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PERIODIC OVERLOAD AND TRANSPORT SPECTRUM FATIGUE CRACK GROWTH TESTS OF Ti62222STA AND Al2024T3 SHEET

ABSTRACT

Variable amplitude loading crack growth tests have been conducted to provide data that can be used to evaluate crack growth prediction codes. Tests with periodic overloads or overloads followed by underloads were conducted on titanium alloy Ti-6Al-2Sn-2Zr-2Mo-2Cr solution treated and aged (Ti62222STA) material at room temperature and at 350°F. Spectrum fatigue crack growth tests were conducted on two materials (Ti62222STA and aluminum alloy 2024-T3) using two transport lower-wing test spectra at two temperatures (room temperature and 350°F (Ti only)). Test lives (growth from an initial crack half-length of 0.15 in. to failure) were recorded in all tests and the crack length against cycles (or flights) data were recorded in many of the tests. The following observations were made regarding the test results: (1) in tests of the Ti62222STA material, the tests at 350°F had longer lives than those at room temperature, (2) in tests to the MiniTwist spectrum, the Al2024T3 material showed much greater crack growth retardations due to the highest stresses in the spectrum than did the Ti62222STA material, and (3) comparisons of material crack growth performances on an “equal weight” basis were spectrum dependent.

INTRODUCTION

The evaluation of the capabilities of crack growth prediction codes or methods requires a body of test data on the crack growth that occurs during various variable amplitude loading sequences. Data for loading sequences that are representative of typical in-service usage and for non-representative, specially-constructed loading sequences can be useful in the evaluations.

The objective of the current work was to conduct and document some pertinent crack growth tests for use in those evaluations. Tests with periodic overloads or overloads followed by underloads were conducted on titanium alloy Ti-6Al-2Sn-2Zr-2Mo-2Cr solution treated and aged (Ti62222STA) material at room temperature and at 350°F. Spectrum fatigue crack growth tests were conducted on two materials (Ti62222STA and aluminum alloy 2024-T3) using two transport lower-wing test spectra at two temperatures (room temperature and 350°F (Ti only)). Although both spectra chosen were for transport lower-wing locations, they are substantially different in cyclic content and may produce different crack growth behaviors. Likewise, the materials tested were chosen because they were likely to exhibit different behaviors. Test lives (growth from an initial crack half-length of 0.15 in. to failure) were recorded in all tests and the crack length against cycles (or flights) data were recorded in many of the tests.

TESTS

Materials and Specimens

Tests were conducted on center-cracked tension specimens of nominally 0.065-in.-thick Ti62222STA titanium alloy and of nominally 0.090-in.-thick Al2024T3 aluminum alloy sheet materials. The chemical compositions and tensile properties for these materials are given in Table 1.

The center-cracked specimens were either 2 or 3 inches wide and had a crack-starter slot electro-discharge machined about the centerline. The specimen configurations are shown in Figure 1. The long axis of the specimens was parallel to the sheet rolling direction. That is, the crack growth was determined for the L-T orientation.

Test Procedures

Tests were conducted in a computer-controlled, axial-loading electrohydraulic fatigue testing machine equipped with a 20 kip load cell that was calibrated to 10 kip and 20 kip ranges. Testing was nominally at a constant loading rate rather than at a constant cyclic frequency, but the tests typically ran at about a 10-12 Hz average frequency. All testing was conducted in laboratory air. Crack lengths were measured visually using a 60X microscope mounted on a micrometer slide.

Tests were conducted isothermally at either room temperature or 350°F. Anti-buckling plates were in place about the specimen in all tests regardless of whether compressive loads were applied. Heating for the elevated temperature tests was supplied by resistive cartridge heaters which were inserted into holes in the metallic anti-buckling plates (see Figure 2). Temperature was controlled and monitored using thermocouples attached to the specimen near the central crack-starter slot. A temperature survey using multiple thermocouples confirmed that this testing arrangement provided temperatures within +/- 2°F of 350°F over the specimen test section.

Periodic Overload/Underload Tests of Ti62222STA

All of these tests were conducted using the 2-in.-wide specimens. Tests were conducted isothermally at either room temperature or 350°F. Specimens were precracked to a crack half-length of 0.15 inches using a constant amplitude loading having a stress ratio of 0.1 and a maximum stress of 20 ksi. After precracking, the specimens were subjected to a repeated overload (or overload followed immediately by an underload) sequence until failure. The repeated loading sequence consisted of 2500 cycles of the precrack loading followed by a single overload (or overload/underload) cycle. The loading sequence is shown schematically in Figure 3. The magnitude of the overload (or overload/underload) was constant during each test, but was varied from test to test. The ratio of the maximum load of the overload cycle to the precrack maximum fatigue load ranged from 1.5 to 3.5. Some tests with an overload ratio of 2.5 also had an underload applied immediately following each overload. The ratio of the minimum load of the underload cycle to the precrack maximum fatigue load ranged from -1.0 to -3.0.

Transport Spectrum Tests of Ti62222STA and Al2024T3

All of these tests were conducted using the 3-in.-wide specimens. Tests on the Ti62222STA alloy were conducted isothermally at either room temperature or 350°F, whereas the tests on the Al2024T3 alloy were conducted at room temperature only. Both alloys were tested to two civil transport aircraft spectra representing wing box lower surface locations. One of the spectra is for a supersonic transport (referred to herein as the SST spectrum), while the other spectrum is for a subsonic transport (referred to herein as the MiniTwist spectrum). The cyclic stress content of the SST spectrum is defined herein while the content of the MiniTwist spectrum is defined in reference 1.

Tests were conducted at several stress levels for each spectrum. (Note that tests are identified by the maximum stress in the spectrum for that test and that stress always means gross-section stress.) The different stress levels were achieved by multiplying all stresses in an initial stress sequence by a constant factor. The stress levels were picked to cover a significant range in crack growth lives.

Specimens were precracked to a crack half-length of 0.15 inches using a constant amplitude loading having a stress ratio of 0.1 and a maximum stress of 0.5 of the spectrum maximum stress for the SST spectrum , or a maximum stress of 0.3 of the maximum spectrum stress for the MiniTwist spectrum. After precracking, the specimens were subjected to the spectrum loading until failure. Cycles to failure and, in most tests, crack length against cycles data were recorded in the tests.

SST spectrum sequence - The cyclic stresses in this spectrum were applied in a flight-by-flight sequence. Each flight was divided into five flight segments (climb, supersonic cruise, descent, subsonic cruise, and approach) and a taxi segment. The frequency of occurrence of cyclic stresses in each of eighteen stress ranges was determined for each flight segment. The taxi segment was represented by a single excursion to the minimum stress expected for the segment. The testing sequence was defined as a repeated sequence of 1600 flights. Stresses that occurred less frequently than once per 1600 flights were not included in the sequence. Stresses that occurred less frequently than once per flight were added to flights in which the accumulated fractions of an occurrence per flight exceeded a whole number. For example, a single cycle of a stress that had a frequency of 0.3 occurrences per flight would be added in flight number 4, 7, 10, 14, etc. For testing purposes, once the cyclic content of all 1600 flights was defined, the location of each of the flights within the 1600 flight sequence was randomized. The sequence of occurrence of individual stress cycles within each flight segment was also randomized. The final sequence contained 105,445 stress cycles. The cyclic content of the test sequence is tabulated in Table 2. A portion of the SST spectrum sequence covering five flights is shown in Figure 4.

MiniTwist spectrum - The cyclic stresses in this spectrum were also applied in a flight-by-flight sequence. Details on the MiniTwist test sequence are given in reference 1. A portion of the MiniTwist sequence is shown in Figure 5. In Figure 5, the MiniTwist sequence is scaled to have the same maximum stress in the test sequence as that shown for the SST sequence in Figure 4. The time scales in the two figures are also the same. Several differences between the MiniTwist and SST test sequences are evident from the two figures. Namely, the MiniTwist sequence: (a) has a constant flight mean stress whereas the SST sequence has different mean stresses for each flight segment, (b) has a lower flight mean stress and higher cyclic stress excursions from the mean, and (c) has widely differing number of cycles in individual flights whereas the SST sequence does not. Other differences are that the MiniTwist sequence repeats after 4000 flights instead of 1600, has 62,442 cycles in the sequence instead of 105,445, and has the flight stress excursions randomized as “half cycles” (positive excursion from the mean always followed by a negative excursion, but not necessarily of the same magnitude) rather than as whole cycles (positive excursion from the mean always followed by a negative excursion of equal magnitude).

A couple of tests were conducted in which the three highest stress peaks in the sequence (one Level I peak and two Level II peaks) were reduced (clipped) to the level of the third highest stress level (Level III) while all other stress peaks remained the same. This was done to determine the effects of the infrequent big stress peaks on the crack growth.

RESULTS AND DISCUSSION

Periodic Overload/Underload Tests of Ti62222STA

Periodic Overload Tests

The lives to failure for tests at room temperature and at 350°F are tabulated in Table 3. In the table, life is defined as the cycles to grow the crack from the pre-cracked half-length of 0.15 in. to failure. The data from Table 3 are plotted in Figure 6 as life against overload ratio, where overload ratio is defined as the overload maximum stress divided by the maximum stress of the baseline constant amplitude loading (the 2500 cycles between overloads). For both temperatures, test lives increased as the overload ratio was increased up to about 2.5. Beyond an overload ratio of 2.5, the lives began to decrease as the growth caused by the baseline loading was almost completely retarded (stopped) and the life-limiting growth was that caused by the overload cycle. The lives of tests at 350°F were consistently longer than those at room temperature.

One specimen was loaded to failure at room temperature just after the normal pre-cracking to a crack half-length of 0.15 in.. The specimen was loaded at the same loading rate used in the overload tests. This test provided an estimate of the material fracture toughness and also indicated the upper limit in overload ratio that could be used in the tests (a ratio of about 6.2 in this case). Another estimate of the fracture toughness was obtained from a test in which the specimen was precracked to a longer half-length (0.60 in. instead of 0.15 in.) and then loaded to failure as before. An interesting observation from the overload tests was that the specimens subjected to the periodic overload sequence appeared to fail at higher fracture toughness values than did the two specimens that were failed after precracking under constant amplitude loading. This observation is illustrated in Figure 7 for the room temperature tests, where apparent fracture toughness, K_{app}, is plotted against nondimensional crack length, 2a/W, and where a = crack half-length and W = specimen width. K_{app} was calculated using the standard ASTM expression used in crack growth testing (ASTM Standard E-647, reference 2) with the crack length measured from the fractured specimen surface and the stress computed from the programed overload maximum value. The overload test specimens actually failed at loads slightly below the programed maximum value. The actual failing load was measured in two of the room temperature tests and in three of the 350°F tests. In these tests, the failing load averaged about 94 percent and was never below 91 percent of the programed maximum load. Even if the K values for the overload tests in Figure 7 were reduced by 10 percent, they would still appear to be higher than what would be expected based on the results from specimens not subjected to the overload sequence. All of the results plotted in Figure 7 are tabulated in Table 4.

Periodic Overload/Underload Tests

The lives to failure for tests at room temperature and at 350°F are tabulated in Table 5 and are plotted in Figure 8 as life against underload ratio, where underload ratio is defined as the underload minimum stress divided by the maximum stress of the baseline constant amplitude loading. Application of the underloads always immediately followed the application of an overload having an overload ratio of 2.5. Note that points plotted at an underload ratio of 0 represent tests to an overload ratio of 2.5 without any underloads. As expected, the greater (more negative) the underload, the shorter the life. However, even at an underload ratio of -3.0, the life-enhancing effect of the 2.5 overload was only reduced by about 50 percent.

Transport Spectrum Tests of Ti62222STA and Al2024T3

The results from the spectrum crack growth tests are presented in three graphical formats: (1) as stress level against test life, (2) as crack length against flights, and (3) as growth rate against stress intensity factor range. The information provided in each of these three formats is needed for a good understanding of the material performance in these tests and for a thorough evaluation of crack growth prediction methods.

Ti62222STA Tests

Test lives - The lives of the spectrum fatigue crack growth tests are tabulated in Table 6 and are plotted in Figure 9 as maximum spectrum stress against life, where life is defined as the number of flights to grow the crack from the initial half-length of 0.15 inches to specimen failure. At equal values of maximum spectrum stress, tests to the MiniTwist spectrum always produced longer lives than tests to the SST spectrum. For both test spectra, specimens tested at 350°F had longer lives than those tested at room temperature.

Crack length against flights - The crack length against flights data for the tests to the SST spectrum at room temperature and 350°F are given in Figures 10 and 11 respectively, and for the tests to the MiniTwist spectrum at room temperature and 350°F in Figures 12 and 13 respectively. The data for the MiniTwist test in which the three biggest peaks in the spectrum were clipped to a lower level are given in Figure 14 along with the data for the comparable unclipped spectrum test. Clipping the big peaks caused only about a 12 percent reduction in test life which indicates that the big peaks did cause some crack growth retardations, but that the retardations were not large.

Crack growth rates - The crack growth rate results are presented as growth rate, in inches/flight, against stress intensity factor range, ΔK, where the ΔK values are based on the maximum and minimum stresses in the spectrum. The expression used to calculate K and the procedure used to calculate rates (secant method) were taken from ASTM Standard E-647 (ref. 2). The results for the tests to the SST spectrum at room temperature and 350°F are given in Figures 15 and 16 respectively, and for the tests to the MiniTwist spectrum at room temperature and 350°F in Figures 17 and 18 respectively. The MiniTwist spectrum tended to cause greater retardations than the SST spectrum as evidenced by the greater scatter in rates, especially at the higher ΔK values. However, neither spectrum caused large retardations. The data from the tests of the clipped and unclipped MiniTwist spectrum are given in Figure 19.

Al2024T3 Tests

Test lives - The lives of the spectrum fatigue crack growth tests are tabulated in Table 7 and are plotted in Figure 20 as maximum spectrum stress against life, where life is defined in the same way as for the Ti62222STA tests. At equal values of maximum spectrum stress, tests to the MiniTwist spectrum always produced longer lives than tests to the SST spectrum.

Crack length against flights - The crack length against flights data for the test to the SST spectrum are given in Figure 21 and for the tests to the clipped and unclipped

MiniTwist spectrum in Figure 22. In the tests to the MiniTwist spectrum, the clipping of the three big peaks caused a 60 percent reduction in test life which indicates that the big peaks were causing large retardations of the crack growth. The much greater retardations experienced for the Al2024T3 compared to the Ti62222STA is related to the higher ratio of maximum stress to yield strength (and therefore bigger plastic zone size) in the Al2024T3 test as compared to that in the Ti62222STA test.

Crack growth rates - The results for the test to the SST spectrum are given in Figure 23 and for the tests to the clipped and unclipped MiniTwist spectrum in Figure 24. It is clear in Figure 24 that the big stress peaks in the unclipped MiniTwist spectrum were effective in reducing the growth rate and that the biggest reductions occurred after several occurrences of the big peaks.

Comparison of the Performance of Ti62222STA and Al2024T3

Comparisons between the spectrum crack growth performances of the Ti62222STA material and the Al2024T3 material can be made by plotting the "specific spectrum stress" (or spectrum maximum stress divided by material density) against life in flights for the two materials. The plots for tests to the SST and MiniTwist spectra are given in Figures 25 and 26, respectively. Interestingly, the plot for the SST tests would indicate about equal performance for the two materials, but the plot for the MiniTwist tests would indicate that the Al2024T3 shows substantially better performance. These results suggest that some care must be exercised in selecting an appropriate spectrum for comparing the spectrum crack growth performance of different materials.

CONCLUDING REMARKS

Variable amplitude loading crack growth tests have been conducted to provide data that can be used to evaluate crack growth prediction codes. Tests with periodic overloads or overloads followed by underloads were conducted on titanium alloy Ti-6Al-2Sn-2Zr-2Mo-2Cr solution treated and aged (Ti62222STA) material at room temperature and at 350°F. Spectrum fatigue crack growth tests were conducted on two materials (Ti62222STA and aluminum alloy 2024-T3) using two transport lower-wing test spectra at two temperatures (room temperature and 350°F (Ti only)). Test lives (growth from an initial crack half-length of 0.15 in. to failure) were recorded in all tests and the crack length against cycles (or flights) data were recorded in many of the tests.

The following observations were made regarding the test results: (1) in tests of the Ti62222STA material, the tests at 350°F had longer lives than those at room temperature, (2) in tests to the MiniTwist spectrum, the Al2024T3 material showed much greater crack growth retardations due to the highest stresses in the spectrum than did the Ti62222STA material, and (3) comparisons of material crack growth performances on an "equal weight" basis were spectrum dependent.

REFERENCES

1. Lowak, H.; deJonge, J.B.; Franz, j.; and Schutz, D.: MINITWIST - A Shortened Version of TWIST. Laboratorium fur Betriebsfestigkeit (LBF), Report No. TB-146, 1979 or National Lucht-en Ruimtevaartlaboratorium (NLR), NLR MP-79018U, 1979.
2. Metals Test Methods and Analytical Standards. Volume 03.01 of the 1997 Annual Book of ASTM Standards, ASTM, 1997, pp. 557-593.

Table 1. Material Chemical Compositions and Tensile Properties.

Ti62222STA

a. Chemical composition (Average weight percent):

Al	Sn	Zr	Mo	Cr	Si	O	Fe	C	N	Y
5.74	1.96	2.04	2.10	2.05	0.17	0.11	0.11	0.01	0.004	<50ppm

Balance: Ti

b. Tensile properties for longitudinal direction:

	Room Temperature	350°F
Ultimate tensile strength:	190 ksi	168 ksi
0.2%-offset yield strength:	172 ksi	141 ksi
Elongation to failure:	8 %	8 %

Al2024T3

a. Chemical composition (Average weight percent):

Cu	Mg	Mn	Fe	Si	Zn	Cr
4.61	1.51	0.57	0.33	0.16	0.06	0.02

Balance: Al

b. Tensile properties for longitudinal direction:

	Room Temperature
Ultimate tensile strength:	72 ksi
0.2%-offset yield strength:	52 ksi
Elongation to failure:	22 %

Table 2. Cyclic Stress Content of SST Test Sequence. (Stresses normalized by supersonic cruise mean stress.)

	Climb	Supersonic cruise	Descent	Subsonic cruise	Approach and land	Taxi
Mean stress	1.260	1.000	1.178	1.417	1.220	---
Alternating stress	Cycles per 1600 flights					
0.109	23788	11832	2024	5507	25302	
0.146	7517	5309	778	1434	6486	
0.182	2539	2757	392	661	1896	
0.219	943	1389	216	374	635	
0.255	406	703	123	218	261	
0.292	202	357	71	128	122	
0.328	114	181	41	75	63	
0.365	69	92	24	44	33	
0.401	44	46	14	26	18	
0.438	28	23	8	15	10	
0.474	18	12	4	9	5	
0.511	12	6	2	5	3	
0.547	8	3	1	3	1	
0.584	5	1		1		
0.620	3			1		
0.657	2					
0.693	1					
0.730	1					
Taxi minima	Occurrences per 1600 flights					
-0.415						912
-0.451						626
-0.488						58
-0.524						4

Note: With a few exceptions, each cycle tabulated above for the five flight segments defines two stress reversal points, a peak and a trough, that occur consecutively. The peak is the segment mean stress plus the alternating stress and the trough is the mean minus the alternating. Exceptions to this occur at the end of the climb segment, where in 996 of the 1600 flights, the last peak in the segment is followed by a trough that is lower than would be calculated using the alternating stress used for the peak. The troughs in these cases are actually those corresponding to the first two levels of the supersonic cruise segment. This situation occurs because the test protocol required that each peak be followed by a trough, and in the cases cited, the first peak of the supersonic cruise segment would have been less than the last trough of the climb segment. In those cases, the last trough and the first peak were deleted.The deletions are accounted for in the table. Another exception is that the last peak in the approach/land segment of each flight is paired with one of the taxi minima instead of the usual flight trough.

Table 3. Crack Growth Lives of Ti62222STA Specimens Subjected to a Periodic Overload Sequence.

Overload ratio	Initial crack half-length, inches	Test Life, cycles
Room Temperature		
1.00	0.151	52,709
1.00	0.148	52,503
1.50	0.149	57,522
1.50	0.150	57,522
1.75	0.149	127,550
1.75	0.150	107,542
2.00	0.148	1,506,145
2.00	0.150	1,585,633
2.50	0.145	2,671,068
2.50	0.171	2,443,476
3.00	0.149	2,395,957
3.00	0.150	1,435,573
3.50	0.147	862,844
3.50	0.151	565,225
350°F		
1.00	0.149	70,143
1.50	0.149	89,294
1.75	0.149	437,674
2.00	0.149	2,683,572
2.50	0.150	5,871,936
3.00	0.150	3,516,405
3.50	0.151	2,541,015

Table 4. Apparent Fracture Toughness Values from Periodic Overload Tests of Ti62222STA Specimens at Room Temperature.

Overload Ratio	2a/W	K_{app} based on overload max. load, ksi√in.	K_{app} based on measured failure load, ksi√in.	K_{app} from constant amplitude loading tests, ksi√in.
1.00	0.16	-----	89.4	89.4
1.00	0.60	-----	92.3	92.3
1.00	0.86	70.3	-----	70.3
1.00	0.86	70.1	-----	70.1
1.00	0.85	67.8	-----	67.8
1.50	0.81	88.2	-----	-----
1.50	0.81	87.8	81.4	-----
1.75	0.77	91.6	-----	-----
1.75	0.78	94.0	-----	-----
2.00	0.74	96.6	-----	-----
2.00	0.74	96.7	90.6	-----
2.50	0.66	100.8	-----	-----
2.50	0.68	105.4	-----	-----
3.00	0.67	123.5	-----	-----
3.00	0.62	111.7	-----	-----
3.50	0.62	130.2	-----	-----
3.50	0.57	118.5	-----	-----

Table 5. Crack Growth Lives of Ti62222STA Specimens Subjected to a Periodic Overload/Underload Sequence.

Underload ratio	Initial crack half-length, inches	Test Life, cycles
Room Temperature		
-1.00	0.151	1,926,012
-2.00	0.150	1,685,673
-2.00	0.150	1,635,653
-3.00	0.150	1,247,998
350°F		
-1.00	0.149	4,051,619
-2.00	0.151	3,186,273
-2.00	0.150	3,248,419
-3.00	0.150	2,293,416

Note: All of the tests listed in this Table had overloads with an overload ratio of 2.5. An underload immediately followed each of the overloads.

Table 6. Spectrum Crack Growth Lives for Tests on Ti62222STA.

Stress level, ksi		Initial crack half-length, in.	Test life, flights
Spectrum max.	Flight mean		
SST Spectrum			
Room Temperature			
30	---	0.152	18,992
40	---	0.151	7,944
40	---	0.154	7,521
50	---	0.151	3,670
350°F			
30	---	0.152	25,574
40	---	0.153	12,438
40	---	0.151	12,063
50	---	0.152	6,493
MiniTwist Spectrum			
Room Temperature			
31.2	12	0.151	29,655
39.0	15	0.152	16,911
34.5[a]	15[a]	0.151	14,935
52.0	20	0.152	7,519
78.0	30	0.152	1,655
350°F			
31.2	12	0.151	46,855
39.0	15	0.151	28,105
52.0	20	0.151	13,460

[a] The three highest stress peaks in the spectrum (one 39.0 ksi and two 37.5 ksi) were reduced to 34.5 ksi. All other stresses were the same as in the test with the maximum stress of 39.0 ksi.

Table 7. Spectrum Crack Growth Lives for Tests on Al2024T3.

Stress level, ksi		Initial crack half-length, in.	Test life, flights
Spectrum max.	Flight mean		
SST Spectrum			
Room Temperature			
18	---	0.149	21,642
24	---	0.150	9,232
24	---	0.152	9,138
30	---	0.150	3,848
MiniTwist Spectrum			
Room Temperature			
23.4	9.0	0.151	173,464
26.39	10.15	0.150	109,655
26.39	10.15	0.150	113,655
23.34[a]	10.15[a]	0.150	42,323
31.2	12.0	0.150	39,975
39.0	15.0	0.150	6,524

[a] The three highest stress peaks in the spectrum (one 26.39 ksi and two 25.38 ksi) were reduced to 23.34 ksi. All other stresses were the same as in the test with the maximum stress of 26.39 ksi.

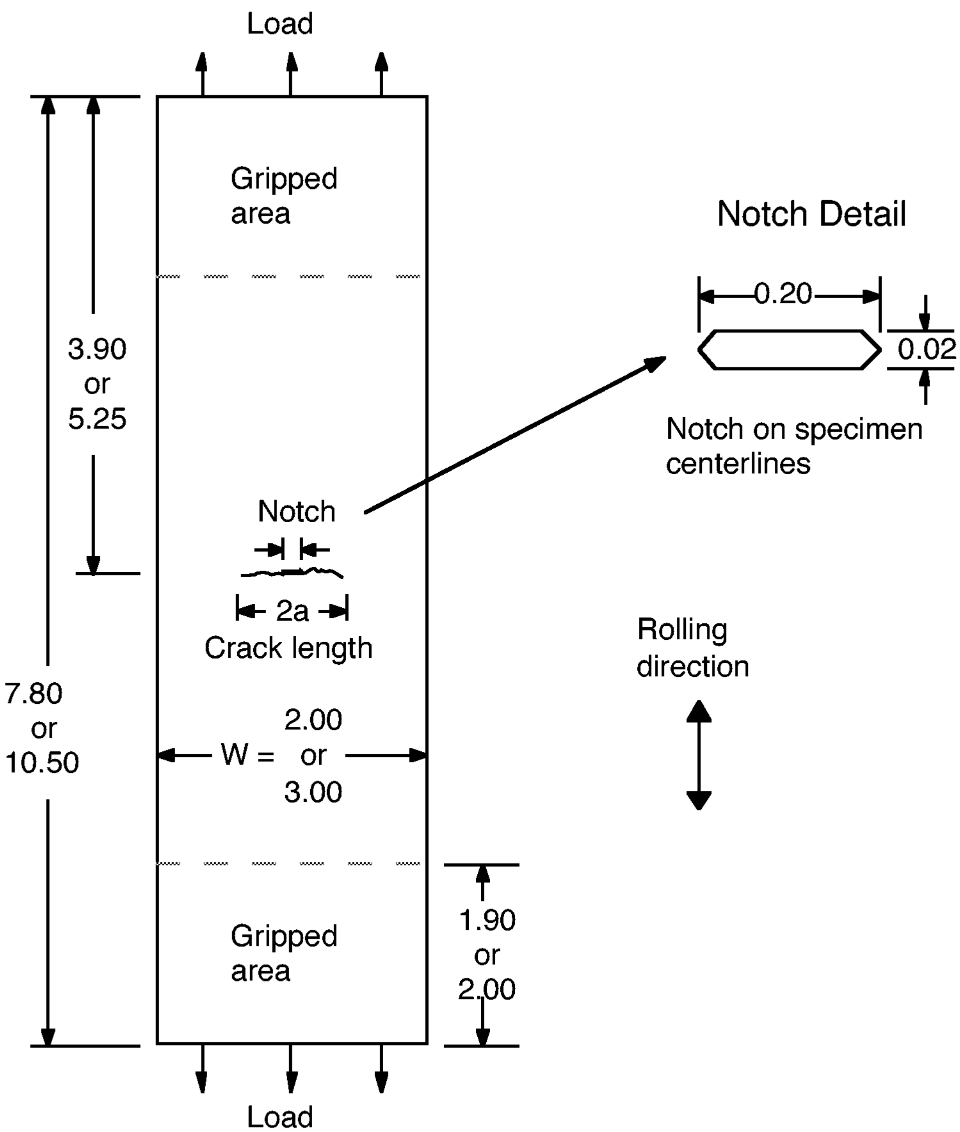

Figure 1. - Specimen configurations. Smaller dimensions refer to 2.00-in.-wide specimen. (Dimensions in inches.)

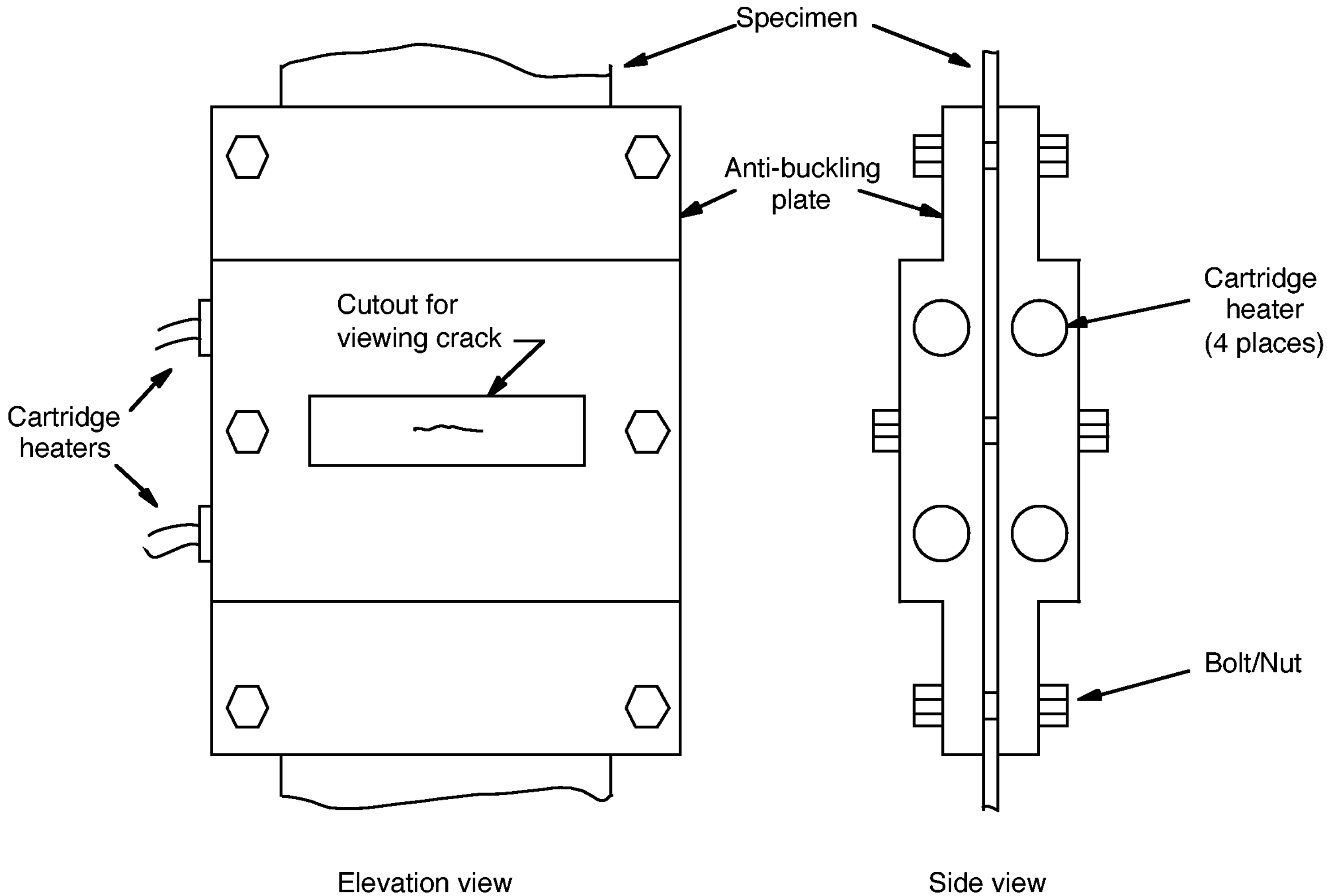

Figure 2. - Schematic of testing arrangement showing anti-buckling plates and cartridge heaters.

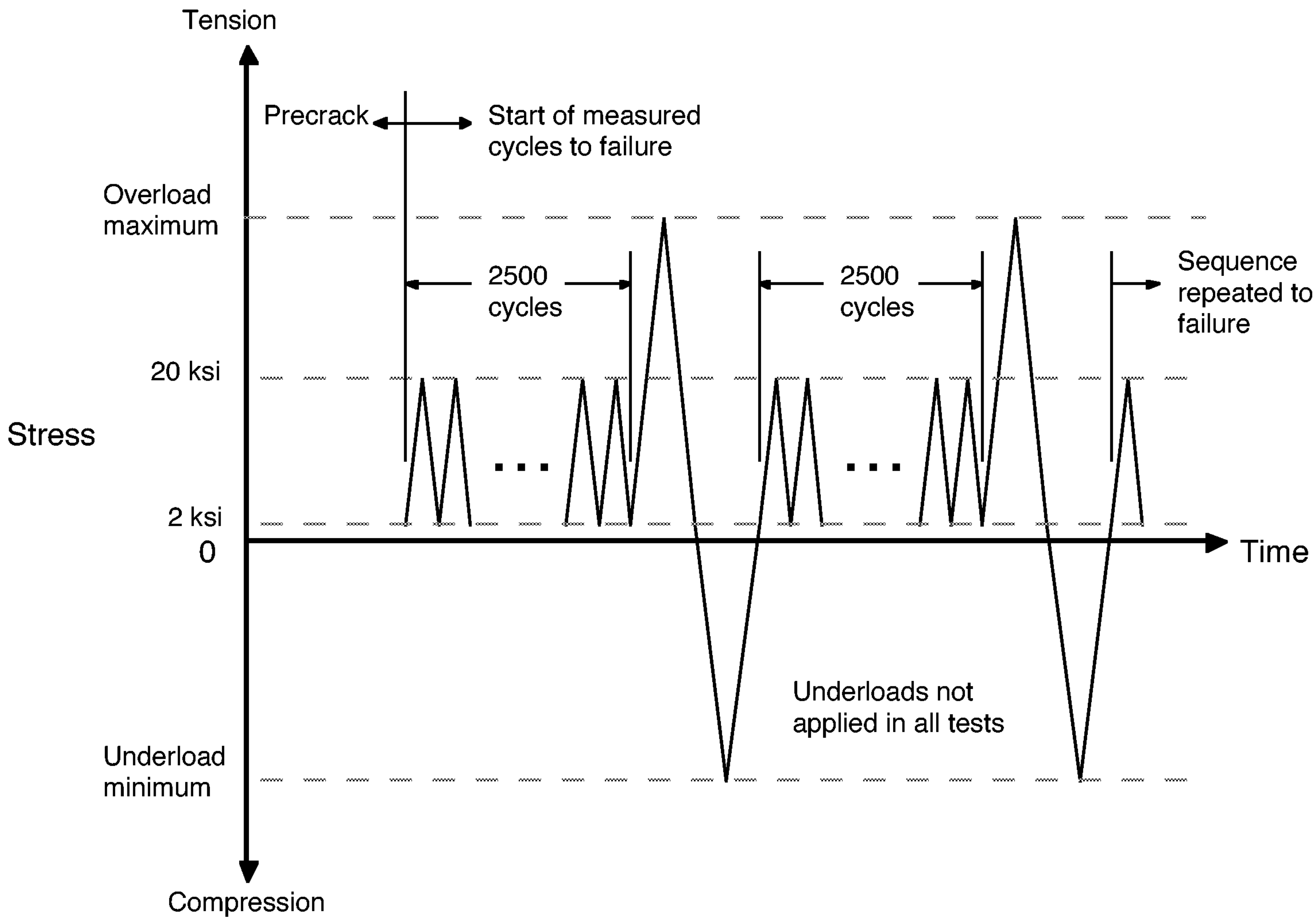

Figure 3. - Sequence of stress cycles used in overload/underload tests.

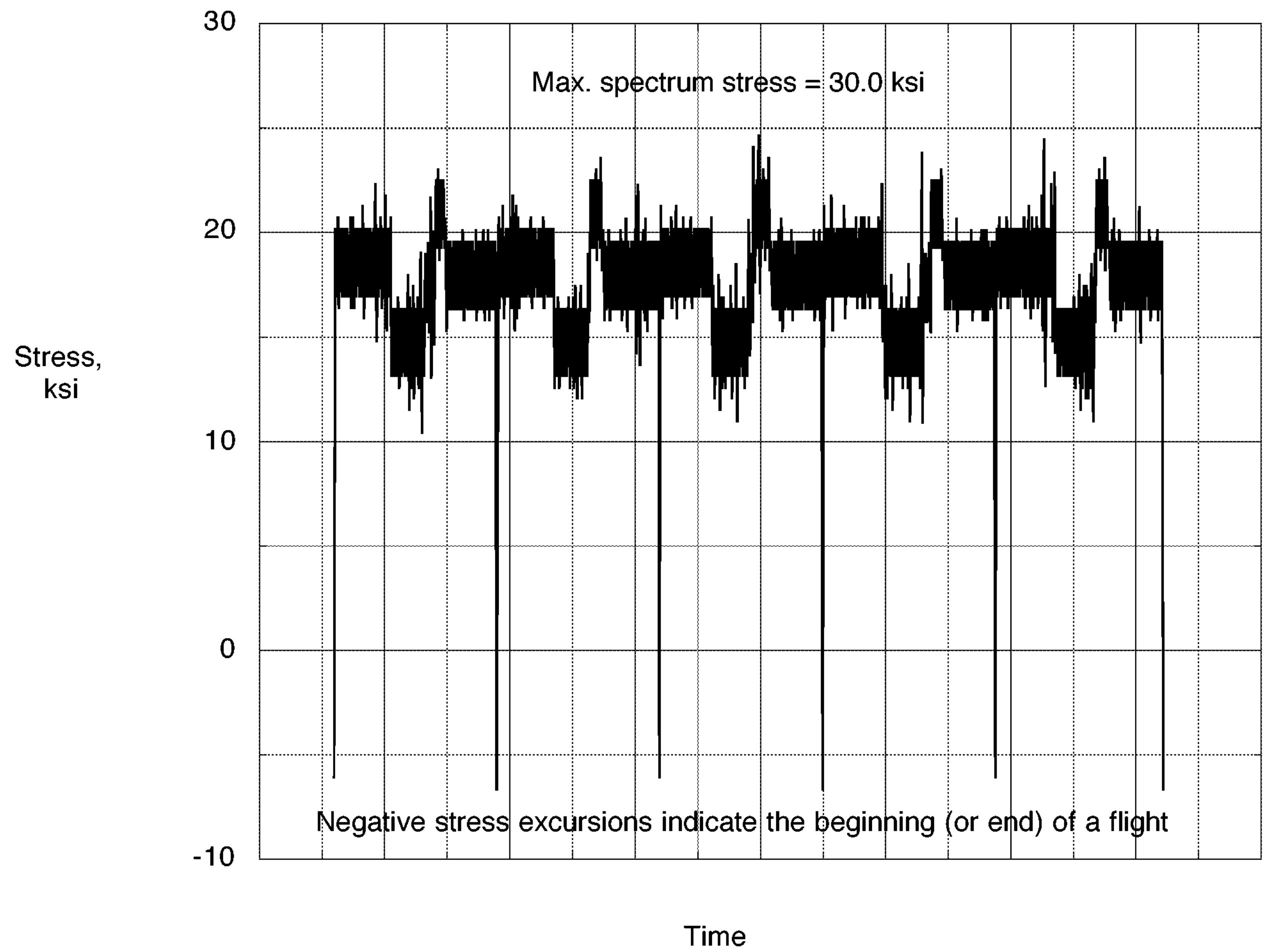

Figure 4. - Sample of the SST stress sequence covering 5 flights.

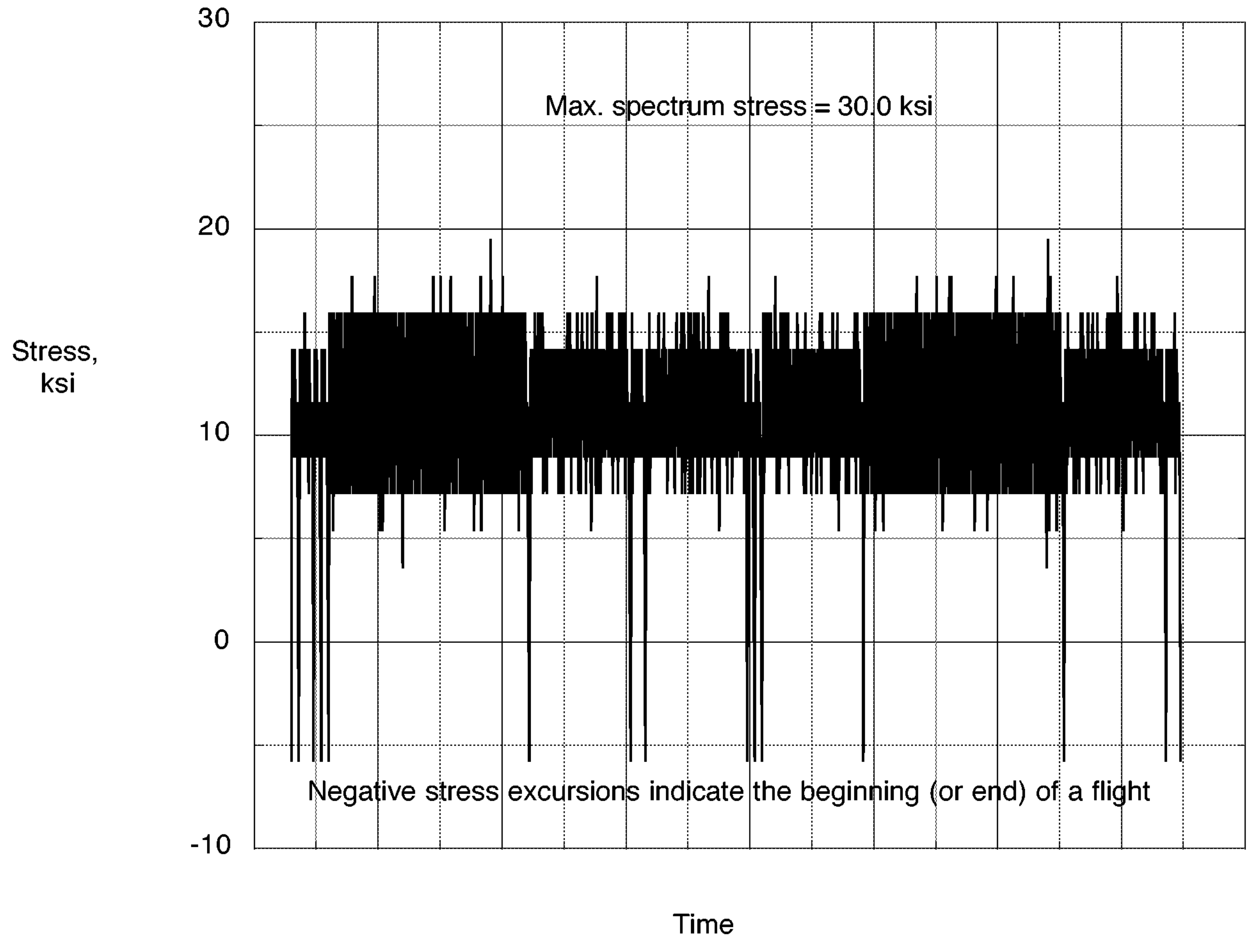

Figure 5. - Sample of the MiniTwist stress sequence covering 14 flights.

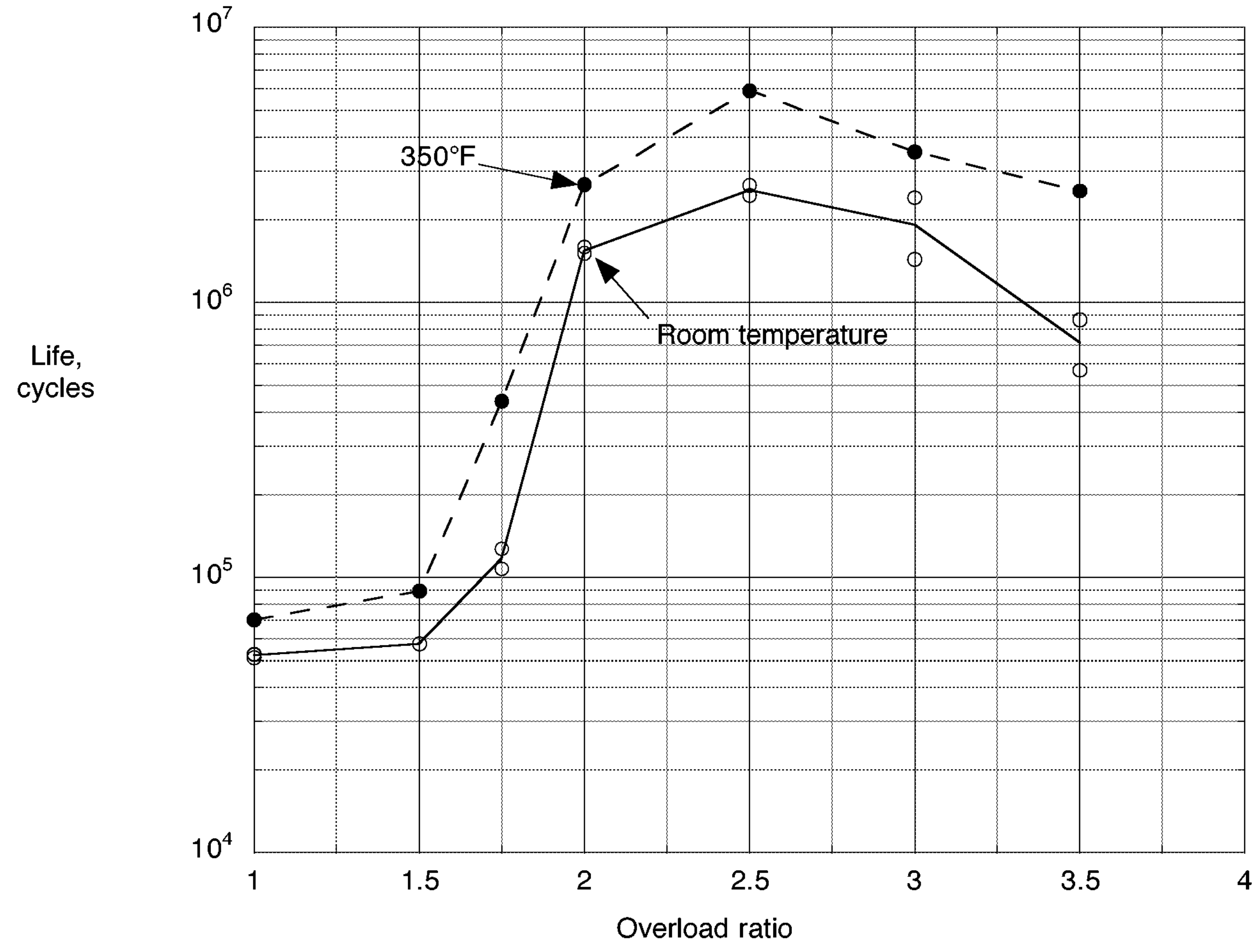

Figure 6. - Test lives of Ti62222STA specimens subjected to periodic overloads at room temperature or 350°F.

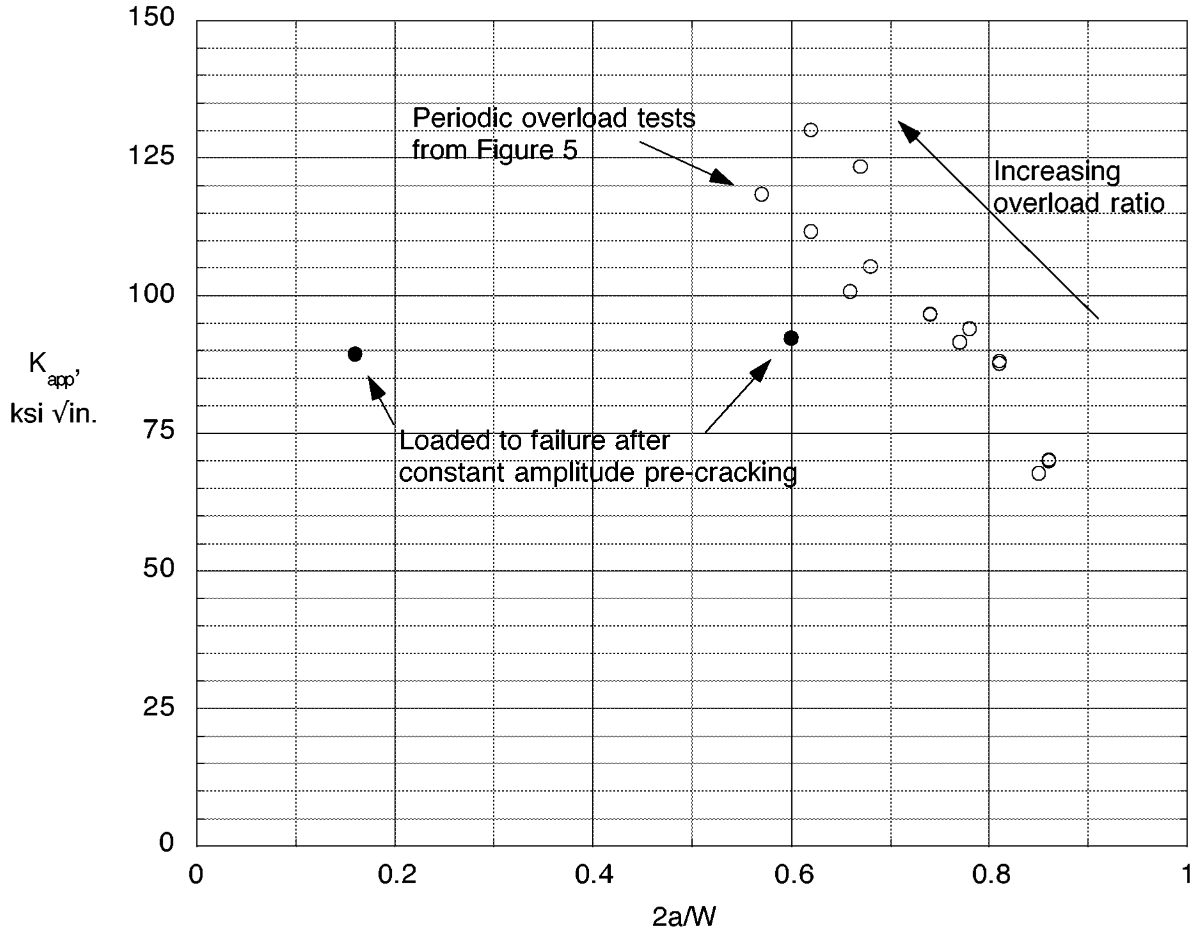

Figure 7. - Effects of exposure to overload history on apparent fracture toughness.

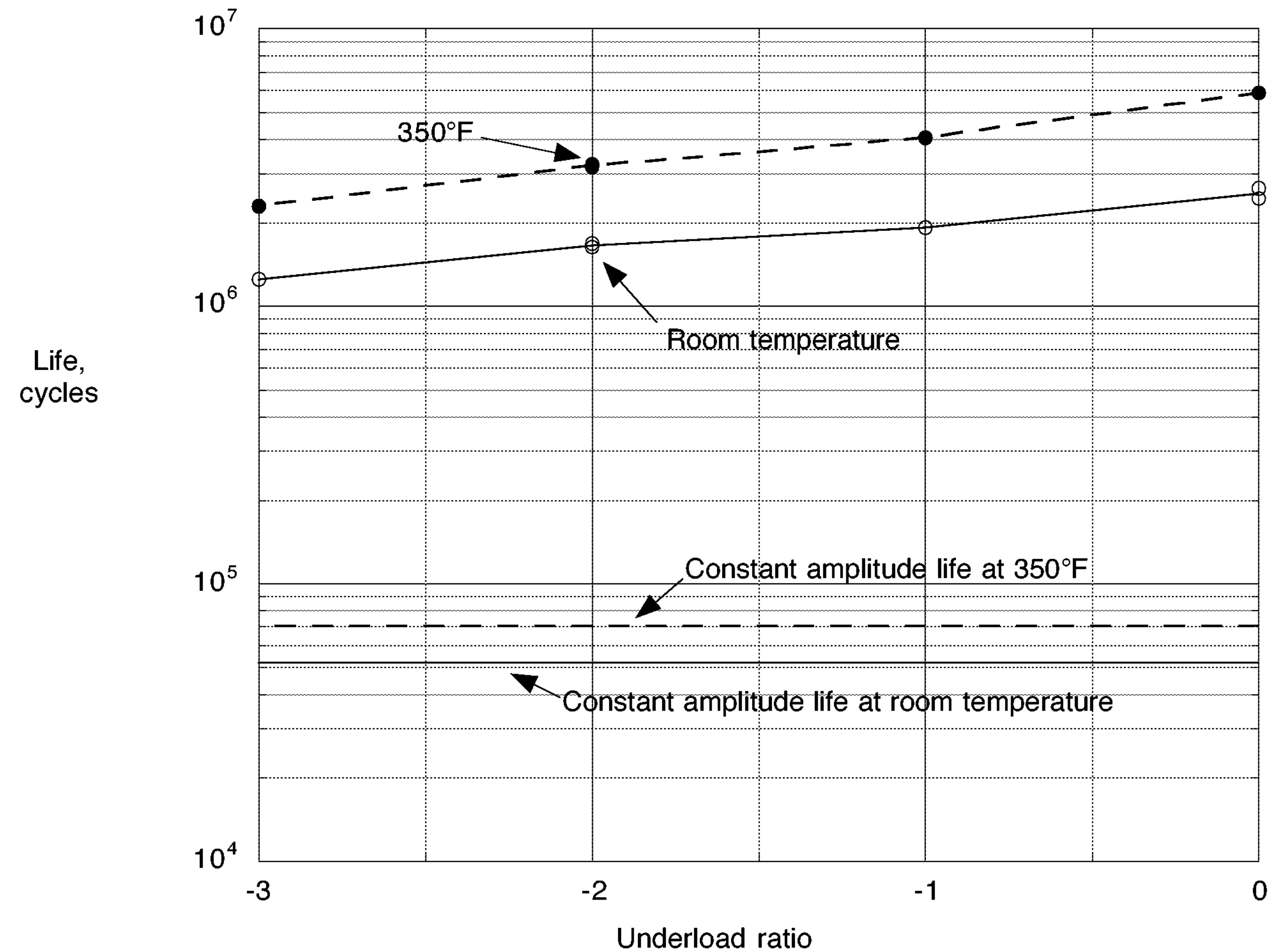

Figure 8. - Test lives of Ti62222STA specimens subjected to periodic underloads at room temperature or 350°F.

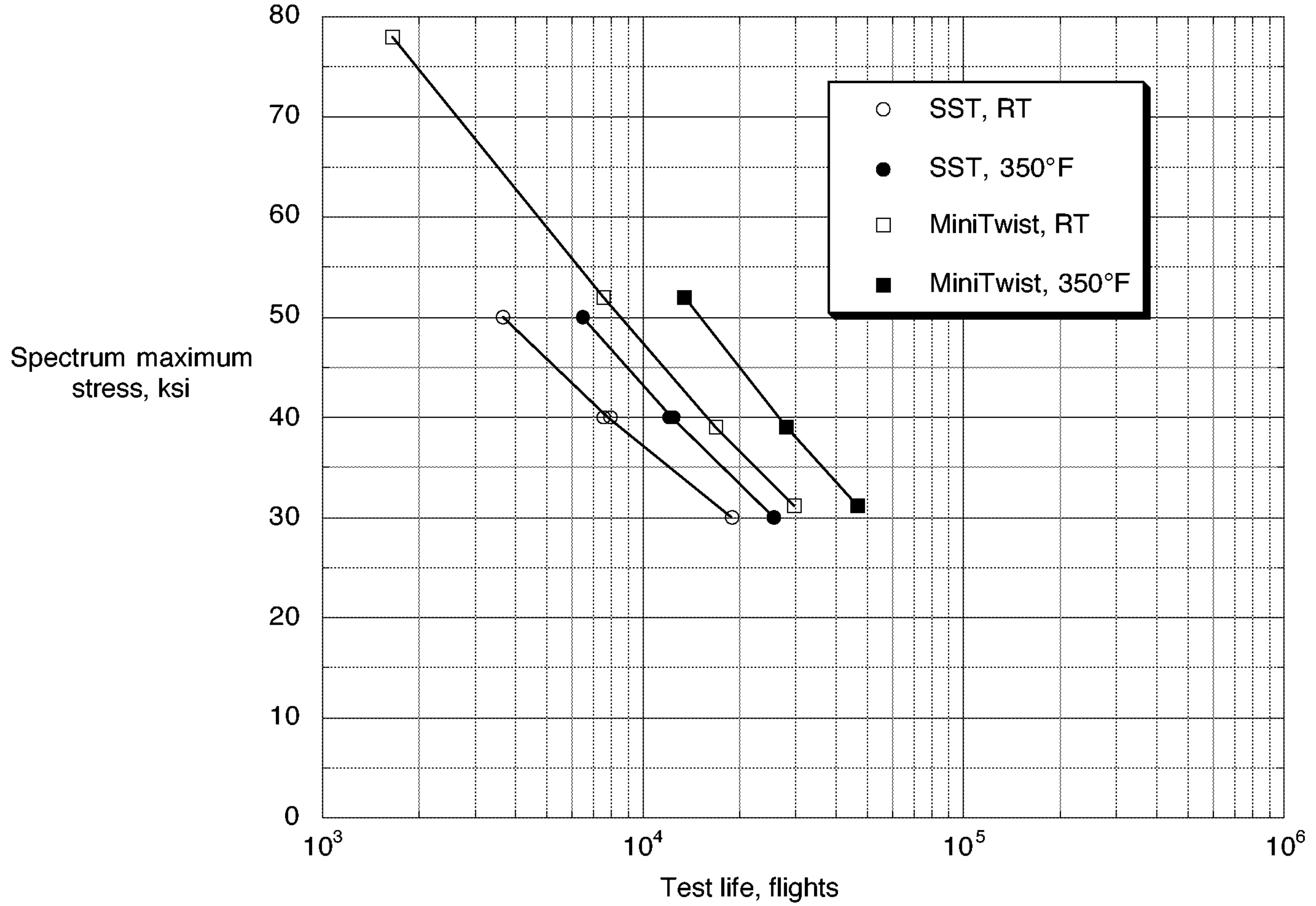

Figure 9. - Fatigue crack growth lives of Ti62222STA specimens subjected to the SST and MiniTwist spectra at room temperature and 350F.

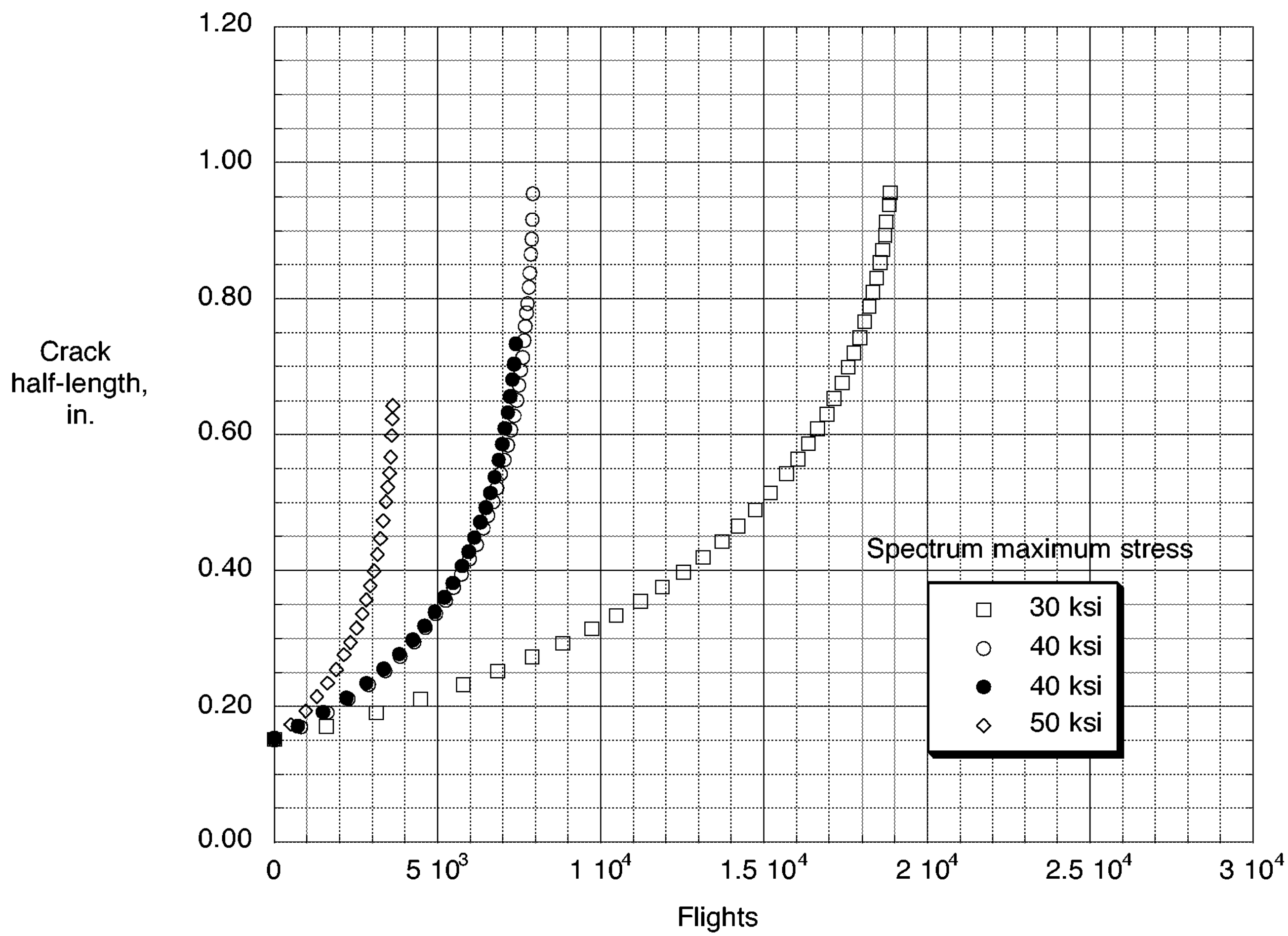

Figure 10. - Test results for Ti 62222STA specimens tested to the SST spectrum at room temperature.

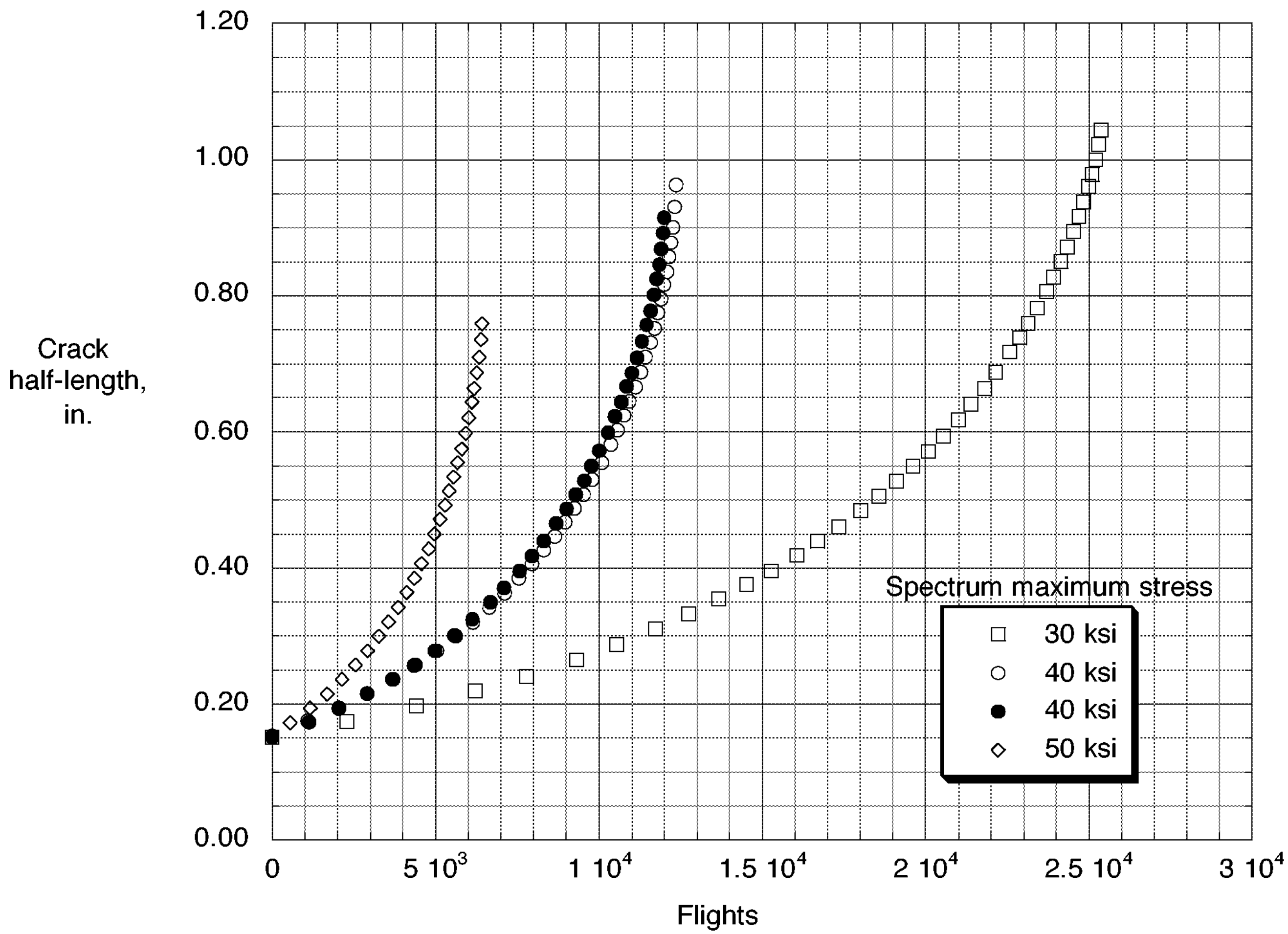

Figure 11. - Test results for Ti 62222STA specimens tested to the SST spectrum at 350°F.

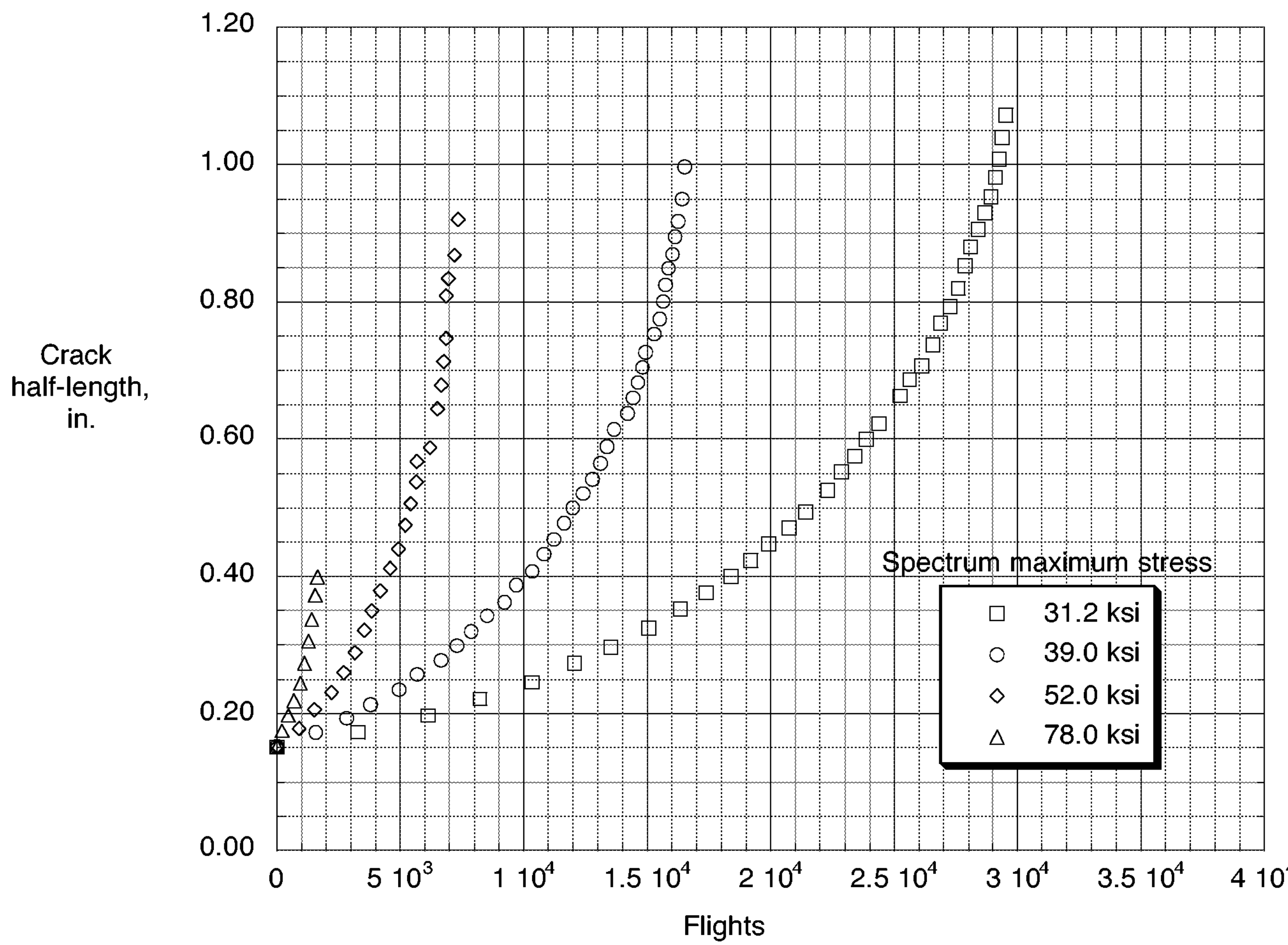

Figure 12. - Test results for Ti 62222STA specimens tested to the MiniTwist spectrum at room temperature.

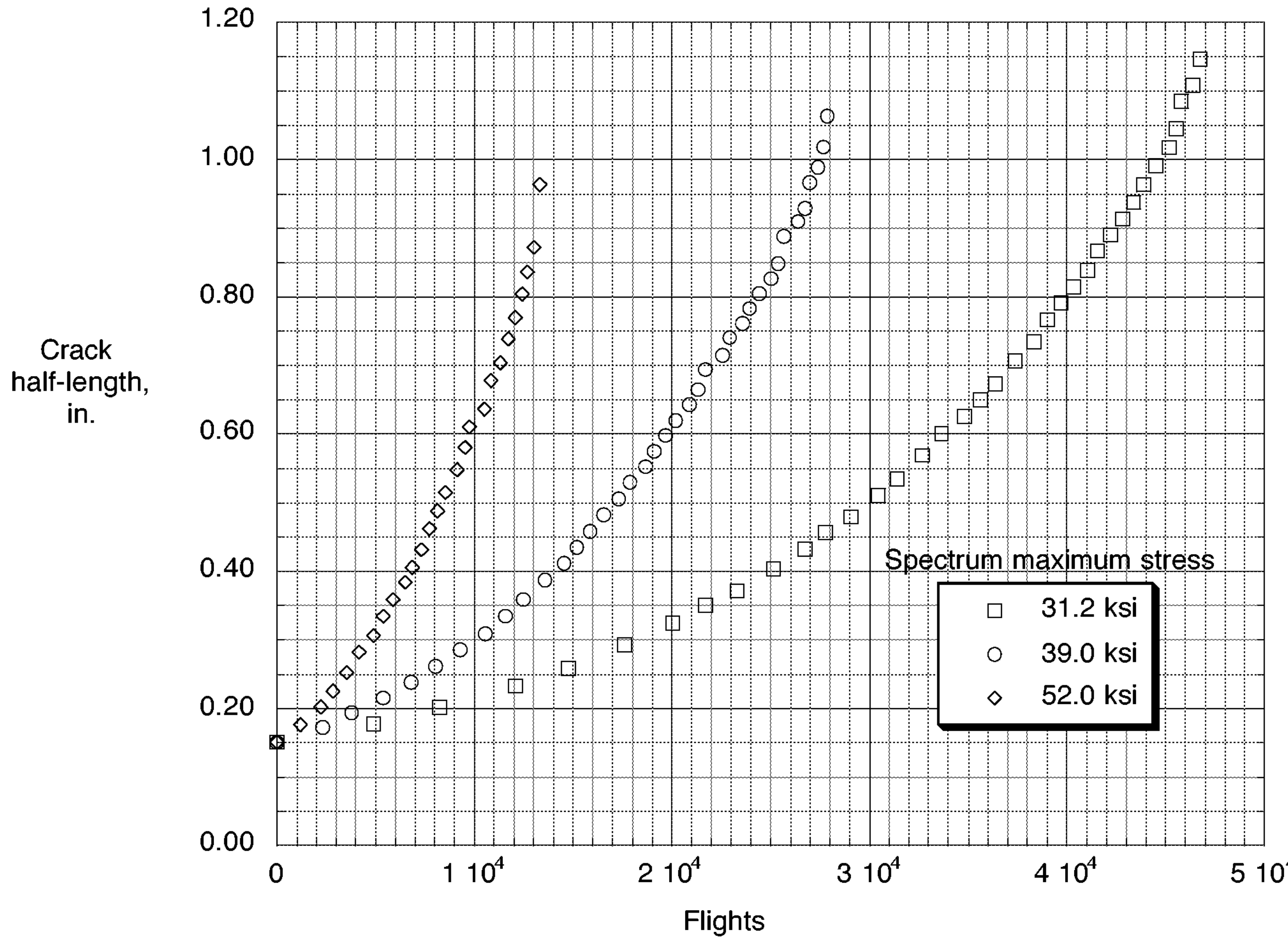

Figure 13. - Test results for Ti 62222STA specimens tested to the MiniTwist spectrum at 350°F.

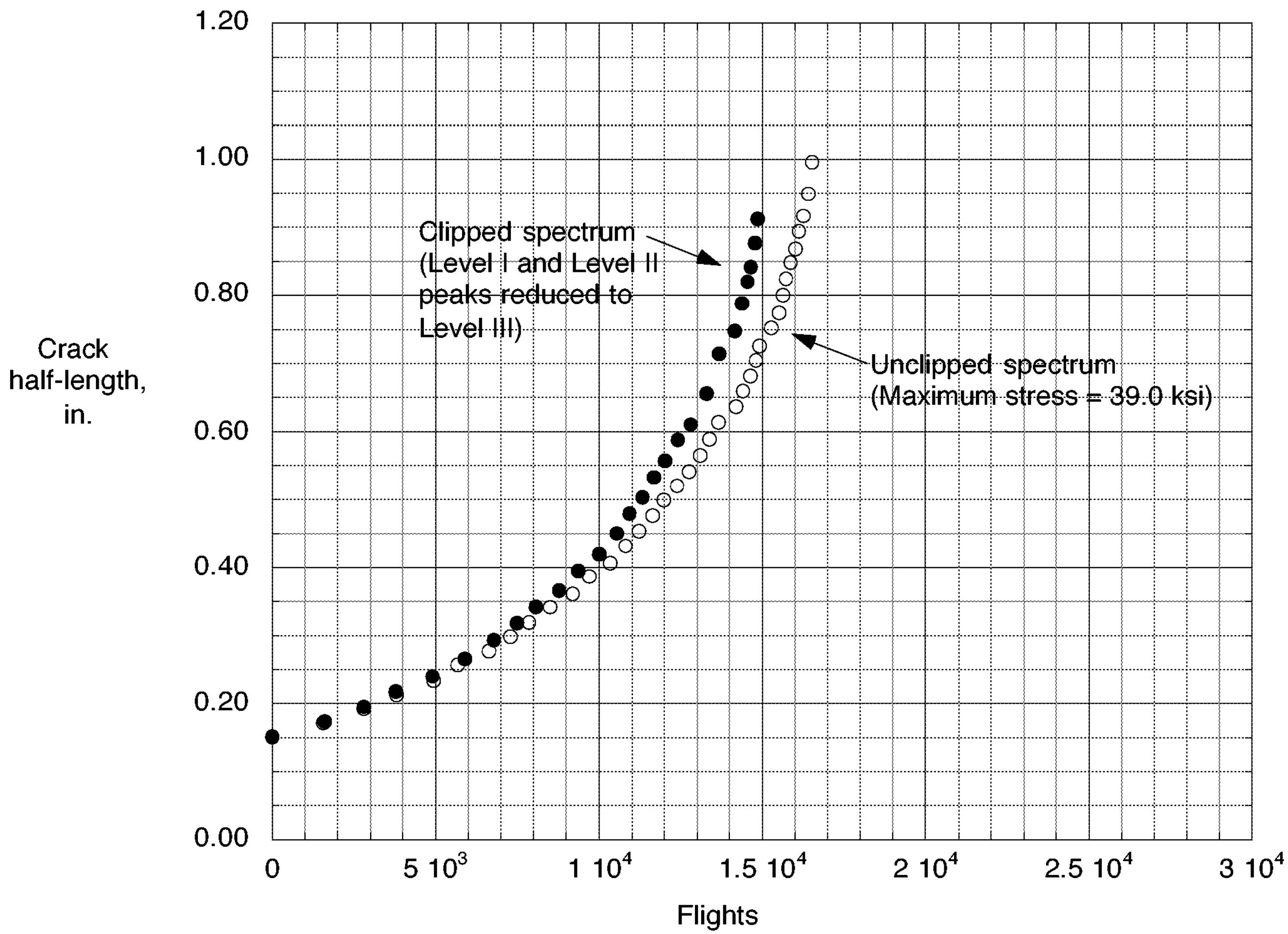

Figure 14. - Test results for Ti 62222STA specimens tested to the unclipped and clipped MiniTwist spectrum at room temperature.

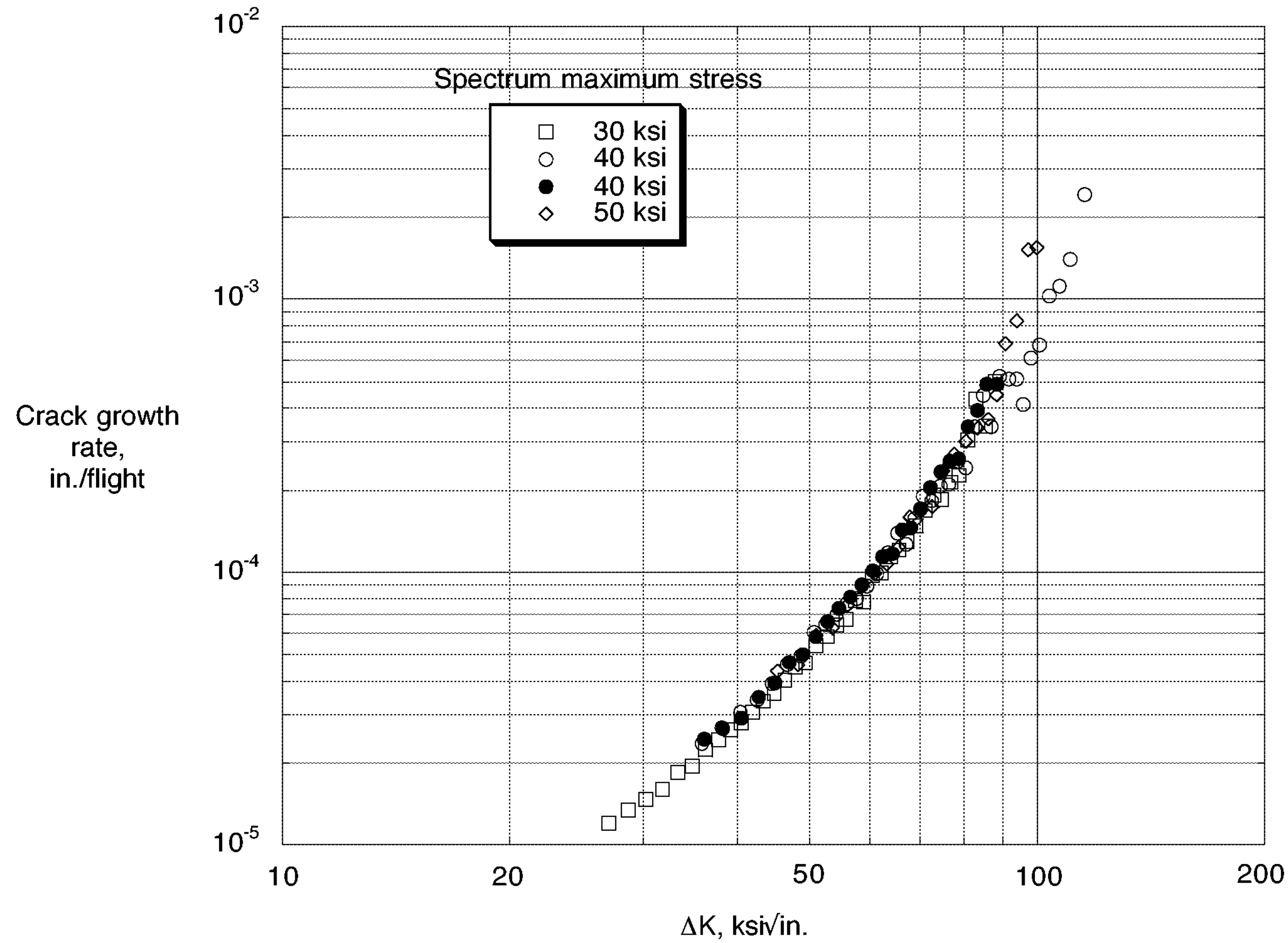

Figure 15. - Crack growth rates for Ti62222STA tested to the SST spectrum at room temperature.
(Note: ΔK based on max. and min. stresses in spectrum)

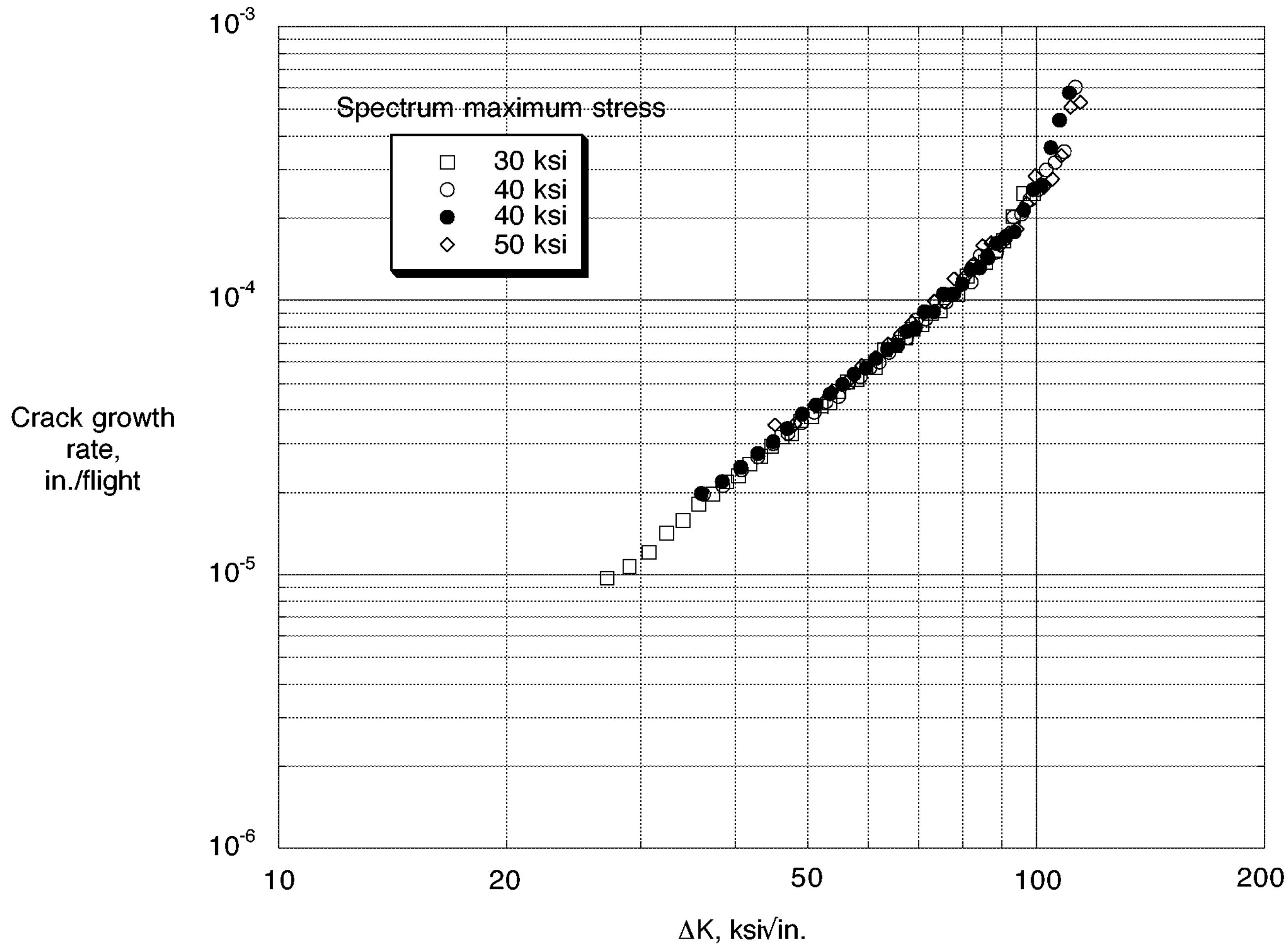

Figure 16. - Crack growth rates for Ti62222STA tested to the SST spectrum at 350°F.
(Note: ΔK based on max. and min. stresses in spectrum)

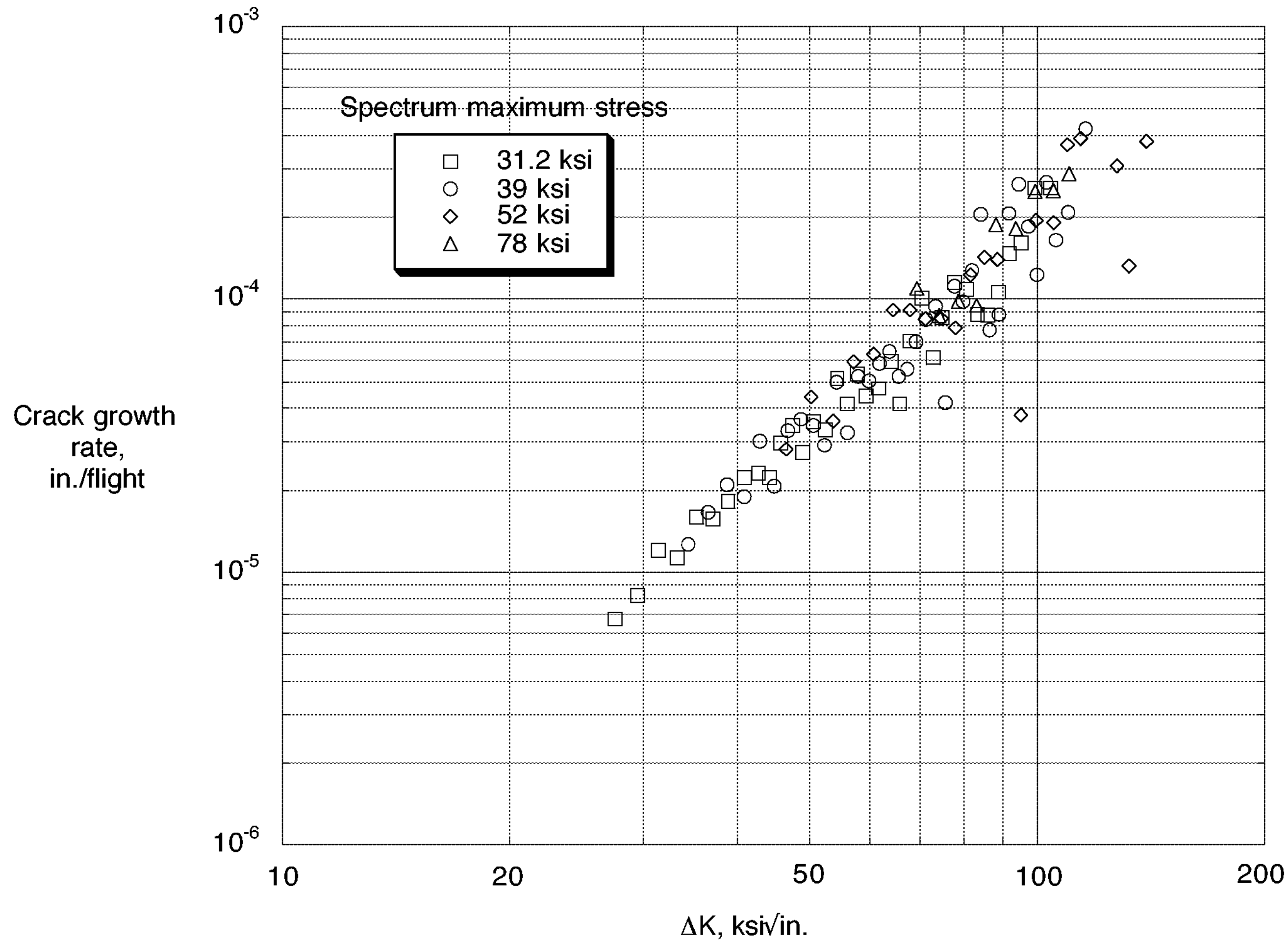

Figure 17. - Crack growth rates for Ti62222STA tested to the MiniTwist spectrum at room temperature. (Note: ΔK based on max. and min. stresses in spectrum)

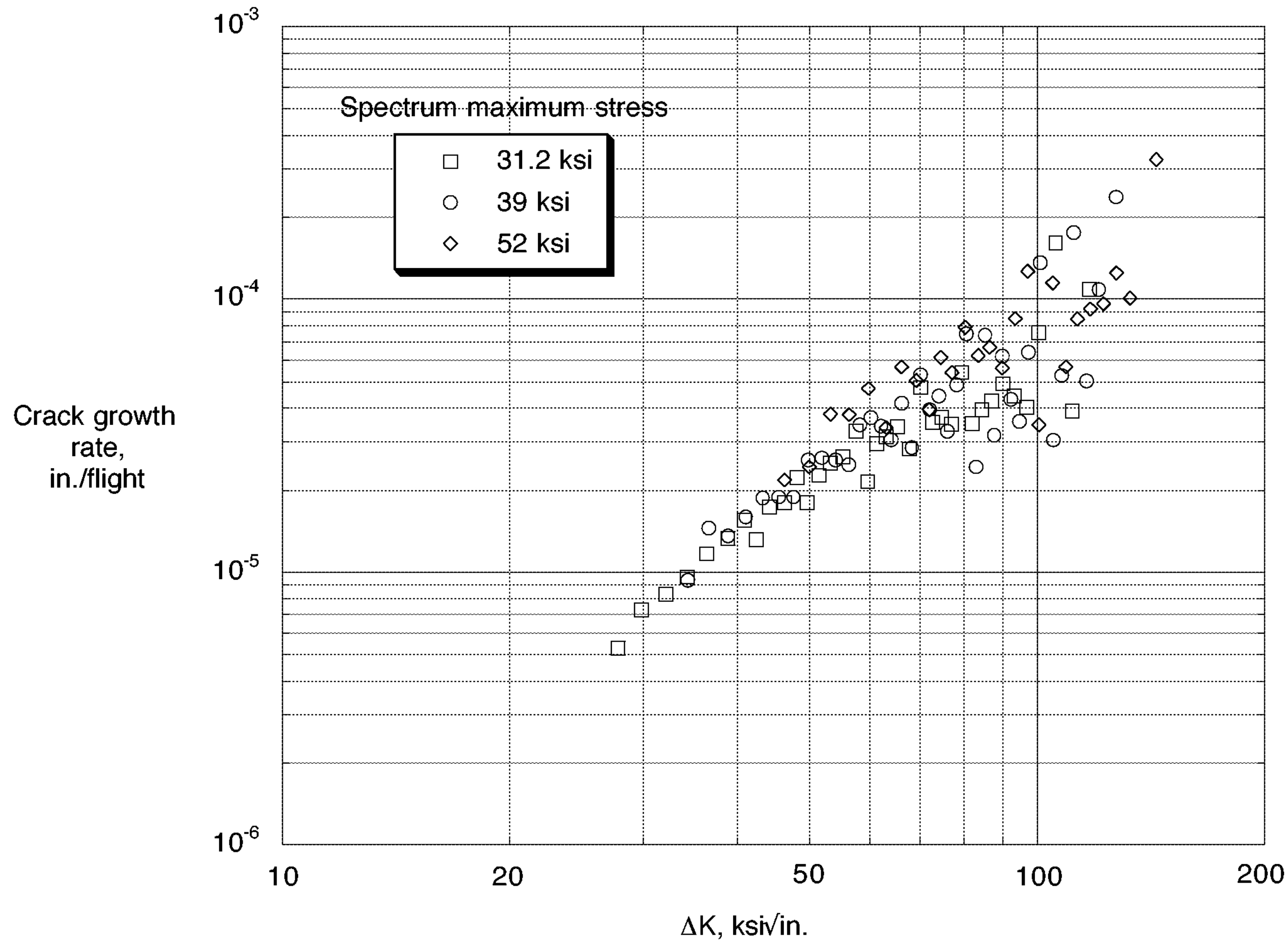

Figure 18. - Crack growth rates for Ti62222STA tested to the MiniTwist spectrum at 350°F.
(Note: ΔK based on max. and min. stresses in spectrum)

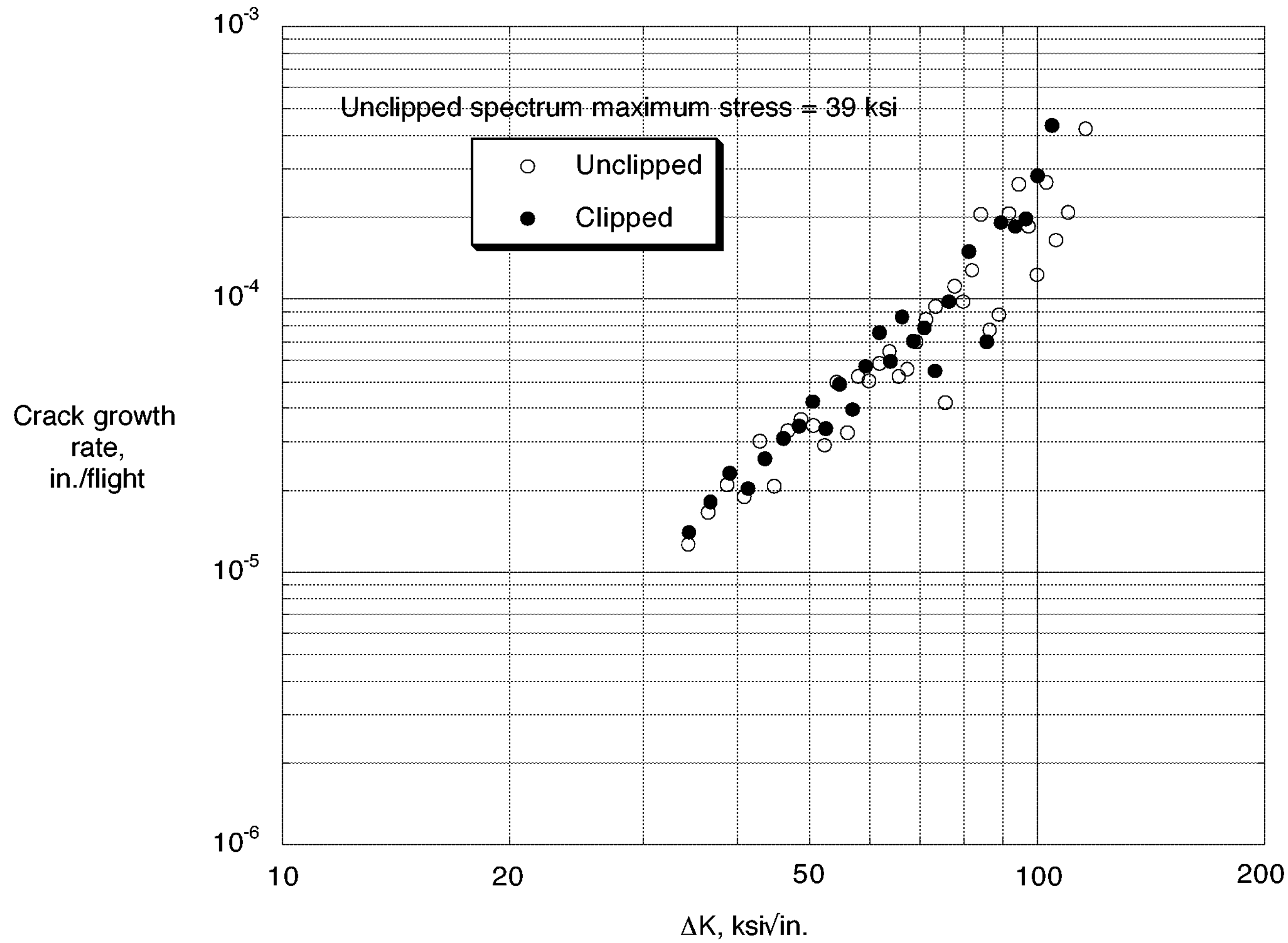

Figure 19. - Crack growth rates for Ti62222STA tested to the unclipped and clipped MiniTwist spectrum at room temperature. (Note: ΔK based on max. and min. stresses in spectrum)

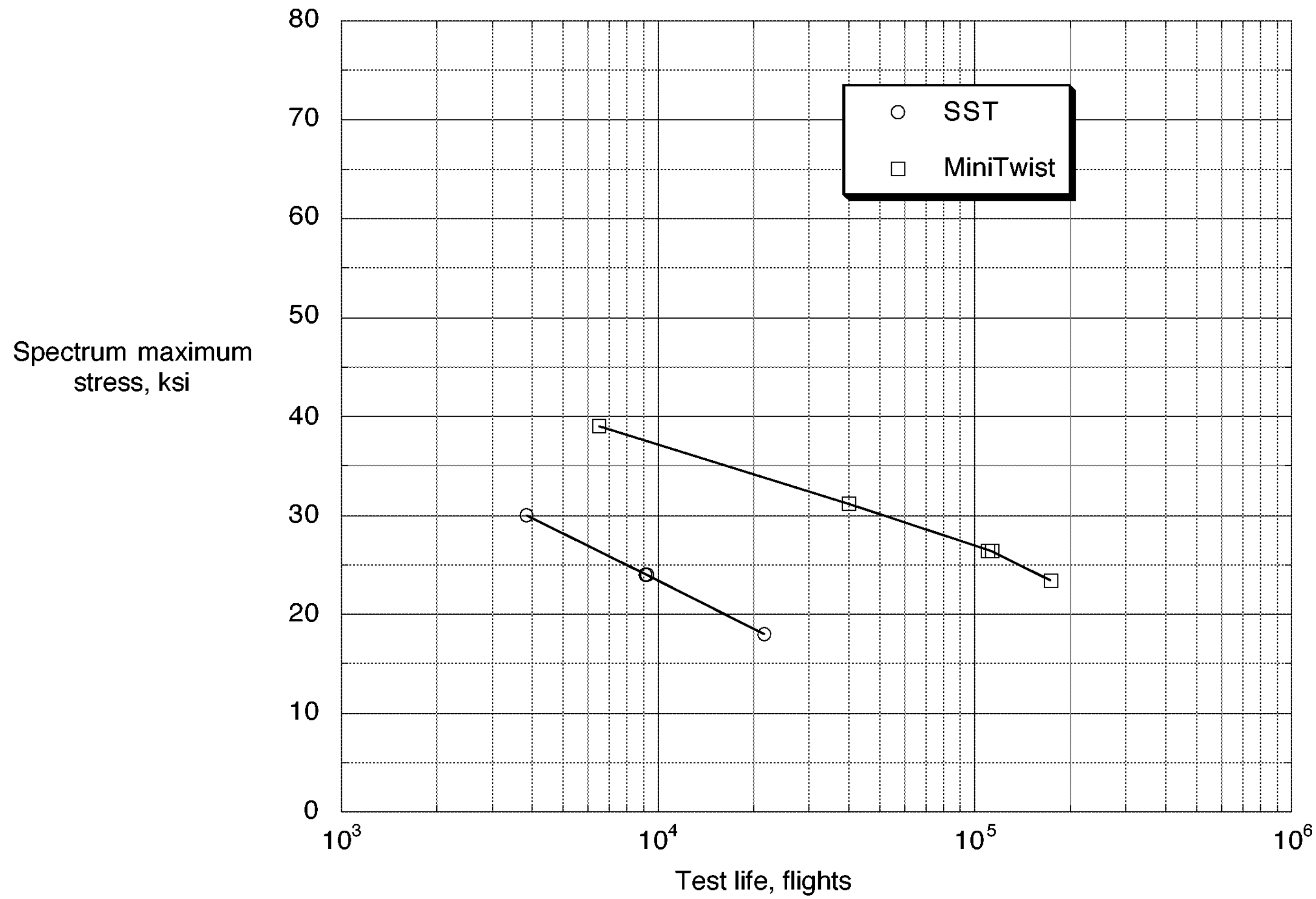

Figure 20. - Fatigue crack growth lives of Al2024T3 specimens subjected to the SST and MiniTwist spectra at room temperature.

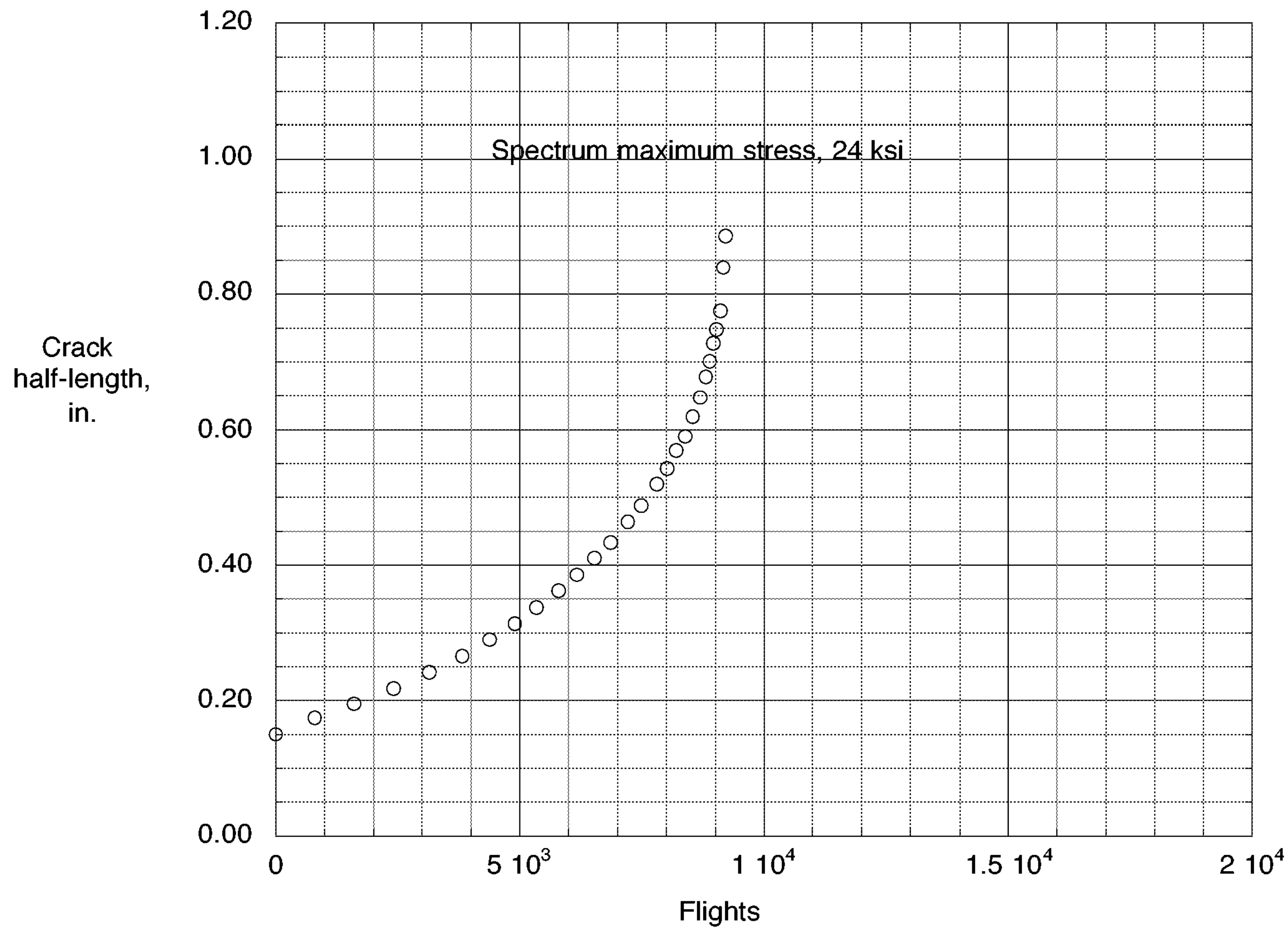

Figure 21. - Test results for Al 2024T3 tested to the SST spectrum at room temperature.

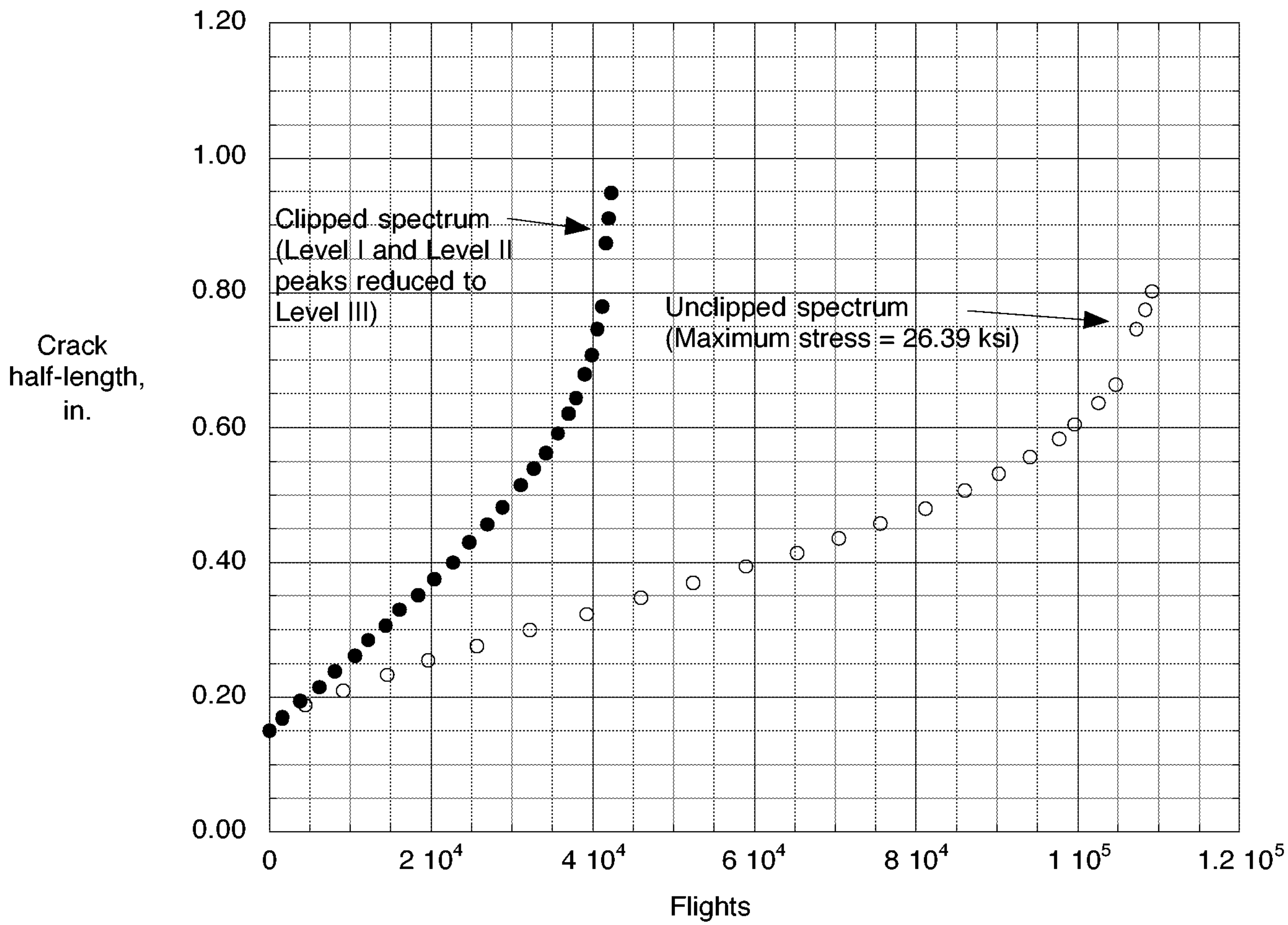

Figure 22. - Test results for Al 2024T3 specimens tested to the unclipped and clipped MiniTwist spectrum at room temperature.

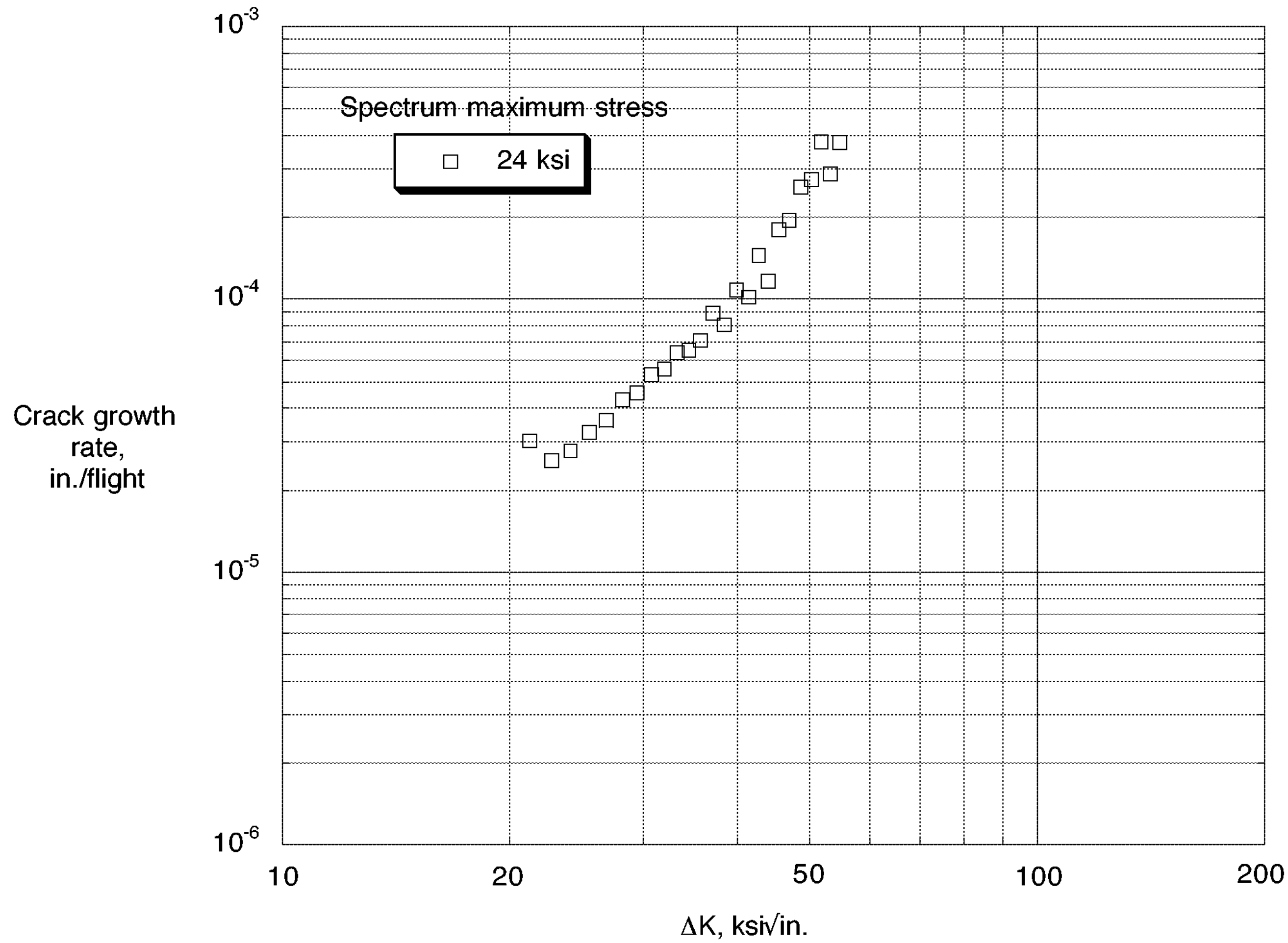

Figure 23. - Crack growth rates for Al2024T3 tested to the SST spectrum at room temperature.
(Note: ΔK based on max. and min. stresses in spectrum)

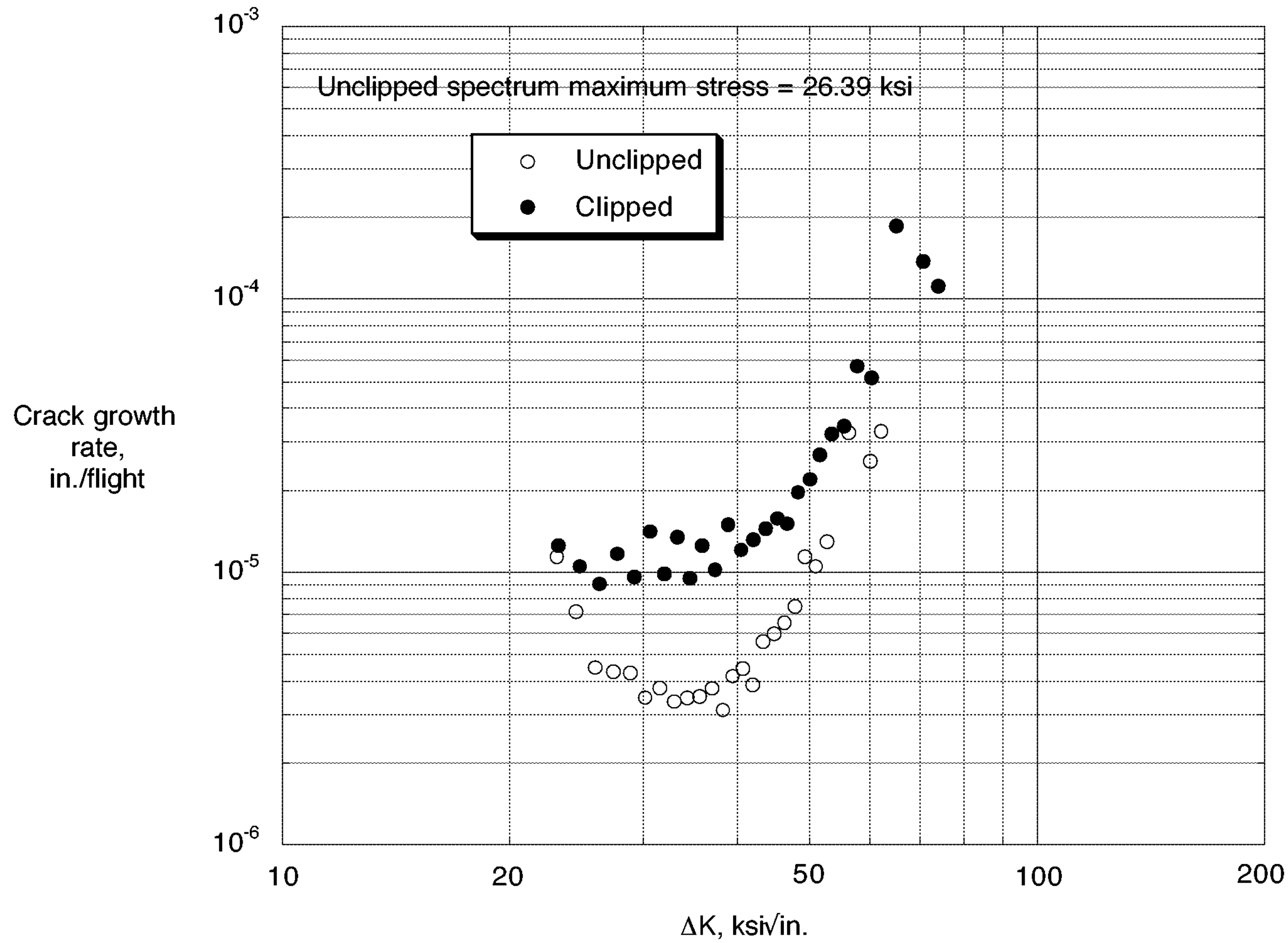

Figure 24. - Crack growth rates for Al2024T3 tested to the unclipped and clipped MiniTwist spectrum at room temperature. (Note: ΔK based on max. and min. stresses in spectrum)

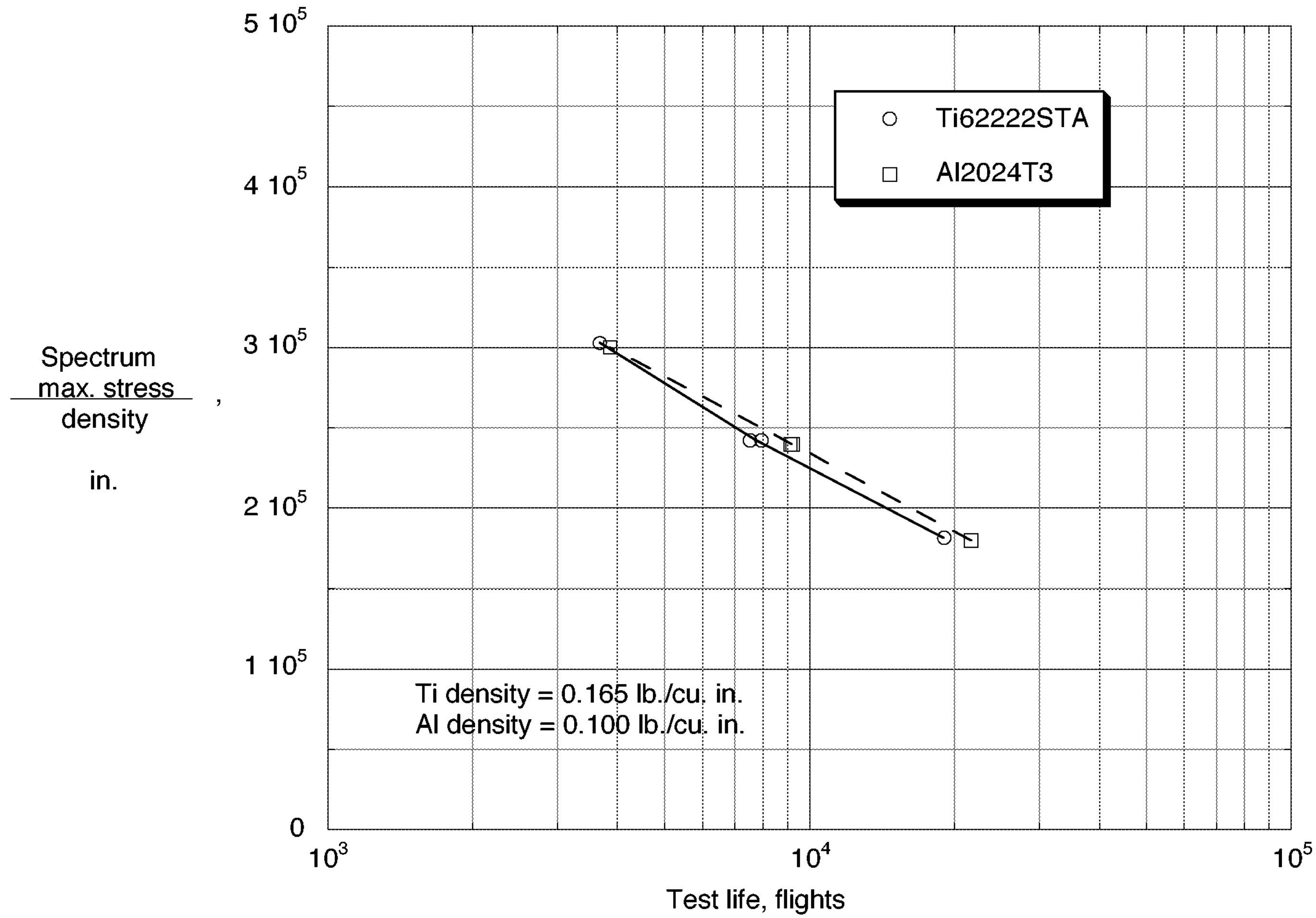

Figure 25. - Equal-weight fatigue crack growth performances of Ti62222STA and Al2024T3 when subjected to the SST spectrum at room temperature.

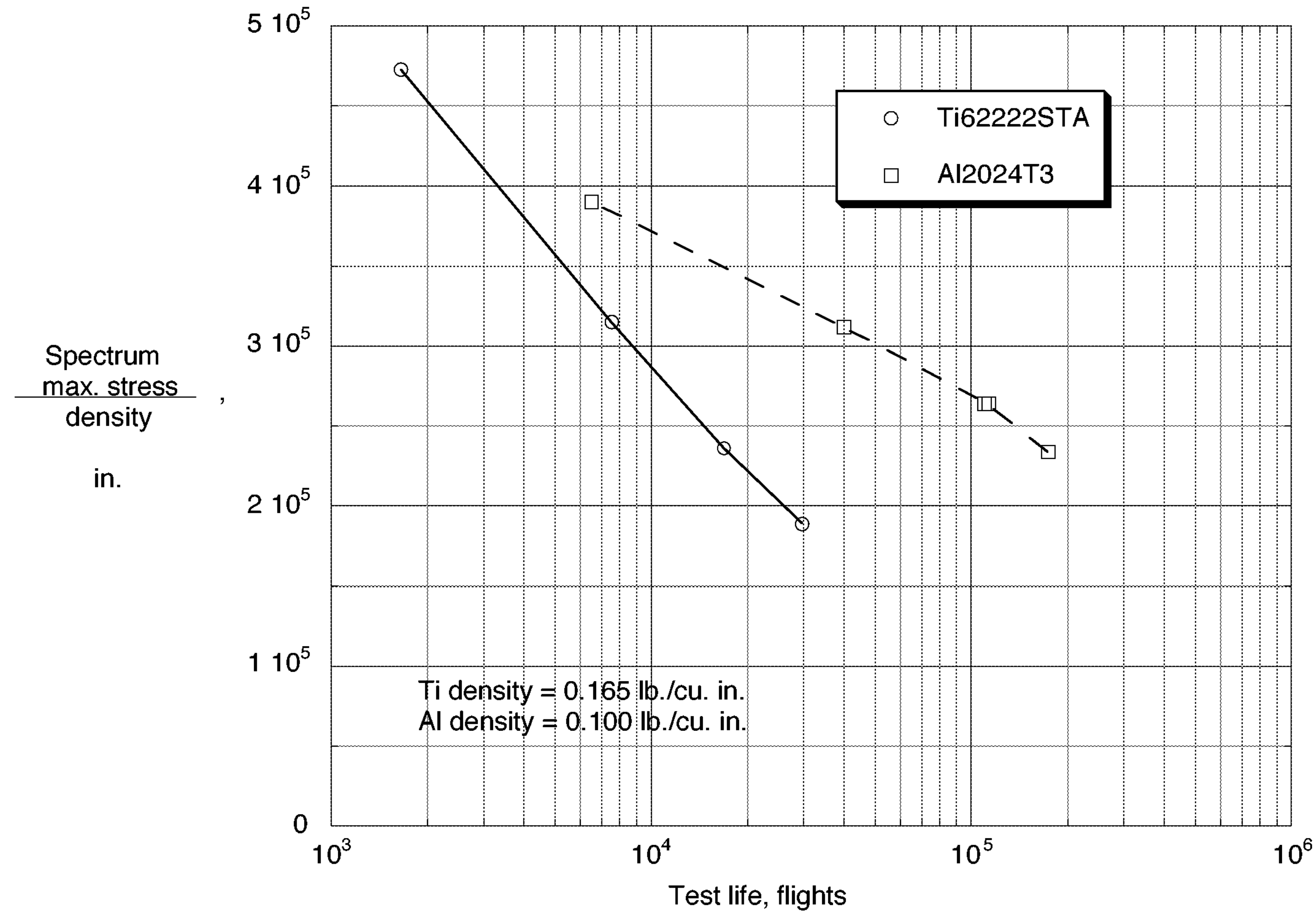

Figure 26. - Equal-weight fatigue crack growth performances of Ti62222STA and Al2024T3 when subjected to the MiniTwist spectrum at room temperature.

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13. ABSTRACT (Maximum 200 words)

Variable amplitude loading crack growth tests have been conducted to provide data that can be used to evaluate crack growth prediction codes. Tests with periodic overloads or overloads followed by underloads were conducted on titanium alloy Ti-6Al-2Sn-2Zr-2Mo-2Cr solution treated and aged (Ti62222STA) material at room temperature and at 350°F. Spectrum fatigue crack growth tests were conducted on two materials (Ti62222STA and aluminum alloy 2024-T3) using two transport lower-wing test spectra at two temperatures (room temperature and 350°F (Ti only)). Test lives (growth from an initial crack half-length of 0.15 in. to failure) were recorded in all of the tests and the crack length against cycles (or flights) data were recorded in many of the tests. The following observations were made regarding the test results: (1) in tests of the Ti62222STA material, the tests at 350°F had longer lives than those at room temperature, (2) in tests to the MiniTwist spectrum, the Al2024T3 material showed much greater crack growth retardations due to the highest stresses in the spectrum than did the Ti62222STA material, and (3) comparisons of material crack growth performances on an “equal weight” basis were spectrum dependent.

14. SUBJECT TERMS

Metal fatigue; Crack propagation; Spectrum loading; Variable amplitude loading; Titanium alloys; Aluminum alloys

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