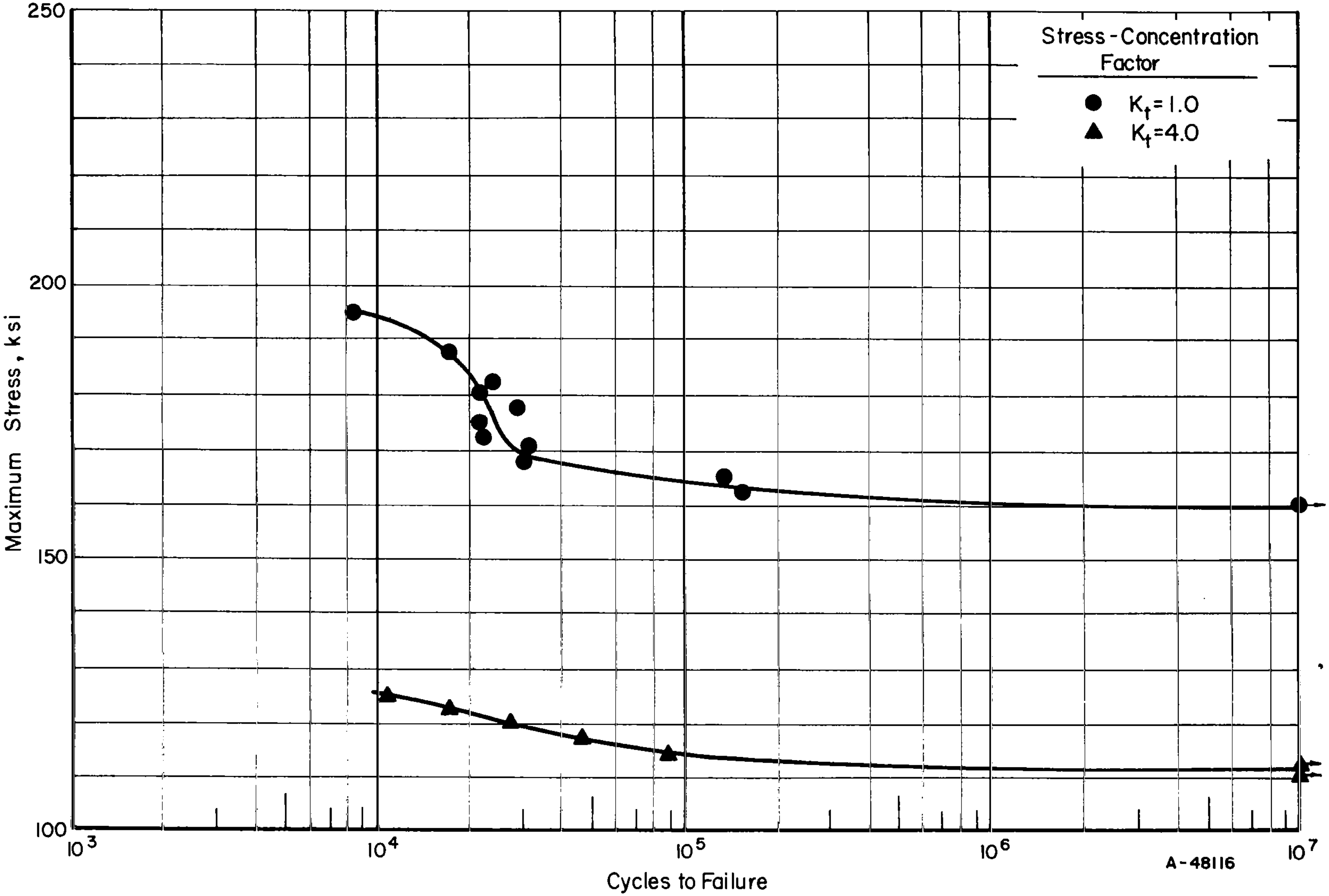


FIGURE 21. FATIGUE BEHAVIOR OF UNEXPOSED LONGITUDINAL AM-350 STAINLESS STEEL SPECIMENS AT 550 F AND 100-KSI MEAN STRESS

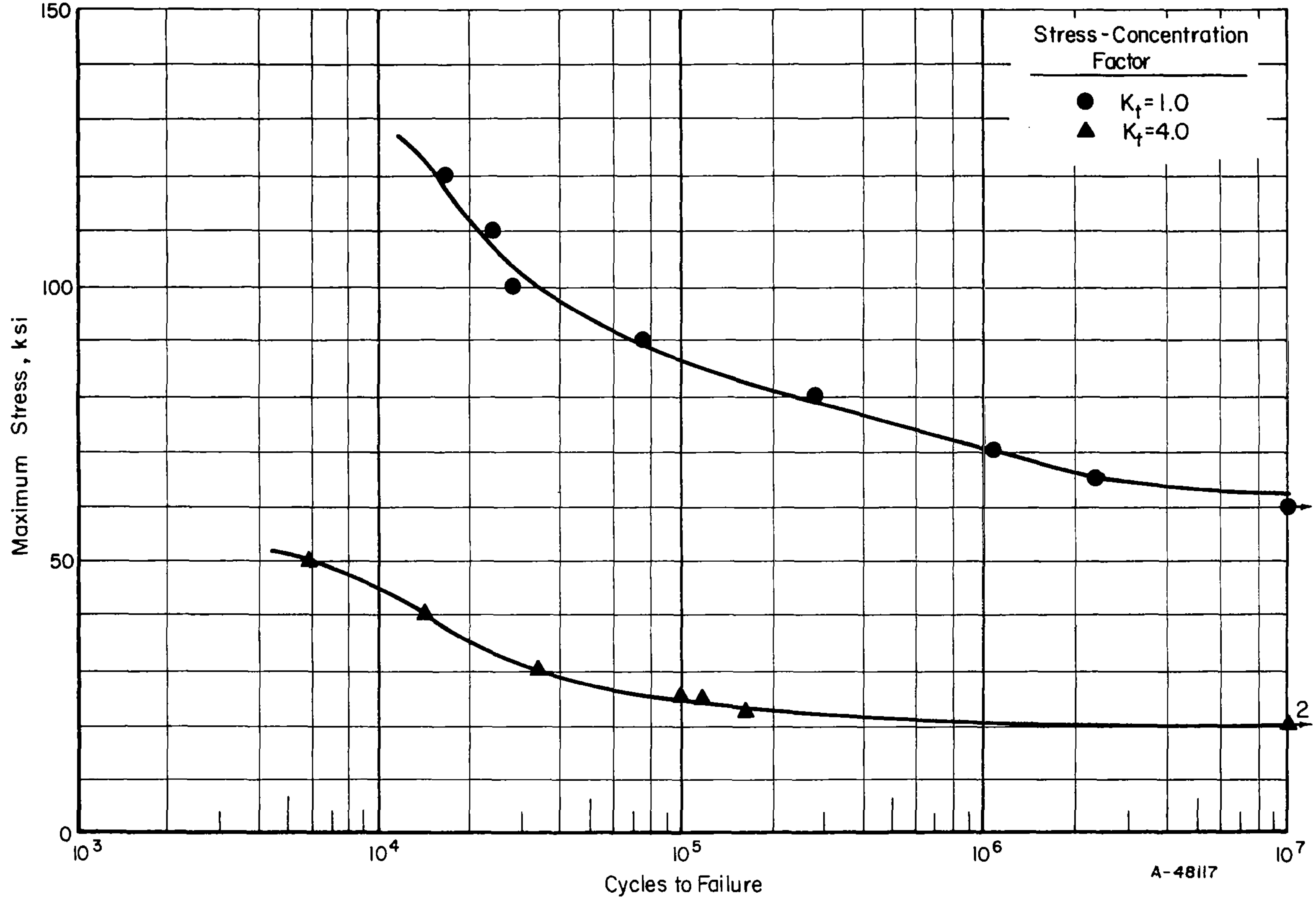


FIGURE 22. FATIGUE BEHAVIOR OF UNEXPOSED LONGITUDINAL Ti-8Al-1Mo-1V ALLOY SPECIMENS AT ROOM TEMPERATURE AND ZERO MEAN STRESS

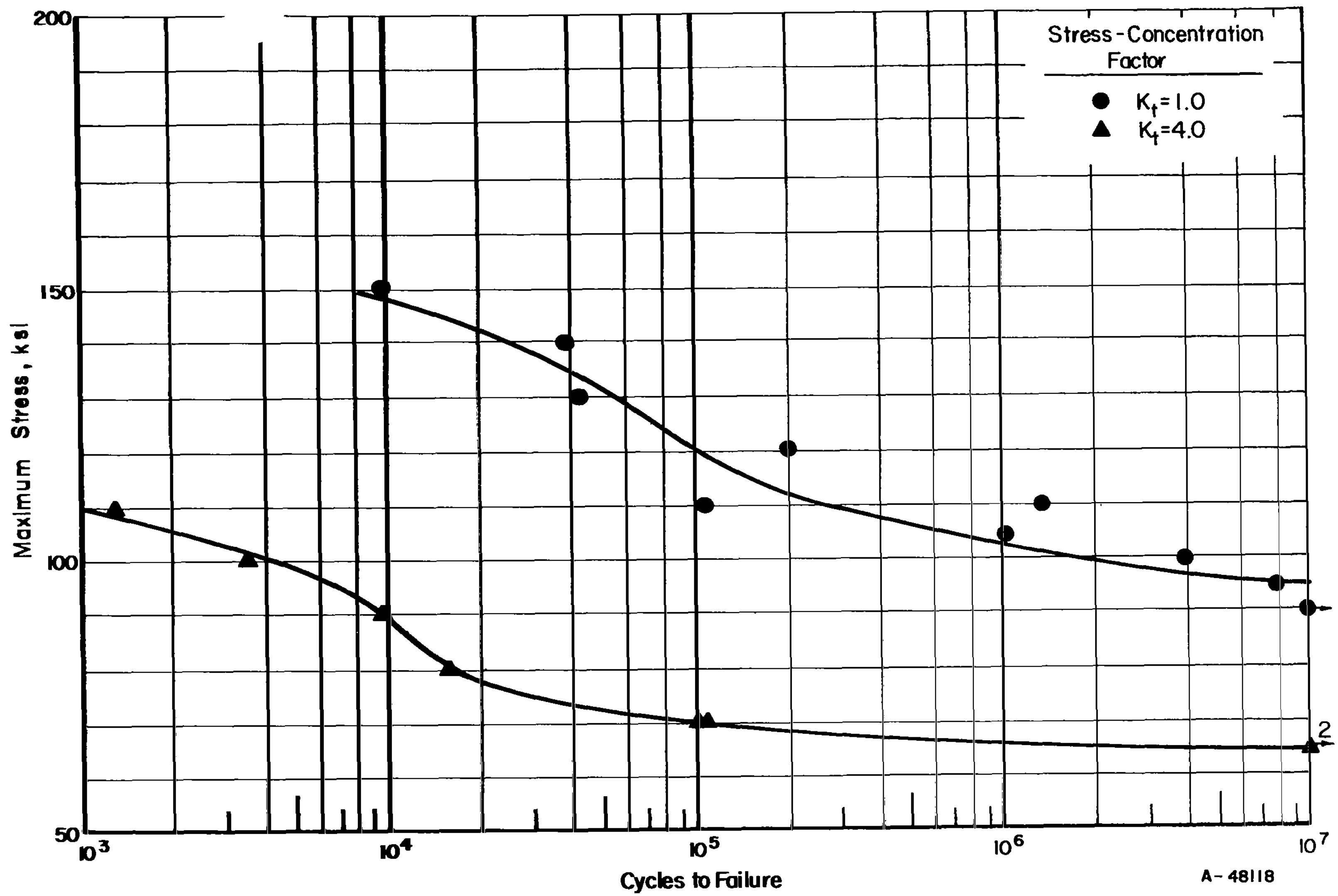


FIGURE 23. FATIGUE BEHAVIOR OF UNEXPOSED LONGITUDINAL Ti-8Al-1Mo-1V ALLOY SPECIMENS AT ROOM TEMPERATURE AND 60-KSI MEAN STRESS

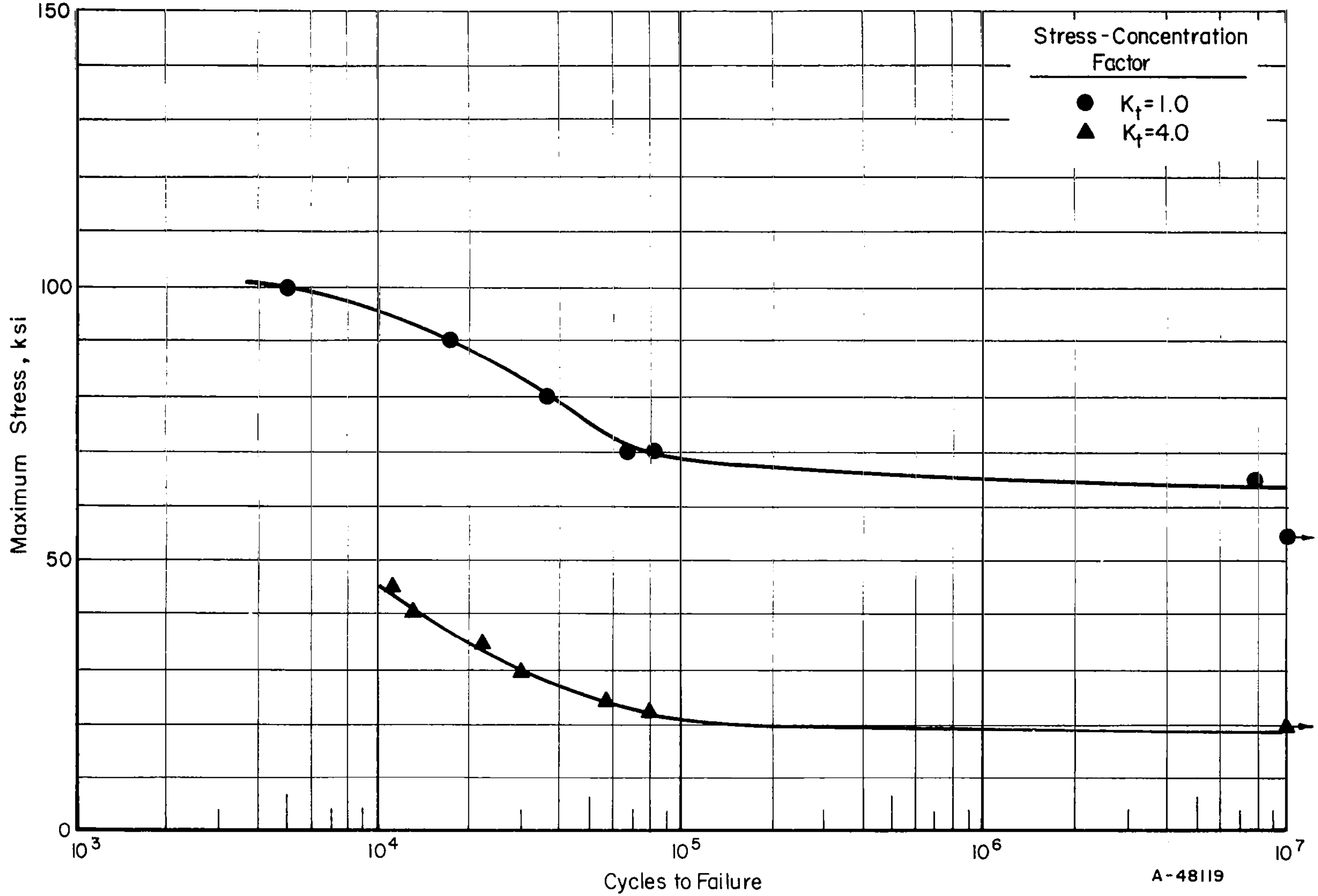


FIGURE 24. FATIGUE BEHAVIOR OF UNEXPOSED LONGITUDINAL Ti-8Al-1Mo-1V ALLOY SPECIMENS AT 550 F AND ZERO MEAN STRESS

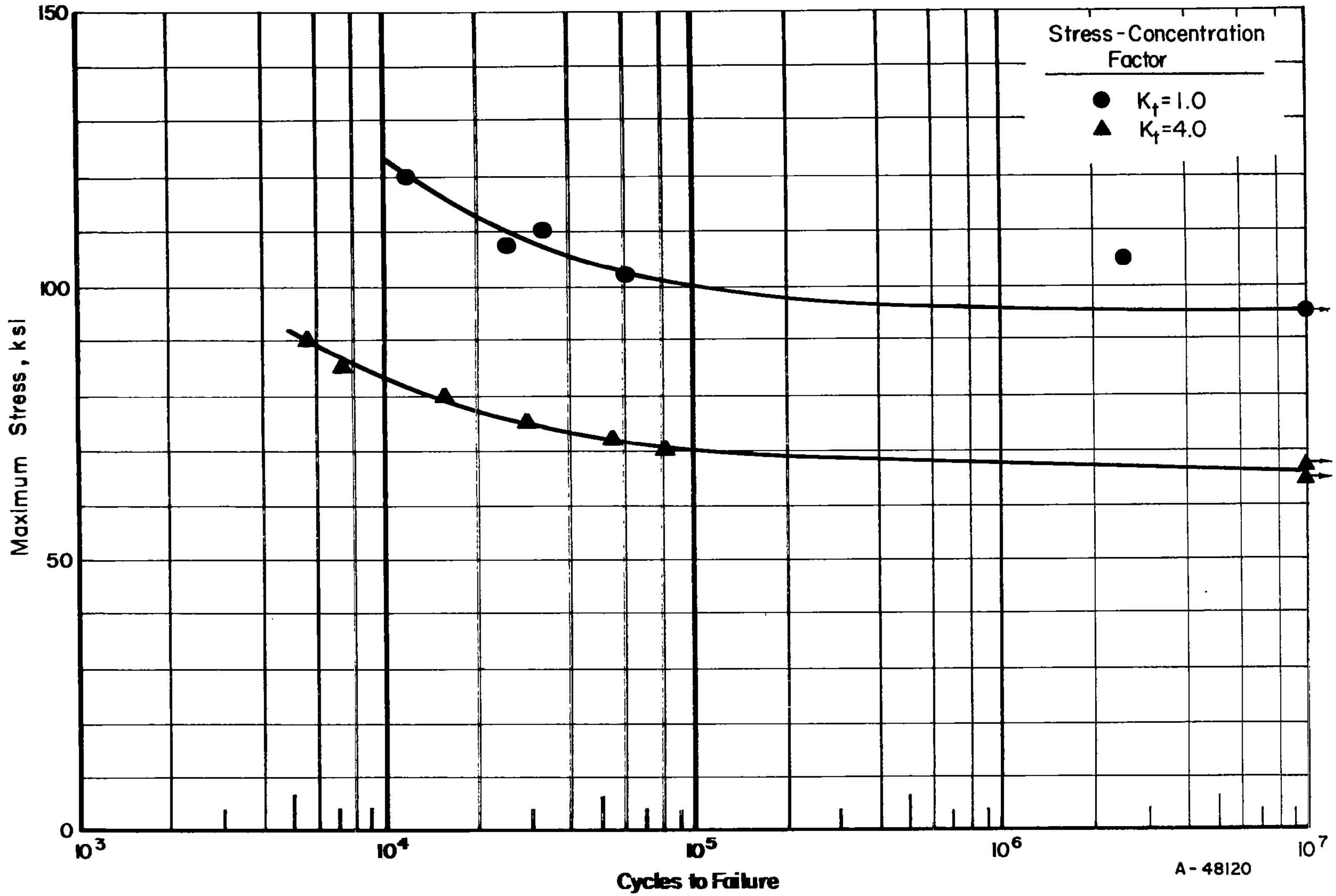


FIGURE 25. FATIGUE BEHAVIOR OF UNEXPOSED LONGITUDINAL Ti-8Al-1Mo-1V ALLOY SPECIMENS AT 550 F AND 60-KSI MEAN STRESS

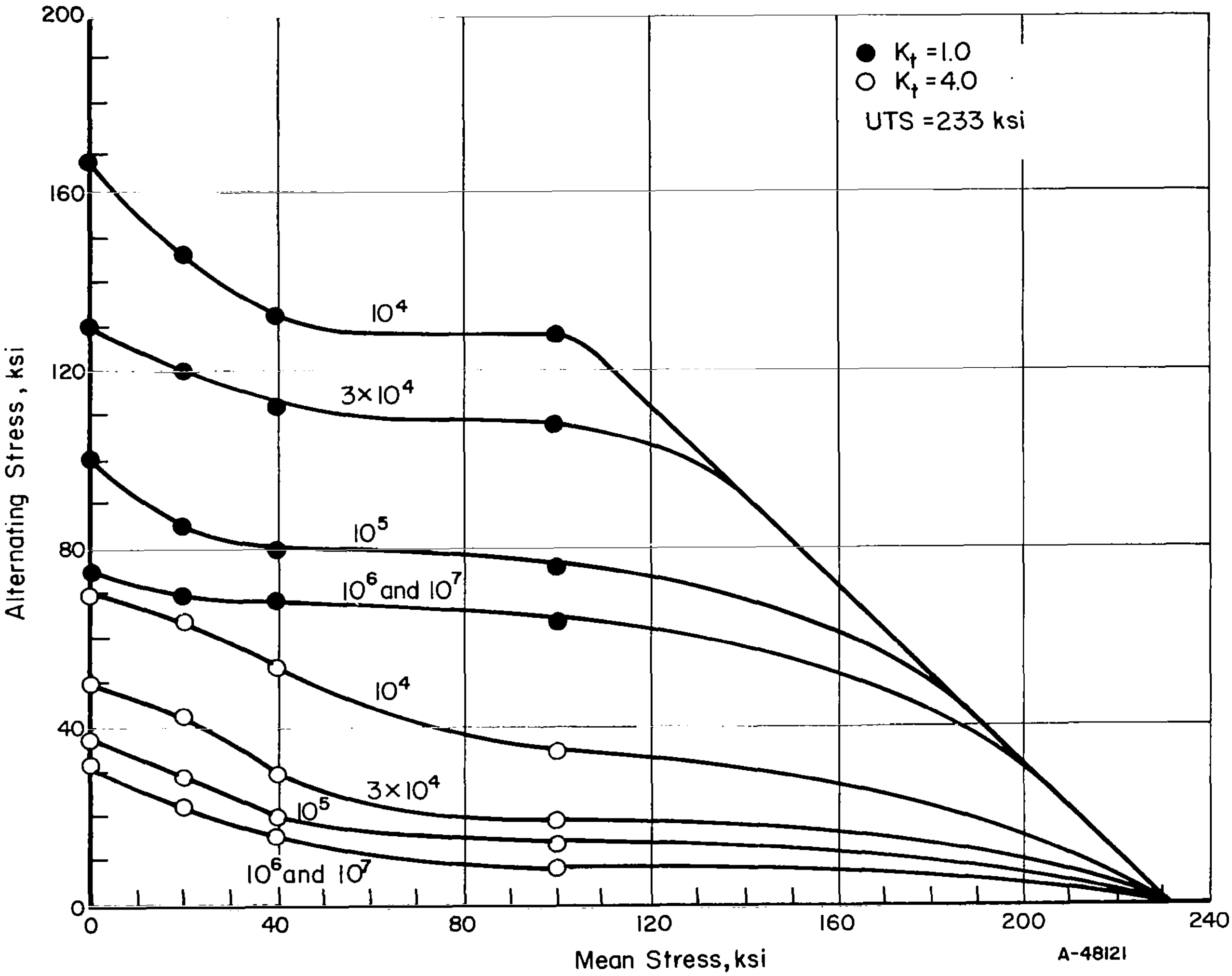


FIGURE 26. STRESS-RANGE DIAGRAM FOR AM-350 STAINLESS STEEL AT ROOM TEMPERATURE

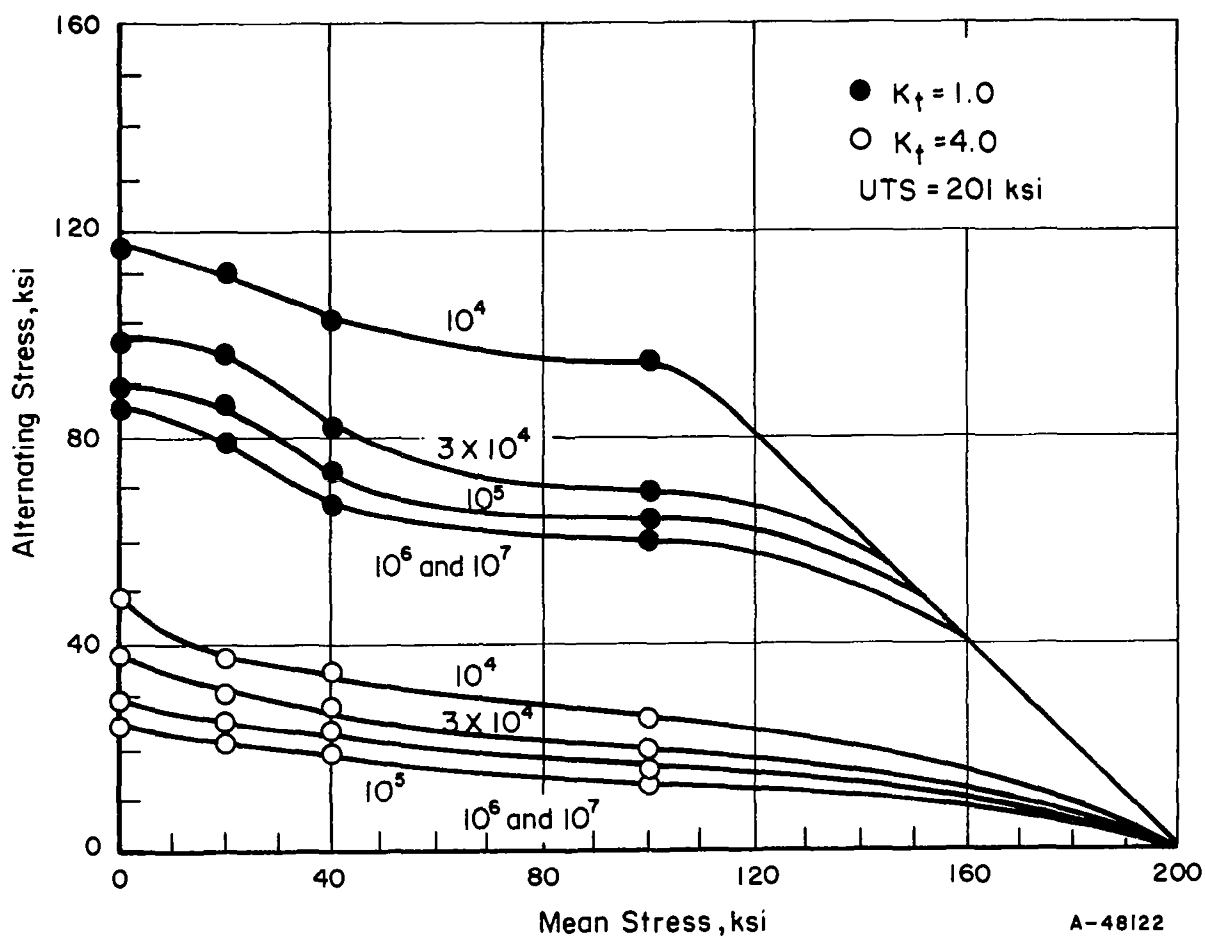


FIGURE 27. STRESS-RANGE DIAGRAM FOR AM-350 STAINLESS STEEL AT 550 F

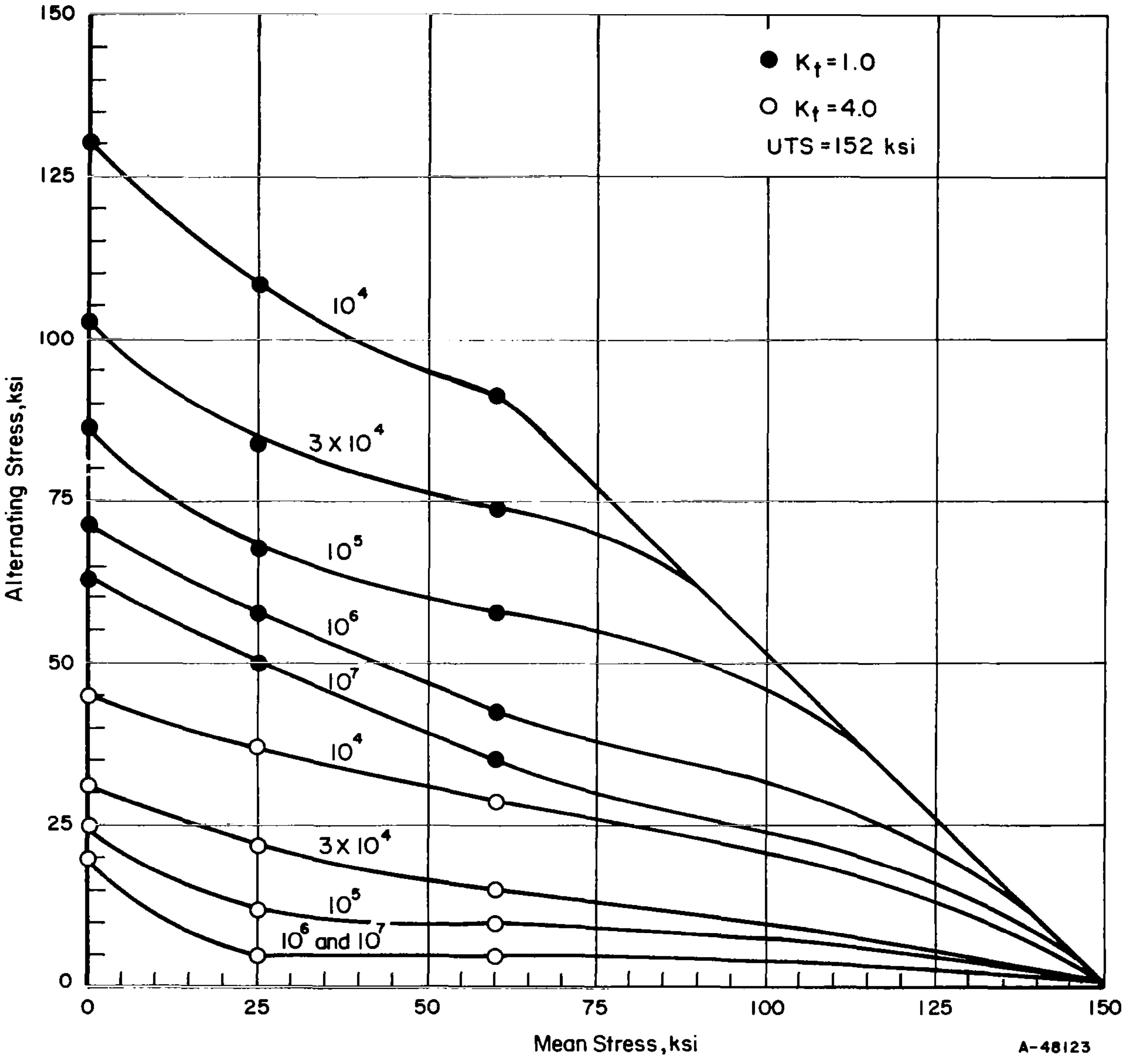


FIGURE 28. STRESS-RANGE DIAGRAM FOR Ti-8Al-1Mo-1V ALLOY AT ROOM TEMPERATURE

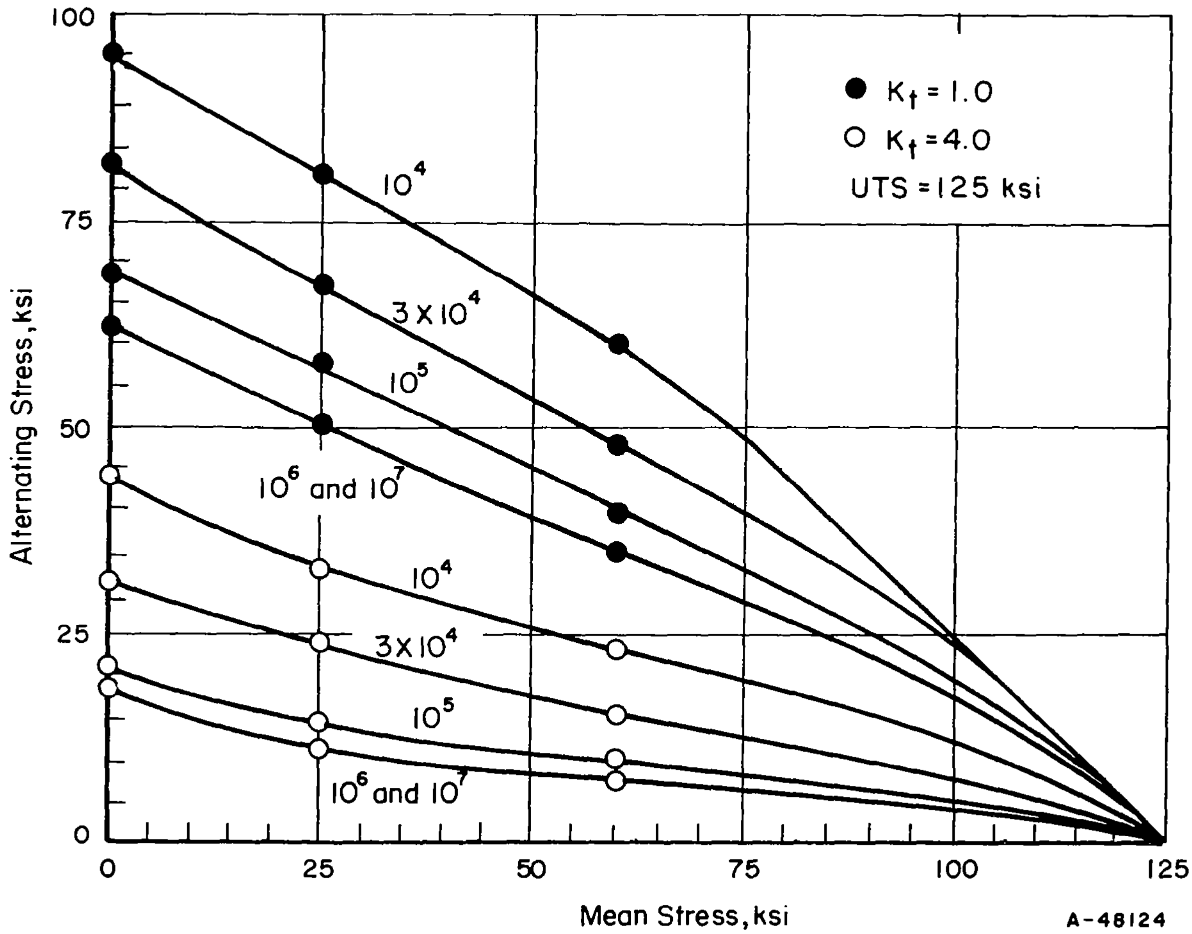


FIGURE 29. STRESS-RANGE DIAGRAM FOR Ti-8Al-1Mo-1V ALLOY AT 550 F

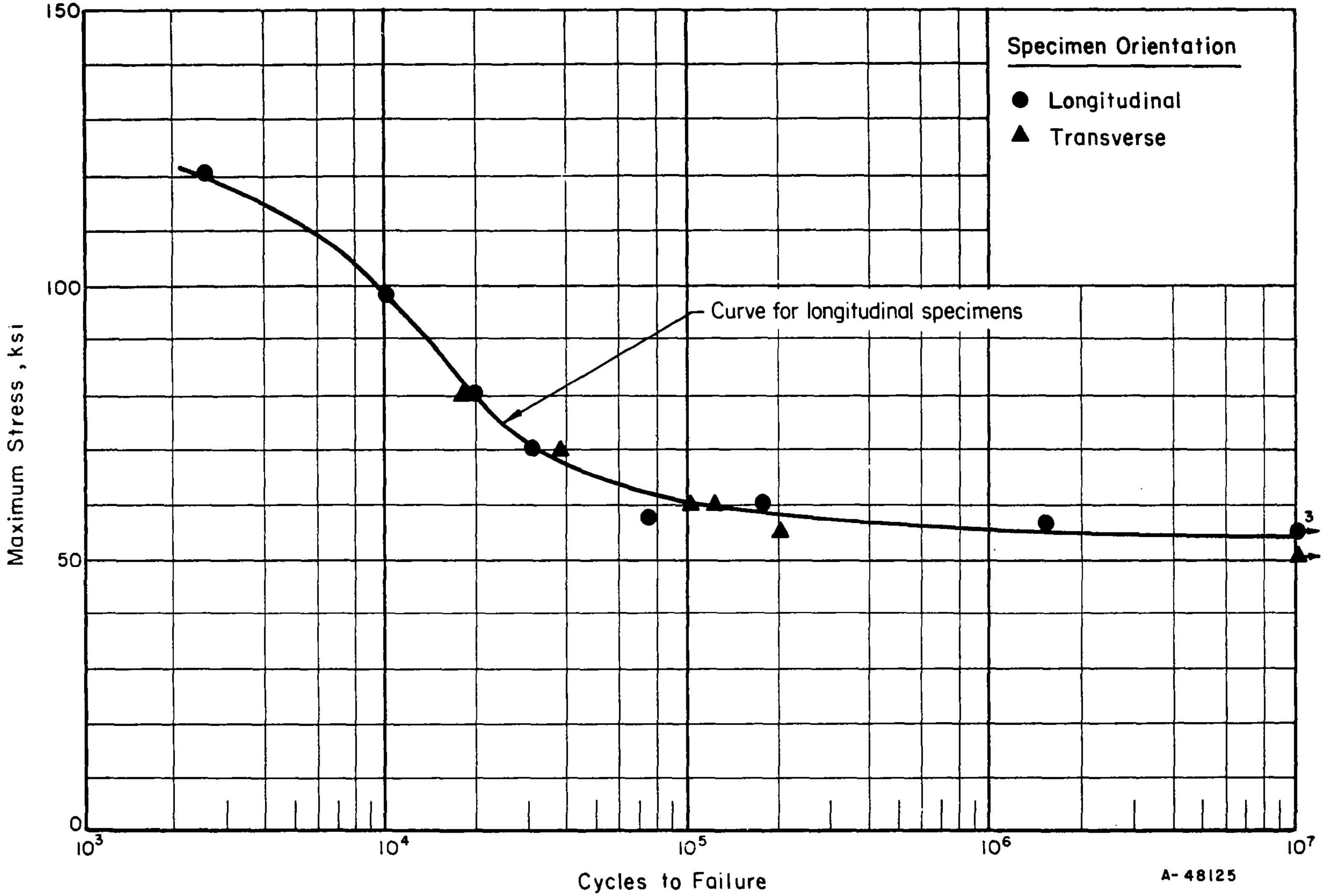


FIGURE 30. EFFECT OF SPECIMEN ORIENTATION ON FATIGUE BEHAVIOR OF UNEXPOSED NOTCHED (K_t = 4.0) AM-350 STAINLESS STEEL AT ROOM TEMPERATURE AND 40-KSI MEAN STRESS

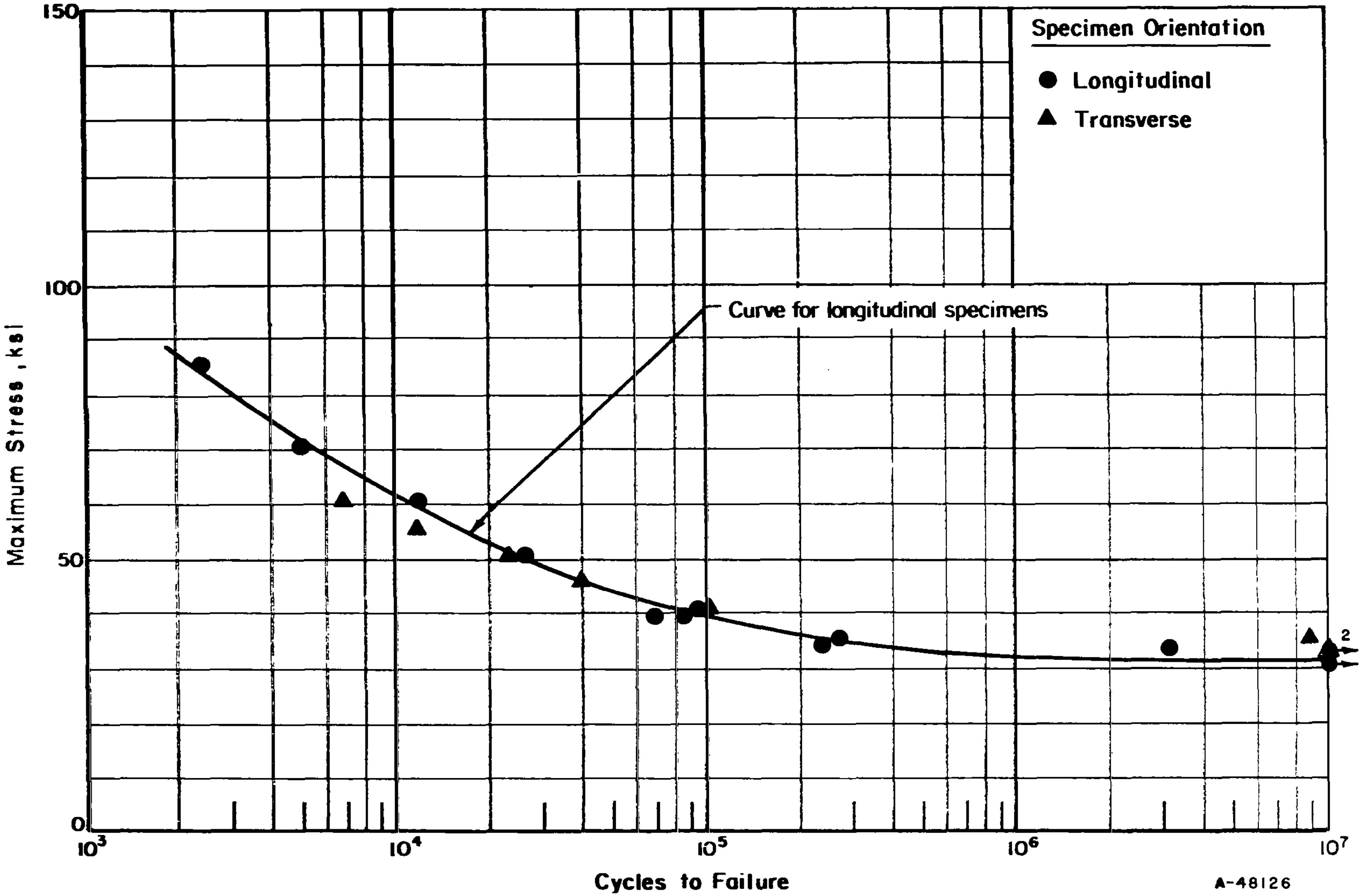


FIGURE 31. EFFECT OF SPECIMEN ORIENTATION ON FATIGUE BEHAVIOR OF UNEXPOSED NOTCHED (K_t = 4.0) Ti-8Al-1Mo-1V ALLOY AT ROOM TEMPERATURE AND 25-KSI MEAN STRESS

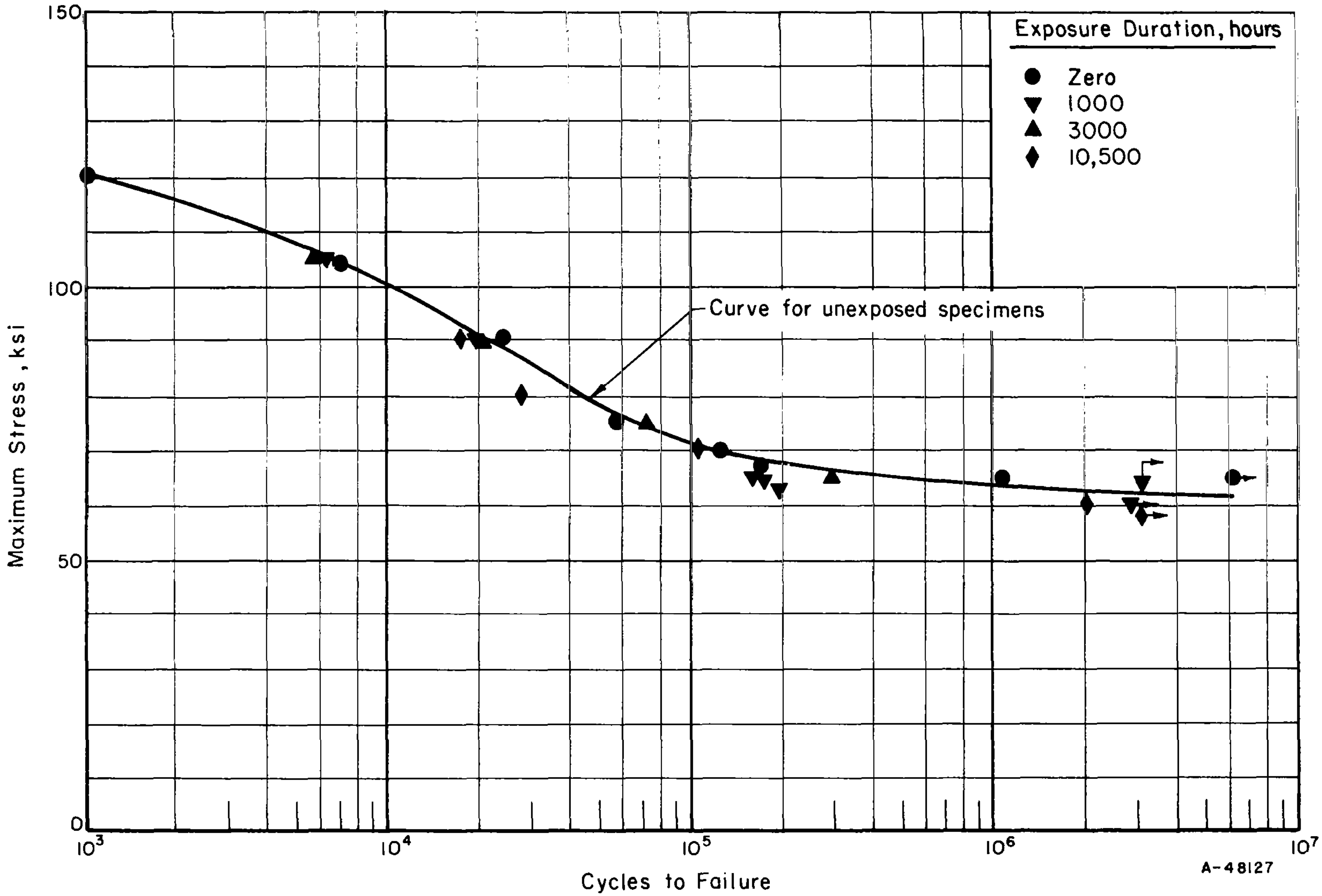


FIGURE 32. EFFECT OF STRESSED EXPOSURE ON FATIGUE BEHAVIOR OF NOTCHED (K_t = 4.0) AM-350 STAINLESS STEEL AT -110 F AND 40-KSI MEAN STRESS

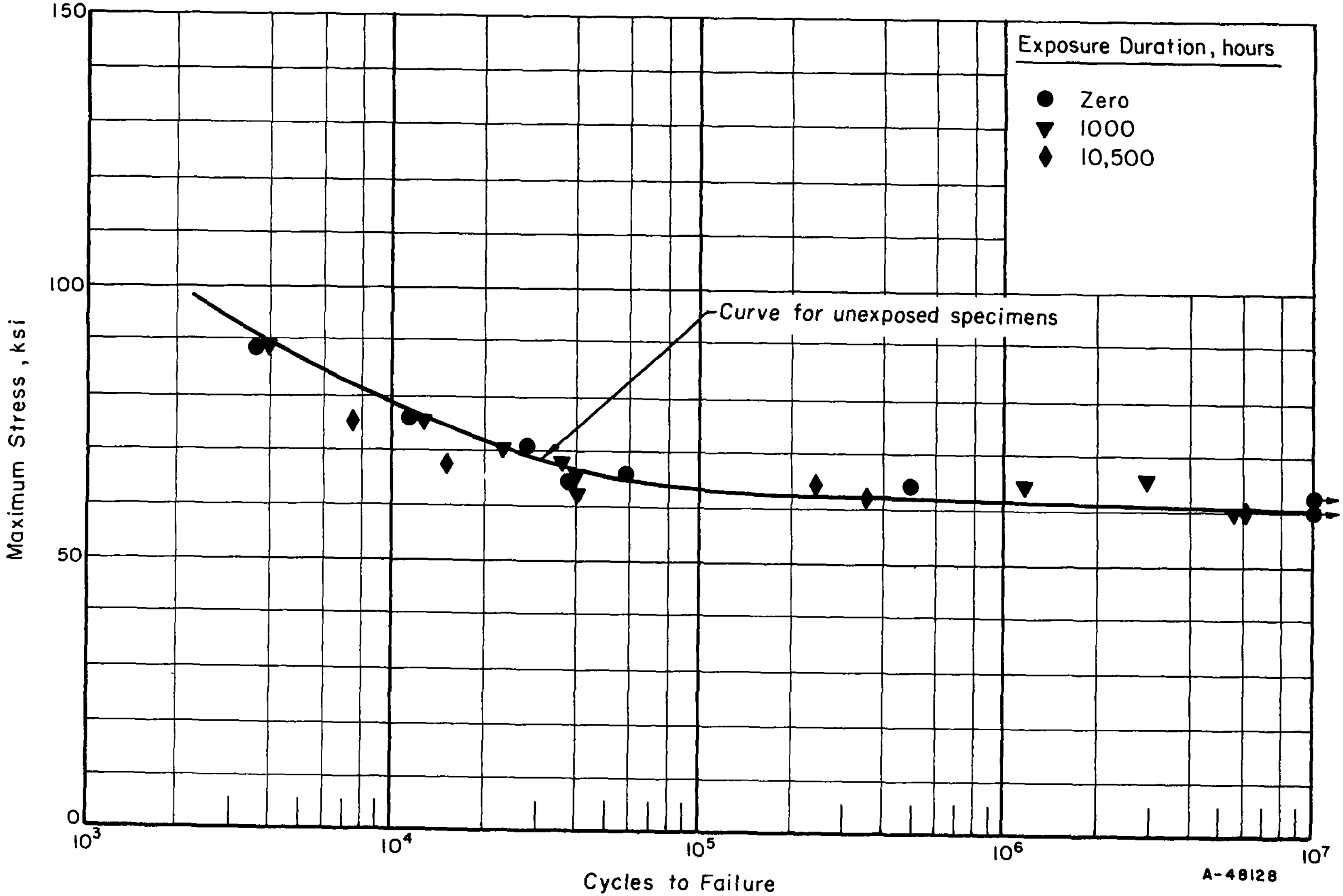


FIGURE 33. EFFECT OF STRESSED EXPOSURE ON FATIGUE BEHAVIOR OF NOTCHED (K_t = 4.0) AM-350 STAINLESS STEEL AT 550 F AND 40-KSI MEAN STRESS

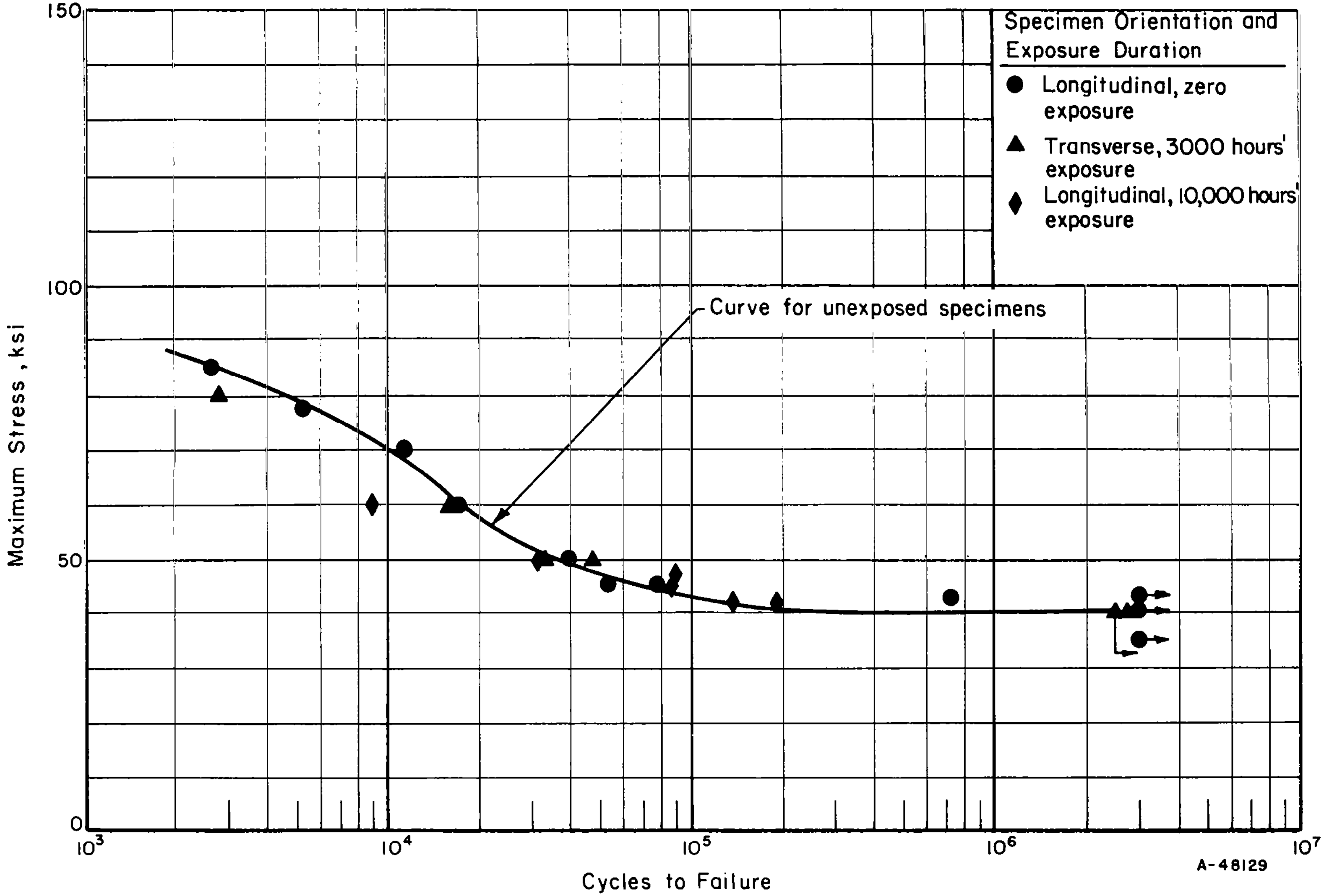


FIGURE 34. EFFECT OF STRESSED EXPOSURE ON FATIGUE BEHAVIOR OF NOTCHED (K_t = 4.0) Ti-8Al-1Mo-1V ALLOY AT -110 F AND 25-KSI MEAN STRESS

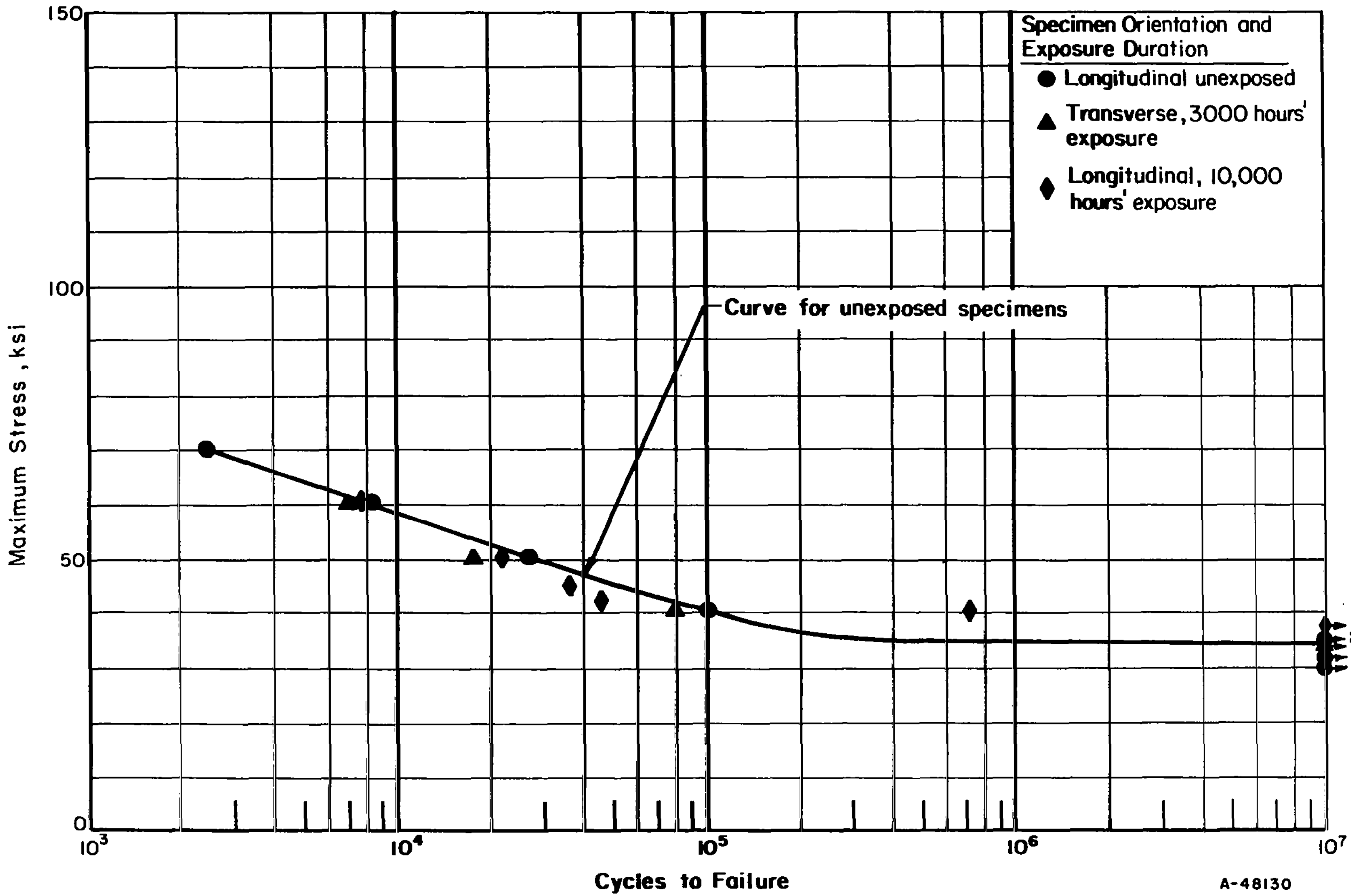


FIGURE 35. EFFECT OF STRESSED EXPOSURE ON FATIGUE BEHAVIOR OF NOTCHED (K_t = 4.0) Ti-8Al-1Mo-1V ALLOY AT 550 F AND 25-KSI MEAN STRESS

The manner in which prior stressed exposure affected the fatigue strength of the two alloys in question is shown by the data plotted on Figures 32 through 35. Figures 32 and 33 illustrate all of the data obtained on AM-350 CRT alloy. Involved are exposure times of 0 hours, 1000 and 3000 hours from Reference (1), and 10,500 hours. From the two figures it is seen that there is no influence of prior stressed exposure, to lifetimes of 10,500 hours, on fatigue strength.

Figures 34 and 35 show for the titanium alloy that prior stressed exposure also does not influence fatigue strength for lifetimes up to 10,000 hours.

Since the exposure temperature is higher than the expected service temperatures for skin surfaces other than leading edges, it would appear that metallurgical instability is not a problem for the two alloys, at least up to about 10,000 hours.

DISCUSSION AND CONCLUDING REMARKS

This program has been concerned with a study of the fatigue behavior of two materials under consideration as skin materials for the supersonic transport: AM-350 CRT and triplex-annealed Ti-8Al-1Mo-1V alloy. The intended operating environment of this aircraft raises questions, concerned with structural material behavior, not encountered in the past in relation to subsonic flight. One of these is concerned with the problem of moderate-temperature exposure. The problem is that of metallurgical instability of the two materials for the operating life of 30,000 to 40,000 hours. Another is also stimulated by temperature. This relates to the fact that operating conditions include subzero temperatures in addition to the moderate-temperature regime.

It is for this reason that this program (consisting of 2 year's research) has included examination of the effect of temperature on fatigue behavior over the range from -110 F to 550 F. This range is somewhat broader than the expected service temperature range.

A number of aspects are of interest in relation to fatigue of the skin and structural materials. In this program three were considered: (1) crack propagation, (2) remaining static strength, and (3) the base fatigue behavior. All of the testing was carried out on small laboratory specimens, so that the data in certain cases are indicative of what may be expected of the materials; however, judgment has to be exercised in translating the information to large scale structure.

In this concluding section, information obtained during the past 2 years is reviewed briefly and discussed in terms of prior experience. Conclusions are drawn when warranted in each subsection.

Crack Propagation

The factors that were considered important to examine in regard to its effect on crack propagation were as follows:

(1) Alternating stress amplitude

(2) Crack length

(3) Specimen orientation

(4) Stress-cycle rate

(5) Temperature

(6) Prior stressed exposure.

Mean stress also is a variable that is known to affect crack propagation. In this program, however, one mean stress was used for each material.

From the experimental program, the following conclusions appear warranted in regard to crack propagation:

(1) The alternating stress component and the crack length strongly influenced the rate of crack propagation. Where direct comparison was possible, the rate of crack propagation of the stainless steel frequently was slightly higher than that of the titanium alloy at the same relative alternating stress level (θ) and crack length.

(2) Specimen orientation with rolling direction was a slight influence on crack propagation. For the titanium alloy, longitudinal specimens had higher propagation rates than did transverse specimens.

(3) Cyclic rate had an effect on the crack-propagation behavior of the titanium alloy. Crack-propagation rate increased with decreasing cyclic rate. This effect was more noticeable at high alternating stress and with long cracks. It was not clear whether there was a frequency effect for the stainless steel.

(4) Temperature at which the fatigue crack is propagated was found to be important. For the titanium alloy, crack-growth rates increased with decreasing temperature. However, for the steel alloy, crack-growth rates decreased with decreasing temperature.

(5) Exposure to steady stress and to a temperature of 550 F for 10,000 hours prior to crack propagation did not influence the rate of crack propagation of AM-350 alloy. Exposure time of 8,000 hours for the titanium alloy resulted in a slight increase in crack propagation rate.

Residual Static Strength

Once again there were many factors considered important that might influence the residual strength of these materials. Included in this program were the following:

(1) Crack length

(2) Specimen orientation with rolling direction

(3) Temperature

(4) Prior exposure

(5) Fatigue conditions to introduce the crack.

Since most of the data for AM-350 alloy were presented in Reference (1), Figures 36 and 37 contain a summary of all pertinent data. Note that in these figures residual static strength is expressed as a ratio of the gross-area stress to the ultimate strength of the material.

A number of conclusions can be stated based upon the program results:

(1) For both materials, the residual static strength was strongly affected by crack length at all temperatures. The fact that all specimens failed at net stress values at or above the yield strength indicates that both materials were relatively tough. AM-350 steel was slightly stronger than the titanium alloy at room temperature.

(2) Specimen orientation with rolling direction had an influence on residual static strength. Transverse specimens of AM-350 alloy had much lower strength than did longitudinal specimens Ti-8Al-1Mo-1V alloy exhibited essentially no effect of orientation on residual strength based upon σ_G/σ_u as shown in Figure 37. However, since σ_u in the transverse direction was less than that in the longitudinal direction, there was actually a small reduction in static strength of transverse specimens compared with longitudinal specimens.

(3) Temperature of test also had an important influence on remaining strength. For AM-350 either the high or the low temperature reduced strength, whereas, with the titanium alloy only the low temperature reduced strength.

(4) Prior exposure at 550 F to a static stress of 40 ksi for 10,000 hours for the steel and of 25 ksi for 8,000 hours for the titanium alloy did not produce a large change in residual strength, in general, for either material. The results for AM-350 alloy were not consistent, suggesting no certain effect of exposure. Those for titanium showed a slight reduction in residual strength after exposure.

Among the factors that were examined concerned with fatigue conditions used in growing cracks prior to residual strength testing were stress amplitude, fatigue cracking temperature, and cyclic frequency. The results indicate the following conclusions:

(5) Stress amplitude, fatigue cracking temperature, and cyclic frequency — all related to fatigue conditions to form the crack — did not influence the residual strength of either material.

Fatigue Behavior

The fatigue strength of the two materials has been evaluated primarily at room temperature and at 550 F. Some study was made at -110 F. Notched and unnotched

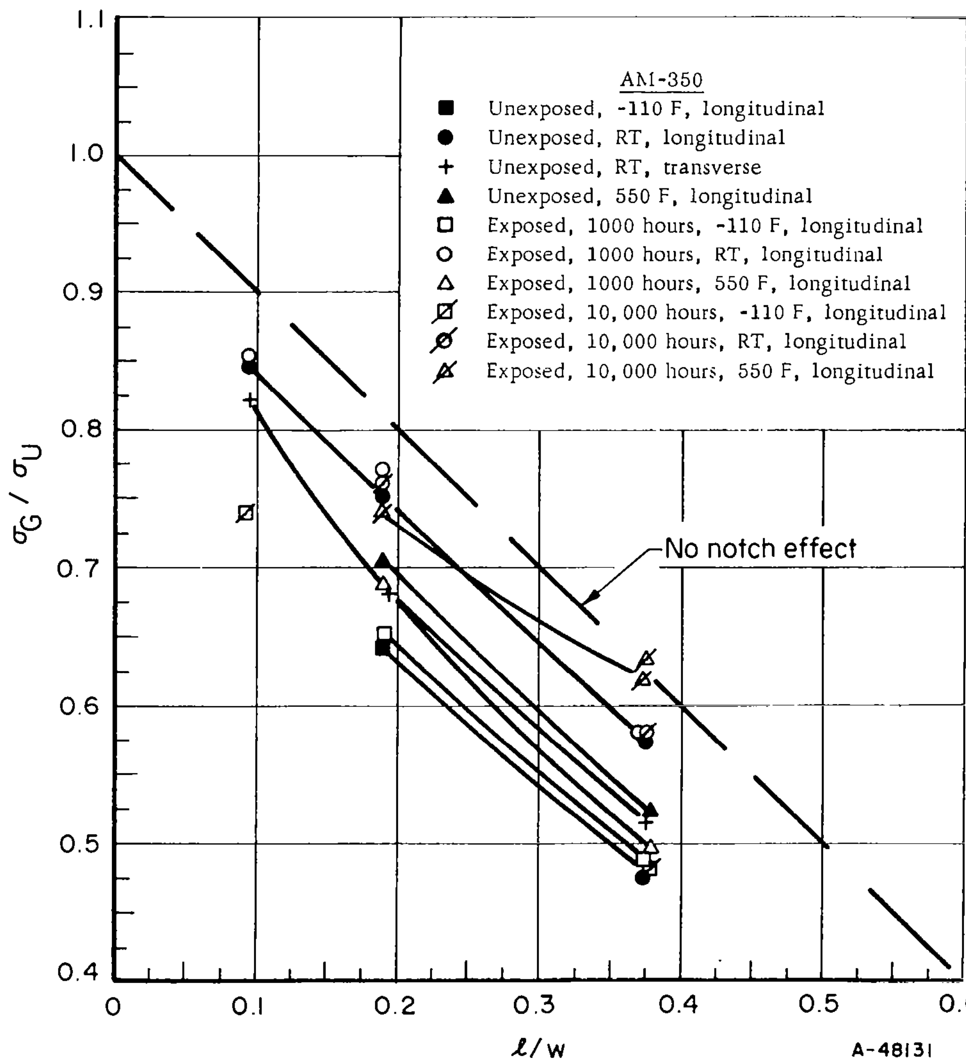


FIGURE 36. EFFECTS OF CRACK LENGTH ON THE RATIO OF RESIDUAL STRENGTH TO ULTIMATE STRENGTH FOR 2-INCH-WIDE AM-350 STAINLESS STEEL SHEET SPECIMENS

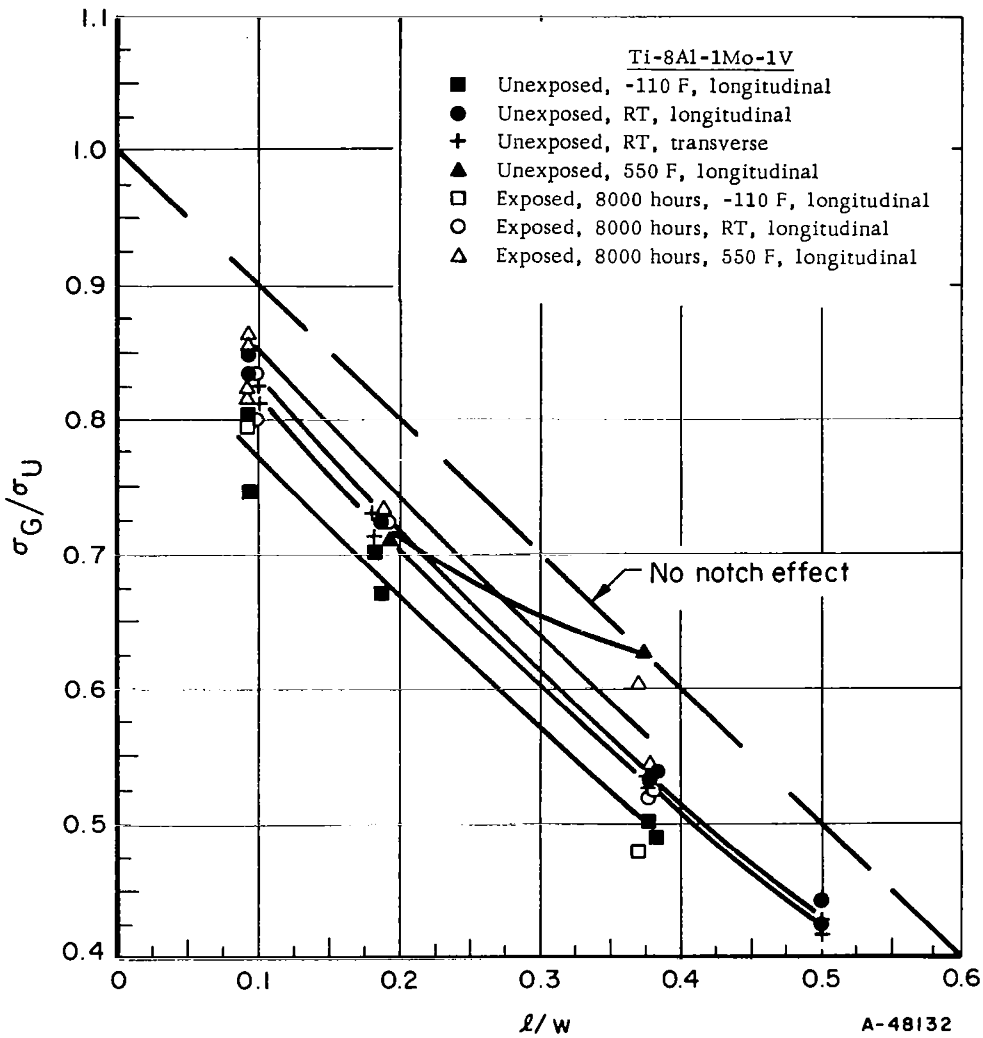


FIGURE 37. EFFECTS OF CRACK LENGTH ON THE RATIO OF RESIDUAL STRENGTH TO ULTIMATE STRENGTH FOR 2-INCH-WIDE Ti-8Al-1Mo-1V ALLOY SHEET SPECIMENS

specimen behavior was evaluated. A number of comments can be made regarding the data.

(1) From the stress-range diagrams of Figures 26 to 29, it is seen that both materials behaved in fatigue much like other structural materials.

(2) AM-350 had higher values of fatigue strength than did the titanium alloy.

(3) There was no evidence that prior stressed exposure of about 10,000 hours at 550 F influenced fatigue strength of the notched specimens.

A final point concerns notch sensitivity of the two materials. Table 13 has been prepared from the stress-lifetime diagrams for room-temperature conditions. In this table, K_f values are listed for several lifetimes and for two mean-stress conditions. These values were computed on the basis of the ratio of unnotched maximum stress to the notched maximum stress at the same mean stress and lifetime. These values can be compared with similar information listed in Table 13 obtained on two aluminum alloys extensively used in aircraft construction[2,17]. In this table the mean stress for each aluminum alloy represents approximately the same ratio of mean stress to ultimate strength as existed for the two test materials. It appears from the tabulation that the fatigue strength reduction factors, K_f, for the two materials were comparable to K_f values for 2024-T3 and 7075-T6 aluminum alloys.

On the basis of the investigation it appears that the fatigue behavior of both sheet materials, AM-350 and Ti-8Al-1Mo-1V, are not too different from that of materials currently used in subsonic aircraft. Neither material exhibited a significant tendency toward metallurgical instability as a consequence of about 10,000 hours' exposure at a temperature of 550 F.

TABLE 13. FATIGUE NOTCH FACTORS AT ROOM TEMPERATURE FOR EDGE-NOTCHED SPECIMENS OF AM-350 AND Ti-8Al-1Mo-1V WITH K_t = 4.0

Lifetime, cycles	K_f	
	AM-350	Ti-8Al-1Mo-1V
	Zero Mean Stress	Zero Mean Stress
4×10^4	2.7	3.5
1×10^5	2.6	3.0
1×10^7	2.3	3.4
	40 Ksi Mean Stress	25-Ksi Mean Stress
4×10^4	2.1	2.2
1×10^5	2.0	2.2
1×10^7	2.1	2.2

TABLE 14. FATIGUE NOTCH FACTORS AT ROOM TEMPERATURE FOR TWO AIRCRAFT STRUCTURAL ALUMINUM ALLOYS WITH K_t = 4.0

Lifetime, cycles	K_f	
	2024-T3	7075-T6
	Zero Mean Stress	Zero Mean Stress
4×10^4	3.0	2.6
1×10^5	3.4	3.1
1×10^7	3.6	3.6
	12 Ksi Mean Stress	14-Ksi Mean Stress
4×10^4	2.4	2.8
1×10^5	2.6	2.7
1×10^7	1.9	2.7

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APPENDIX A

TENSILE DATA

APPENDIX A

TENSILE DATA ON AM-350 AND Ti-8Al-Mo-1V SHEETS

TABLE A-1. MANUFACTURER'S DATA ON AM-350 CRT STAINLESS STEEL

Material:	AM-350 stainless steel, CRT condition
Number of Sheets:	Three, designated XA5, XA7, XA8
Size of Sheet:	36 x 96 x 0.050 in.
Heat:	55431

Chemical Analysis		
Element	Weight, per cent	Mechanical Properties
C	0.096	Yield Strength, 183,970 psi
Mn	0.75	Tensile Strength, 233,460 psi
P	0.015	Elongation, 13.0 per cent
S	0.010	Hardness, 48 R_C
Si	0.27	
Cr	16.64	
Ni	4.30	
Mo	2.79	
N_2	0.096	

TABLE A-2. MANUFACTURER'S DATA ON Ti-8Al-1Mo-1V ALLOY

Material:	8Al-1Mo-1V titanium alloy
Condition:	Triplex annealed 8 hours, 1450 F, furnace cool +5 minutes, 1850 F, air cool +15 minutes, 1375 F, air cool
Number of Sheets:	Three, designated TA6, TA7, TA8
Size of Sheets:	36 x 96 x (0.038 to 0.049) inch

Chemical Analysis		Mechanical Properties		
Element	Weight, per cent	Yield Strength, psi	Tensile Strength, psi	Elongation, per cent
C	0.023	130,300 min	142,300 min	11 min
Fe	0.09	141,100 max	152,600 max	16 max
N_2	0.013	133,000 avg	147,000 avg	13 avg
Al	7.6			
Va	1.0			
Mo	1.1			
H_2	0.010-0.014			

APPENDIX B

CRACK-PROPAGATION DATA

TABLE B-1. CRACK-PROPAGATION DATA FOR 2-INCH WIDE Ti-8Al-1Mo-1V ALLOY SHEET SPECIMENS WITH CONSTANT NET-SECTION STRESS

Center-notched, triplex-annealed specimens at a constant net-section mean stress of 25 ksi.

		Crack Propagation Rate, μin./cycle, at Indicated Crack Length[a], inch						Total Thousands of Cycles to Indicated Crack Length[a], inch								
Condition	Specimen	0.250	0.350	0.500	0.625	0.750	0.950	0.150 (Initiation)	0.250	0.350	0.500	0.625	0.750	0.950	1.000	Failure[b]
A		$\theta^{(c)}$ = 0.26, Room Temperature, 1725 cpm, Longitudinal, Unexposed														
	7335	1.3	2.2	2.8	3.3	4.0	4.0	635	853	915	973	1013	1045	1095	1107	1181
	8331	1.4	2.2	2.9	3.4	3.4	3.4	1080	1229	1291	1349	1385	1422	1481	1492	1578
B		θ = 0.38, Room Temperature, 1725 cpm, Longitudinal, Unexposed														
	6330	4.2	5.3	8.1	8.1	8.7	8.7	66.0	101	123	146	161	176	199	205	240
	6353	4.5	6.2	8.5	8.7	10.4	9.0	59.5	95.5	116	136	151	164	183	189	(d)
	7327	4.2	5.4	7.2	8.8	8.8	8.8	60.2	92.5	113	135	151	164	187	192	228
	8327	4.3	5.3	8.6	8.6	9.6	9.6	53.0	84.0	105	127	141	156	177	181	--
	8332	4.5	6.7	8.0	9.6	9.6	9.0	67.2	95.7	116	138	151	165	186	191	--
C		θ = 0.38, Room Temperature, 1725 cpm, Transverse, Unexposed														
	7225	4.3	4.9	7.2	8.3	9.2	9.2	77.3	119	142	165	180	195	217	222	--
	7351	4.5	4.5	6.7	7.8	7.8	8.3	88.0	127	149	172	190	207	232	236	269
	7352	3.6	4.5	5.8	8.0	8.0	8.0	103	151	179	206	224	239	264	271	312
	8230	3.7	4.8	5.8	7.4	7.4	8.0	77.9	119	143	169	189	206	230	236	--
D		θ = 0.38, 550 F, 1725 cpm, Longitudinal, Unexposed														
	6350	3.0	3.8	4.6	5.5	5.2	5.2	57.3	109	139	175	199	223	264	273	333
	6357	3.8	4.0	4.9	5.5	6.1	5.3	57.5	90.2	117	149	174	195	229	239	298
E		θ = 0.74, -110 F, 1725 cpm, Longitudinal, Unexposed														
	6356	23	23	38	38	42	42	8.6	14.7	19.1	24.7	28.0	31.4	36.2	37.4	45.9
	7341	20	24	34	34	34	34	11.1	17.6	22.0	27.5	31.1	34.8	40.1	41.7	50.7
	8162	21	26	35	35	35	--	8.3	15.3	19.5	24.8	28.4	31.9	--	--	--
	8174	22	24	35	35	35	--	8.8	15.3	19.4	24.8	28.4	32.0	--	--	--

F

θ = 0.74, Room Temperature, 34 cpm, Longitudinal, Unexposed

6339	24	28	35	39	39	39	6.0	11.7	15.7	20.3	23.7	26.9	32.0	32.9	39.4
7334	19	29	34	38	38	38	5.5	11.9	16.2	21.3	24.8	28.2	33.4	34.7	42.6
7343	24	28	34	40	40	--	7.8	12.9	17.1	21.9	25.4	28.5	--	--	--
8163	23	26	33	36	36	--	6.5	12.4	16.7	21.8	25.4	28.9	--	--	--

G

θ = 0.74, Room Temperature, 1725 cpm, Longitudinal, Unexposed

6331	18	24	29	31	31	31	7.2	14.1	19.3	25.4	29.6	31.8	40.2	41.5	50.0
6335	19	23	28	31	31	--	7.5	14.3	19.4	25.3	29.7	33.7	--	--	--
6337	19	23	28	30	30	--	6.9	13.9	18.8	24.7	28.8	32.9	--	--	--
7328	22	25	30	33	33	33	6.8	11.7	16.3	22.2	26.3	30.2	36.2	37.7	45.1
7333	21	24	30	30	30	--	7.5	13.8	18.9	24.5	28.7	32.9	--	--	--
7337	21	25	31	31	36	34	6.9	13.4	17.9	23.5	27.4	31.0	36.8	38.1	--
7338	21	24	29	31	31	--	7.5	13.7	18.5	24.3	28.5	32.6	--	--	--
8167	19	23	29	30	30	--	7.2	13.5	18.5	24.4	28.7	32.9	--	--	--
8175	19	23	30	32	32	--	6.7	12.8	17.6	23.5	27.6	31.5	--	--	--
8328	17	22	27	31	31	31	6.7	14.0	19.2	25.2	29.5	33.7	40.2	41.9	--

H

θ = 0.74, Room Temperature, 1725 cpm, Longitudinal, 8000 Hours' Exposure

7402	24	31	37	45	45	--	6.6	11.2	15.0	19.3	22.2	25.0	--	--	--
7403	23	28	35	37	37	--	7.7	13.1	17.1	22.0	25.4	28.8	--	--	--
7404	21	33	33	39	39	--	6.0	11.4	15.5	20.0	23.5	26.7	--	--	--
7414	24	23	34	38	38	--	6.7	11.9	15.9	20.7	24.0	27.3	--	--	--
7420	23	26	32	34	38	38	6.5	12.7	17.1	22.1	25.9	29.3	34.6	36.0	43.0
7421	23	27	35	39	39	39	6.6	12.0	16.2	21.0	24.3	27.5	32.7	34.0	41.5
7427	23	28	35	37	37	--	5.3	10.9	15.0	19.8	23.3	26.7	--	--	--

I

θ = 0.74, Room Temperature, 1725 cpm, Transverse, Unexposed

6209	16	21	25	29	29	--	8.7	15.6	21.6	28.0	32.6	36.9	--	--	--
6211	18	22	27	30	31	31	8.8	15.7	21.0	27.0	31.2	35.3	41.7	43.1	51.8
7227	19	21	28	31	31	33	7.5	14.7	19.8	25.8	29.9	33.9	40.0	41.6	--
7350	20	21	28	31	31	31	8.5	14.5	19.2	25.4	29.9	34.0	40.5	42.1	51.1
8225	18	23	27	27	31	31	7.3	14.1	19.4	25.5	29.9	34.3	40.9	42.6	--
8227	17	22	26	26	26	--	8.3	16.2	21.8	28.5	33.3	38.1	--	--	--

Table B-1. (Continued)

Condition	Specimen	Crack Propagation Rate, μin./cycle, at Indicated Crack Length[a], inch						Total Thousands of Cycles to Indicated Crack Length[a], inch								
		0.250	0.350	0.500	0.625	0.750	0.950	0.150 (Initiation)	0.250	0.350	0.500	0.625	0.750	0.950	1.000	Failure[b]
J	θ = 0.74, 550 F, 1725 cpm, Longitudinal, Unexposed															
	6344	12	14	17	17	17	--	6.9	17.5	25.2	34.8	42.0	49.2	--	--	--
	7336	14	15	18	18	18	--	8.7	16.7	23.7	32.9	39.7	46.5	--	--	--
	7339	13	15	17	18	18	18	8.3	18.0	25.5	35.0	42.1	48.9	59.9	62.2	78.7
	8171	13	17	19	20	20	20	6.5	15.6	23.0	31.9	38.6	44.9	54.9	57.4	74.3
K	θ = 1.04, Room Temperature, 1725 cpm, Longitudinal, Unexposed															
	6329	36	43	52	52	52	52	4.4	7.9	10.6	14.1	16.6	18.8	22.5	23.4	30.2
	7324	36	36	43	50	50	50	3.4	7.0	9.8	13.2	15.8	18.3	22.4	23.4	30.5
	8326	35	43	47	47	47	47	3.4	6.8	9.5	13.7	16.5	19.1	23.3	24.3	--
L	θ = 1.38, -110 F, 1725 cpm, Longitudinal, Unexposed															
	6350	57	71	83	89	89	89	1.8	4.2	5.7	7.6	9.0	10.4	12.6	13.1	15.8
	6357	58	63	82	82	82	82	1.9	4.2	5.8	7.9	9.4	10.9	13.4	14.0	17.0
M	θ = 1.38, Room Temperature, 34 cpm, Longitudinal, Unexposed															
	7342	58	63	78	78	78	78 8	1.5	3.7	5.4	7.5	9.1	10.7	13.3	13.8	16.5
	7347	56	63	79	79	79	--	1.2	3.8	5.5	7.5	9.1	10.7	--	--	--
	8161	53	58	71	71	76	76	1.2	3.8	5.7	7.9	9.7	11.4	14.0	14.6	17.5
	8168	49	63	78	78	78	--	1.8	4.3	6.2	8.5	10.1	11.7	--	--	--
N	θ = 1.38, Room Temperature, 1725 cpm, Longitudinal, Unexposed															
	6342	44	50	62	62	62	56	2.3	5.3	7.4	10.1	12.2	14.2	17.8	18.8	23.7
	7325	50	56	64	64	64	64	1.8	4.3	6.2	8.8	10.7	12.6	15.7	16.5	--
	8324	45	53	59	59	59	59	2.4	4.9	7.2	9.7	11.8	13.9	17.3	18.1	21.0
O	θ = 1.38, Room Temperature, 1725 cpm, Transverse, Unexposed															
	6207	43	48	61	61	61	61	2.2	5.2	7.4	10.1	12.2	14.2	17.5	18.3	--
	6210	38	46	52	52	52	52	2.4	5.6	8.2	11.3	13.7	16.1	20.0	21.0	25.1
	7353	44	46	60	60	70	50	2.5	5.2	7.5	10.4	12.5	14.5	18.0	19.1	--
	8177	42	46	58	58	58	58	1.3	4.7	7.0	9.9	12.0	14.2	17.6	18.5	22.2

P	θ = 1.38, 550 F, 1725 cpm, Longitudinal, Unexposed															
	8165	31	39	45	45	53	45	1.6	5.3	8.4	11.9	14.7	17.2	21.6	22.7	26.0
	8172	30	42	44	44	44	44	1.8	5.5	8.6	12.1	14.9	17.7	22.2	23.3	28.2
Q	θ = 1.74, Room Temperature, 1200 cpm, Longitudinal, Unexposed															
	6347	57	70	83	83	83	76	1.4	3.6	5.3	7.3	8.8	10.3	12.9	13.6	16.6
	7332	58	71	83	83	83	78	1.1	3.2	4.7	6.7	8.2	9.7	11.9	12.6	--
	7340	61	71	85	85	85	83	1.1	2.2	4.7	6.5	8.0	9.5	11.8	12.4	15.1
	8330	50	61	71	75	75	63	1.5	4.0	5.7	8.1	9.8	11.5	14.5	15.3	--

(a) Tip-to-tip crack length.
(b) Specimens cycled to failure from a 1-inch nominal crack length without further adjustment of net-section stress.
(c) θ = Net-section alternating stress amplitude/net-section mean stress.
(d) Blank indicates specimen test stopped; specimen employed in residual-static-strength studies.

TABLE B-2. CRACK-PROPAGATION DATA FOR 4-INCH WIDE Ti-8Al-1Mo-

Center-notched, longitudinal, unexposed triplex-annealed specimens at a

θ(b)	Specimen	Crack Propagation Rate, μ in./cycle, at Indicated Crack Length(a), inch												0.150
		0.250	0.350	0.500	0.625	0.700	0.750	0.950	1.000	1.250	1.500	1.750	1.900	(Initiation)
0.38	8-C	6.2	9.1	14	17	17	17	21	21	22	23	23	23	30.7
	8-D	5.6	8.5	12	14	17	17	21	21	23	23	23	23	47.0
0.74	8-A	24	34	38	44	50	52	60	60	65	69	69	69	7.3
	8-B	24	29	40	45	47	50	59	59	67	67	67	67	7.3

(a) Tip-to-tip crack length.
(b) θ = Net-section alternating stress amplitude/net-section mean stress.
(c) Specimens cycled to failure from 2-inch nominal crack length without further adjustment of net-section stress.

TABLE B-3. CRACK-PROPAGATION DATA FOR 2-INCH WIDE Ti-8Al-1Mo-

Center notched ($K_t \cong 7.9$) longitudinal, unexposed, triplex-annealed specimens at an

θ(b)	Specimen	Crack Propagation Rate, μ in./cycle, at Indicated Crack Length(a), in.					
		0.250	0.350	0.500	0.625	0.750	0.950
0.26	7348	2.0	3.2	5.2	7.9	11	19
0.38	7345	5.6	8.8	14	19	25	35
0.74	7344	22	28	46	55	75	117
1.04	6341	34	50	75	100	142	208
1.38	8166	46	59	81	107	143	285
1.74	8164	70	115	131	225	375	575

(a) Tip-to-tip crack length.
(b) θ = original net-section alternating stress amplitude original net-section mean stress.

TABLE B-4. CRACK-PROPAGATION DATA FOR 2-INCH WIDE AM-350 STAINLESS STEEL SHEET

Center-notched ($K_t \cong 7.9$), longitudinal specimens at a constant net-

Specimen	Crack Propagation Rate, μ in./cycle, at Indicated Crack Length(b), in.						0.130
	0.250	0.350	0.500	0.625	0.750	0.950	(Initiation)
630	19	23	29	33	34	38	3.0
6314	20	25	32	34	36	(d)	2.6
6319	20	25	34	34	34	--	2.4
731	20	27	34	36	43	--	3.5
739	20	24	33	38	38	--	3.1
8314	20	23	28	29	34	35	3.9
838	20	24	30	31	33	--	2.6

(a) θ = net-section alternating stress amplitude/net-section mean stress.
(b) Tip-to-tip crack length.

1V ALLOY SHEET SPECIMENS WITH CONSTANT NET-SECTION STRESS

constant net-section mean stress of 25 ksi, room temperature, and 1200 cpm.

Total Thousands of Cycles to Indicated Crack Length[a], inch													
0.250	0.350	0.500	0.625	0.700	0.750	0.950	1.000	1.250	1.500	1.750	1.900	2.000	Failure[c]
52.8	68.0	80.0	88.4	92.8	95.7	107	109	121	132	143	150	154	183
84.2	98.5	113	123	128	131	142	145	156	167	178	185	190	222
13.7	17.3	21.4	24.8	26.4	27.4	31.1	31.9	35.9	39.6	43.2	45.4	46.9	54.0
12.3	16.1	20.7	23.6	25.2	26.4	30.0	30.9	34.9	38.6	42.4	44.7	46.2	53.5

1V ALLOY SHEET SPECIMENS WITH CONSTANT GROSS-SECTION STRESS

original net-section mean stress of 25 ksi, room temperature, and 1200-1275 cpm.

Total Thousands of Cycles to Indicated Crack Length[a], in.								
0.150 (Initiation)	0.250	0.350	0.500	0.625	0.750	0.950	1.000	Failure
943	1083	1122	1158	1177	1190	1205	1208	1226
89.5	115	129	142	150	156	163	164	172
6.8	12.6	16.7	20.9	23.4	25.3	27.5	27.8	29.6
3.4	7.3	9.8	12.2	13.6	14.6	15.6	15.9	16.6
1.8	4.6	6.6	8.8	10.1	11.2	12.2	12.4	12.8
1.1	2.9	4.1	5.3	6.0	6.4	6.8	6.9	7.2

SPECIMENS AFTER 10,000 HOURS' STRESSED EXPOSURE WITH CONSTANT NET-SECTION STRESS

section mean stress of 40 ksi, room temperature, 1200 cpm, and $\theta^{(a)} = 0.75$.

Total Thousands of Cycles to Indicated Crack Length[b], in.								
0.150 (Initiation)	0.250	0.350	0.500	0.625	0.750	0.950	1.000	Failure[c]
4.8	11.3	16.1	22.1	26.1	29.9	35.4	36.7	45.5
4.1	10.0	14.5	19.9	23.8	27.4	--	--	--
3.9	9.8	14.3	19.3	23.0	26.6	--	--	--
5.3	12.3	16.7	21.8	25.2	28.3	--	--	--
4.7	10.3	14.9	20.3	23.9	27.2	--	--	--
5.5	11.5	16.4	22.1	26.6	30.6	36.4	37.9	47.0
4.5	10.8	15.4	21.0	25.0	28.9	--	--	--

(c) Specimens cycled to failure from 1-inch nominal crack length without further adjustment of net-section stress.
(d) Blank indicates specimen testing stopped; specimen employed in residual-static-strength studies.

APPENDIX C

STRESS-LIFETIME DATA

TABLE C-1. STRESS-LIFETIME DATA FOR AM-350 STAINLESS STEEL AT -110 F

Specimen	Maximum Stress, ksi	Cycles to Failure
	Unexposed, Notched (K_t = 4.0), Longitudinal, 40-Ksi Mean Stress	
7135	120.0	1,000
7163	105.0	7,000
7164	90.0	25,000
7132	75.0	58,000
6139	70.0	120,000
7158	67.5	177,000
6148	65.0	5,959,000, D.N.F.[a]
	10,500 Hours' Exposure, Notched (K_t = 4.0), Longitudinal, 40-Ksi Mean Stress	
8145	90.0	17,800
8128	80.0	27,000
7150	70.0	104,000
8146	65.0	171,800
7138	60.0	1,973,500
8135	57.5	3,067,000, D.N.F.

(a) D.N.F. - did not fail.

TABLE C-2. STRESS-LIFETIME DATA FOR AM-350 STAINLESS STEEL AT ROOM TEMPERATURE

Specimen	Maximum Stress, ksi	Cycles to Failure
	Unexposed, Unnotched, Longitudinal Zero Mean Stress	
8166	160.0	12,300
8167	125.0	43,300
8171	110.0	87,500
8163	100.0	71,500
8165	90.0	256,200
8169	80.0	471,700
8150	75.0	10,107,500, D.N.F.[a]
8148	75.0	16,256,900, D.N.F.
8168	70.0	10,041,600, D.N.F.
	Unexposed, Notched (K_t = 4.0), Longitudinal, Zero Mean Stress	
6319	65.0	16,100
7318	55.0	22,700
6316	50.0	30,000
7324	45.0	43,400
7322	40.0	99,000
8317	37.5	116,000
6320	35.0	88,400
8322	32.5	10,087,000, D.N.F.
	Unexposed, Notched (K_t = 4.0), Longitudinal, 40-Ksi Mean Stress	
7131	120.0	2,500
6143	98.0	10,000
6156	80.0	19,500
6158	70.0	30,000
7130	60.0	173,000
8138	57.5	72,000
6144	56.6	1,484,000
8133	55.0	10,248,000, D.N.F.

TABLE C-2. (Continued)

Specimen	Maximum Stress, ksi	Cycles to Failure
	Unexposed, Notched (K_t = 4.0), Transverse, 40-Ksi Mean Stress	
6180	80.0	17,800
6178	70.0	37,300
6174	60.0	99,400
6179	60.0	119,100
6172	55.0	195,300
6177	55.0	10,115,500, D.N.F.
6173	55.0	14,450,300, D.N.F.
6169	50.0	17,026,300, D.N.F.
	Unexposed, Unnotched, Room Temperature, 100-Ksi Mean Stress	
8154	226.4	11,000
8158	210.0	19,400
6308	195.0	37,600
8309	185.0	52,500
6301	175.0	104,200
7302	170.0	230,000
6310	165.0	11,951,800, D.N.F.
	Unexposed, Notched (K_t = 4.0), Room Temperature, 100-Ksi Mean Stress	
7326	135.0	11,700
7311	134.8	13,700
8319	130.0	11,800
6311	125.0	18,000
8318	120.0	29,700
7321	115.0	80,000
7313	110.0	1,606,000
6324	107.5	10,118,000, D.N.F.

(a) D.N.F. - did not fail.

TABLE C-3. STRESS-LIFETIME DATA FOR AM-350 STAINLESS STEEL AT 550 F

Specimen	Maximum Stress, ksi	Cycles to Failure
	Unexposed, Unnotched, Longitudinal, Zero Mean Stress	
6353	125.0	5,000
6355	110.0	15,000
8173	100.0	26,200
8174	95.0	36,300
7174	90.0	138,200
7306	85.0	11,859,900, D.N.F.[a]
7173	82.5	10,071,900, D.N.F.
	Unexposed, Notched (K_t = 4.0), Longitudinal, Zero Mean Stress	
6323	50.0	9,300
6312	45.0	13,200
7323	40.0	26,000
8312	37.5	31,400
6313	35.0	46,600
6314	32.5	67,200
7316	30.0	128,400
8313	27.5	180,900
7320	25.0	12,006,000, D.N.F.
	Unexposed, Unnotched, Longitudinal, 20-Ksi Mean Stress	
6302	140.0	3,000
8306	135.0	9,100
7184	130.0	11,400
8305	125.0	15,400
6303	120.0	25,500
7183	115.0	31,600
7189	110.0	45,700
6301	105.0	49,600
7171	102.5	6,351,900
7188	97.5	10,001,000, D.N.F.

TABLE C-3. (Continued)

Specimen	Maximum Stress, ksi	Cycles to Failure
	Unexposed, Notched (K_t = 4.0), Longitudinal, 20-Ksi Mean Stress	
6182	60.0	6,600
8324	55.0	15,400
7325	52.5	18,000
7327	50.0	32,900
8326	47.5	45,000
6317	45.0	76,100
7329	42.5	1,984,600, D.N.F.
7328	40.0	10,032,000, D.N.F.
	Unexposed, Notched (K_t = 4.0), Longitudinal, 40-Ksi Mean Stress	
6138	100.0	2,500
6135	88.0	3,500
6145	75.0	11,000
6134	70.0	27,000
8142	65.0	58,000
8141	63.7	38,000
7162	62.5	12,598,000, D.N.F.
7157	60.0	10,044,800, D.N.F.
	10,500 Hours' Exposure, Notched (K_t = 4.0), Longitudinal, 40-Ksi Mean Stress	
8139	75.0	7,200
8131	67.5	14,300
8147	65.0	239,800
7146	62.5	340,200
8129	60.0	6,113,700

TABLE C-3. (Continued)

Specimen	Maximum Stress, ksi	Cycles to Failure
	Unexposed, Unnotched, Longitudinal, 100-Ksi Mean Stress	
7177	195.0	8,400
8303	187.5	17,200
7304	182.5	24,100
7190	180.0	21,800
7303	177.5	29,000
6351	175.0	21,800
6352	172.5	22,300
6354	170.0	31,100
8172	167.5	30,100
6306	165.0	135,200
7305	162.5	152,500
7185	160.0	11,788,900, D.N.F.
	Unexposed, Notched (K_t = 4.0), Longitudinal, 100-Ksi Mean Stress	
6321	125.0	10,900
7319	122.5	17,000
8316	120.0	27,000
7315	117.5	46,000
7317	115.0	89,000
6318	112.5	12,188,000, D.N.F.
8320	110.0	11,959,400, D.N.F.

(a) D.N.F. - did not fail.

TABLE C-4. STRESS-LIFETIME DATA FOR Ti-8Al-1Mo-1V ALLOY AT -110 F

Specimen	Maximum Stress, ksi	Cycles to Failure
	Unexposed, Notched (K_t = 4.0), Longitudinal, 25-Ksi Mean Stress	
8132	85.0	2,600
7120	77.5	5,100
8138	70.0	11,500
7114	60.0	16,700
8150	50.0	39,000
8133	45.0	54,000
8114	45.0	73,000
8134	42.5	722,000
6132	42.5	2,965,400, D.N.F.[a]
7117	40.0	2,760,800, D.N.F.
6134	35.0	2,810,400, D.N.F.
	3000 Hours' Exposure, Notched (K_t = 4.0), Transverse, 25-Ksi Mean Stress	
7141	80.0	2,700
7144	60.0	16,300
8143	50.0	47,500
6140	49.8	36,000
6144	40.0	2,485,200, D.N.F.
	10,000 Hours' Exposure, Notched (K_t = 4.0), Longitudinal, 25-Ksi Mean Stress	
6155	60.0	9,000
6160	50.0	32,000
6152	47.5	89,000
6129	45.0	86,500
6130	42.5	139,000
6138	42.5	192,000
6150	40.0	2,719,400, D.N.F.

(a) D.N.F. - did not fail.

TABLE C-5. STRESS-LIFETIME DATA FOR Ti-8Al-1Mo-1V ALLOY AT ROOM TEMPERATURE

Specimen	Maximum Stress, ksi	Cycles to Failure
	Unexposed, Unnotched, Longitudinal, Zero Mean Stress	
7303	120.0	17,000
7310	110.0	23,800
6311	100.0	28,200
8134	90.0	74,000
8302	80.0	286,000
6309	70.0	1,089,500
6308	65.0	2,280,900
7309	60.0	10,011,600, D.N.F.[a]
	Unexposed, Notched (K_t = 4.0), Longitudinal, Zero Mean Stress	
6177	50.0	5,900
6146	40.0	13,900
6147	30.0	33,400
6176	25.0	115,600
6179	22.0	99,500
6188	22.0	156,300
6189	20.0	10,015,900, D.N.F.
6148	20.0	10,217,800, D.N.F.
	Unexposed, Notched (K_t = 4.0), Longitudinal, 25-Ksi Mean Stress	
6158	85.0	2,400
7113	70.0	5,000
6128	60.0	12,000
8148	50.0	26,000
7111	40.0	94,000
6180	39.0	68,000
6181	39.0	83,500
7118	35.0	267,000
8111	33.7	236,000
7119	33.0	3,098,000
6145	32.5	10,000,000, D.N.F.
8135	30.0	11,483,600, D.N.F.

TABLE C-5. (Continued)

Specimen	Maximum Stress, ksi	Cycles to Failure
	Unexposed, Notched (K_t = 4.0), Transverse, 25-Ksi Mean Stress	
8222	60.0	6,900
8223	55.0	11,600
8141	50.0	22,500
6139	45.0	40,000
7223	40.0	101,300
7222	35.0	8,681,200
7221	32.5	10,012,900, D.N.F.
	Unexposed, Unnotched, Longitudinal, 60-Ksi Mean Stress	
8307	150.0	9,700
8301	140.0	38,200
6318	130.0	42,500
7304	120.0	196,600
8305	110.0	106,900
7305	110.0	1,344,300
7306	105.0	1,014,100
6317	100.0	3,862,500
6313	95.0	8,739,000
8310	90.0	13,206,700
	Unexposed, Notched (K_t = 4.0), Longitudinal, 60-Ksi Mean Stress	
8113	110.0	1,300
6320	100.0	3,500
8137	90.0	9,600
8145	80.0	15,400
6203	70.0	103,400
8128	70.0	109,600
6190	65.0	10,076,000, D.N.F.
7318	65.0	10,013,700, D.N.F.

(a) D.N.F. - did not fail.

TABLE C-6. STRESS-LIFETIME DATA FOR Ti-8Al-1Mo-1V ALLOY AT 550 F

Specimen	Maximum Stress, ksi	Cycles to Failure
	Unexposed, Unnotched, Longitudinal, Zero Mean Stress	
8303	100.0	5,000
6316	90.0	17,200
8309	80.0	35,800
7311	70.0	65,400
7313	70.0	83,400
8311	65.0	7,815,800
6310	55.0	10,936,500, D.N.F.[(a)]
	Unexposed, Notched (K_t = 4.0), Longitudinal, Zero Mean Stress	
6325	45.0	11,300
8317	40.0	13,300
8320	35.0	22,000
6323	30.0	30,000
6324	25.0	57,000
7322	22.5	79,100
7317	20.0	10,093,700
	Unexposed, Notched (K_t = 4.0), Longitudinal, 25-Ksi Mean Stress	
8149	70.0	2,300
7115	60.0	7,500
8147	50.0	25,800
7112	40.0	99,400
8130	35.0	10,197,500, D.N.F.
8131	35.0	14,379,400, D.N.F.
7116	32.5	12,053,000, D.N.F.
6136	30.0	11,174,000, D.N.F.
	3000 Hours' Exposure, Notched (K_t = 4.0), Transverse, 25-Ksi Mean Stress	
7143	60.0	6,500
6142	50.0	17,300
8139	40.0	78,100
7146	35.0	9,827,400, D.N.F.

TABLE C-6. (Continued)

Specimen	Maximum Stress, ksi	Cycles to Failure
	10,000 Hours' Exposure, Notched (K_t = 4.0), Longitudinal, 25-Ksi Mean Stress	
6149	60.0	7,500
6151	50.0	21,500
6161	45.0	35,900
6159	42.5	44,600
6157	40.0	713,400
6131	37.5	11,805,000, D.N.F.
6156	35.0	10,025,000, D.N.F.
	Unexposed, Unnotched, Longitudinal, 60-Ksi Mean Stress	
8312	120.0	12,200
7302	110.0	33,900
6306	107.5	25,000
7303	105.0	2,554,500
6307	102.5	62,700
7301	95.0	10,036,000, D.N.F.
	Unexposed, Notched (K_t = 4.0), Longitudinal, 60-Ksi Mean Stress	
8319	90.0	5,700
8324	85.0	7,400
7316	80.0	15,800
6322	75.0	29,300
6321	72.5	55,500
8321	70.0	82,300
6327	67.5	14,273,500, D.N.F.
8322	65.0	11,202,900, D.N.F.

(a) D.N.F. - did not fail.

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