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FATIGUE, CREEP AND STRESS-RUPTURE PROPERTIES OF Ti-13V-11Cr-3A1 TITANIUM ALLOY (B120-VCA)

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FOREWORD

The work reported herein was conducted by the Department of Aeronautics and Engineering Mechanics at the University of Minnesota Minneapolis, Minnesota 55455, under United States Air Force Contract AF 33(615)-1122. This contract was initiated under Project No. 7381, "Materials Applications", Task No. 738106, "Materials Information Development". The work was monitored by the Air Force Materials Laboratory, Research and Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Dayton, Ohio with Mr. David C. Watson, MAAM acting as Project Engineer.

The following personnel and students of the University of Minnesota contributed to this program: Messrs. Roger Erickson, William Marquardt, Maurice Odegard, Roger Peterson, David Sippel, Gene Jorgenson, Adolph Johnson, Dave Reynolds, Gary Deering, Miss Sandra Thompson, and Mrs. Brigitte Hennecke.

This report covers work done during the period September 1, 1965 to June 30, 1966, with some additional data included from work done in 1958. Manuscript of this report was released by the authors in July 1966, for publication as an RTD Technical Report.

This technical report has been reviewed and is approved.

D. A. Shinn
Chief, Materials Information Branch
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ABSTRACT

A fatigue and creep-rupture testing program was conducted on solution-treated and aged sheet specimens of titanium alloy B-120VCA at room and elevated temperatures. Data on aged bar stock, previously tested, are also included for comparison. All tests were conducted in axial-stress machines with various combinations of alternating and mean stresses. Notched as well as smooth specimens were used.

The data are presented in the form of S-N and creep rupture diagrams, and the effect of various combinations of alternating and mean stresses is shown by means of constant-life diagrams. Creep data are given in the form of creep-time curves, and for design purposes, creep strength curves are presented.

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I. SUMMARY

An experimental program has been conducted to determine the fatigue, creep, and stress rupture properties of titanium alloy B120-VCA at room and elevated temperatures. All tests were performed in axial-stress machines capable of maintaining any alternating stress amplitude and superposing it on any desired static stress. Several ratios of alternating to mean stress (A ratios) were employed so that the complete range of stress from completely reversed ($A = \infty$) to static creep rupture ($A = 0$) was covered. All tests were run at 3600 cpm.

Most of the data was obtained from specimens cut from sheet 0.043" thick. Half of these specimens were in the annealed condition and the other half in an aged condition. Some additional data were obtained from cylindrical specimens machined from bar stock in an aged condition. Three test temperatures were employed: $75^{o}F$, $600^{o}F$, and $800^{o}F$. Creep and stress rupture tests were conducted only at the elevated temperatures.

II. INTRODUCTION

The demand for materials which can withstand high static and dynamic stresses under extreme temperature conditions increases as man's efforts continue to reduce travel time and to explore outer space.

In order to make use of the new materials as they are developed, engineers must have design information on the behavior of the materials in various environments. Of particular interest are the mechanical properties under dynamic stresses. This program was undertaken to provide design data on the fatigue and creep rupture properties of titanium alloy B120-VCA at room and elevated temperatures.

The primary work reported herein was on sheet material, and the testing has been accomplished in the past year. A few years ago, a fatigue program was conducted in this laboratory on B120-VCA bar stock, but the results were never reported. These data are also included in this report.

In the next section, the experimental program is briefly described, and in Section IV the results are presented and discussed.

III. EXPERIMENTAL PROGRAM, EQUIPMENT AND PROCEDURES

3.1 Testing Program

This investigation was conducted under axial load on unnotched and notched specimens of titanium alloy B120-VCA in sheet and bar form. The stress conditions were chosen to cover the range from completely reversed to creep-rupture, with intermediate conditions at specified ratios of alternating-to-mean stresses (A ratios). The stress amplitudes were adjusted to produce failure in a range from 10^4 to 2.6×10^7 cycles, or from 3 minutes to 120 hours at a frequency of 3600 cpm. Creep was recorded at the lower A ratios only.

Sheet specimens, 0.043 in. in thickness, were tested in both solution-treated and aged conditions with identical test programs for both heat treatments. Bar-stock specimens were tested in a solution-treated-aged condition. The testing program for the sheet and bar materials were identical, except that sheet specimens were not tested at A = 0.25. The testing program is summarized in Table I.

3.2 Materials, Specimens, and Testing Equipment

3.2.1 Test Materials. The chemical composition, heat treatment and the source of the B120-VCA sheet and bar materials are shown in Table II.

B120-VCA sheets, 0.043in.x36in.x96in. were received in solution-treated condition. The processing history prior to delivery to the University of Minnesota is as follows: A 3" bar was hot rolled successively in each of two perpendicular directions. The sheet was then descaled, solution-treated, pickled, and finally finished by belt grinding. This is the standard commercial treatment for this material, and no further surface treatment was given in the laboratory before testing.

A considerable amount of out-of-flatness of the sheet material was observed. Subsequent calculations, which were also experimentally verified, showed this out-of-flatness to result in bending stresses less than 5% of the applied stresses, and the material was deemed to be acceptable. As a precaution, however, the curvature of specimens was measured, but no correlation could be determined between it and observed scatter in test results. It should be noted, that in aged specimens this out-of-flatness was reduced to less than 50% by the aging temperature of 900°F which is also a stress relieving temperature for this alloy. The straightening was accomplished by holding the specimens during aging between two flat ceramic plates.

The bar material was solution-treated at 1400°F. It should be noted that this particular bar stock was produced in 1958 when some of the characteristics of this alloy were not as well established as today. While investigating the possible causes for the scatter in the fatigue data, it was determined that variable aging had occurred over the cross section of the bars. This condition possibly had been caused by a straightening operation of the bars after the solution treatment but before the aging (1). A similar dispersion is also evident in the tensile data in Table V which shows the tensile properties for two of the extreme scatter producing bars.

The effect described above was determined rather late in the program so that no duplicate tests could be performed with resolutioned and aged specimens. For this reason, the data on the bar specimens presented in this report should be accepted with some reservations.

3.2.2 <u>Specimen Preparation</u>. The sheet specimens were machined from the solution-treated material as received. The aged specimens were treated after machining. Figure 1 shows the sheet specimen configuration. Considerable care was exercised in the preparation of specimens. The details of equipment and procedures used in the preparation of sheet specimens are given in Reference (2).

The longitudinal axis of sheet specimens was oriented parallel to the final rolling direction of the sheets. Specimen location within sheets is shown in Figs. 2 and 3. The numbers shown are specimen numbers for identification.

The bar specimens shown in Fig. 4 were prepared after the aging treatment. A detailed description of techniques and equipment used during the specimen preparation is given in References (3) and (4). A slight deviation from the techniques described in these references consisted in the use of rolled specimen threads. The reason for using rolled threads was the combination of the relatively high notch sensitivity of this material and the rather small size bar stock (0.6 in. diameter). Initial trials with a section of 1/4 in. diameter (0.25 in. dia.) and cut thread resulted in thread failure. Further reduction of the test section to less than 0.2 in. diameter was found to be impractical. The commonly observed eccentricity of a rolled thread could be well tolerated because of the characteristics of the unique grip-specimen assembly and its alignment.

3.2.3 <u>Testing Equipment</u>. All tests were performed in axial stress fatigue-dynamic creep machines described in a previous publication (5). The alternating forces are produced by a mechanical oscillator operating at 3600 cpm. Mean forces may be superimposed by means of calibrated helical springs, thus providing means for testing at various alternating-to-mean stress ratios. The preload is automatically controlled, keeping the mean forces constant and compensating for specimen elongation during a test.

For testing at A ratios larger than 1.0, including reversed stress, $A = \infty$, a specimen buckling restrainer as described previously (2) was used. The boron nitride, previously used as the friction-reducing element, exhibited a rather high degree of reaction with the titanium test material. This reaction appeared to be dependent to quite a degree on the relative motion between specimens and buckling restrainer. This conclusion was based on the observation that less adhesion occurred between the boron and the specimens with notched than with unnotched specimens.

Because of the boron-titanium reactivity, a buckling restrainer lubricant other than boron nitride was required. Solid compacts and sprayed film of tungsten disulfide (WS_2) were investigated and found to perform satisfactorily with the B120-VCA titanium at the test conditions described in this report. Although annealed WS_2 compacts provided sufficient lubrication, their relative softness caused gradual loosening of the buckling restrainer. Aged compacts were found to provide a much longer lubricant life. The use of the less expensive WS_2 spray coating was investigated and found to perform satisfactorily. The surface plates of the buckling restrainer, which come in direct contact with the specimen, were surface ground and sprayed with the WS_2. A combination of four coatings on the specimen and the buckling restrainer appeared to give optimum coating life. The main breakdown of the coating observed at the ends of the buckling restrainer resulted in fretting damage to the test specimen. By increasing the overall length of the buckling restrainer, the areas of the most fretting damage were moved into the specimen fillets, thus minimizing fretting damage to the test section.

The tests at elevated temperatures were conducted in resistance type furnaces controlled to plus-minus $5^{\circ}F$ by Honeywell proportioning control systems as described previously for sheet specimens (2) and for bar specimens (6).

Creep was measured with a linear variable differential transformer type extensometer which has been previously described (4).

3.3 Testing Procedures

The testing procedures used during the tests of sheet specimens were as previously described (2). After holding the specimen at the test temperature for a period sufficient for the grip and specimen assembly to reach a thermal equilibrium, the mean load was applied. Thereafter the alternating load was applied. The "soaking period" was determined by observing the time required for the drift of an extensometer to terminate. This soaking period was kept constant for all tests.

During the tests of the bar specimens, the sequence of the application of the alternating and mean loads was reversed, i.e., the alternating loads were applied before the mean load. In any case, the reported time to failure is the time from the instant when full load (mean plus alternating) is reached.

The reported creep time curves show the total elongation after the full load was applied. To determine creep strain, corrections for creep in the specimen fillets were made as previously described (4).

IV. RESULTS AND DISCUSSION

4.1 Static Tensile Data

The results of short-time static tensile tests are given in Tables III through V. In Table III, the data for aged B120-VCA sheets are listed for the three test temperatures. Table IV contains the data on annealed B120-VCA sheet specimens, and in Table V the tensile data for the aged bar specimens are given for room temperature only. All of these data appear to fall in the range of published values. Their value to this report is primarily to characterize the materials.

4.2 Fatigue of Aged Sheet Specimens

4.2.1 The S-N Diagrams for this material are given in Figs. 5 through 10. The captions indicate the various conditions. At 75°F, no tests were run at A = 0 and therefore only the two curves for A = 1.0 and A = ∞ are given. At 600°F and 800°F, three curves are given for each condition. To avoid overlapping of the A = 0 curves, the notched and unnotched diagrams are given in separate figures.

4.2.2 Constant-Life Diagrams. As a more convenient way of presenting these data for design purposes, the constant-life diagrams are given in Figs. 11 through 13. These diagrams give the combinations of alternating and mean stresses which may be imposed for a given life. In Fig. 11, the 75°F data are shown for both notched and unnotched specimens. The average ultimate tensile strength was plotted along the A=0 line for the room temperature diagram.

Figure 12 gives the 600°F data, and Fig. 13 the 800°F data. The crossing of the notched and unnotched curves at low A ratio is a rather common behavior and is an indication that, in this region, creep is more pronounced than fatigue.

4.3 Creep of Aged Sheet Specimens.

Figures 14 and 15 give the static creep-time curves for aged sheet at 600°F and 800°F respectively. In Figs. 16 and 17, the creep-strength design diagrams are given for 600°F and 800°F respectively. These families of curves give the maximum stress that may be imposed for a given time without exceeding a given amount of creep strain.

4.4 Fatigue of Annealed Sheet Specimens.

4.4.1 The S-N and Creep Rupture Diagrams for this material are given in Figs. 18 through 23, the captions indicating the pertinent test conditions. Families of curves for the various A ratios are included in the graphs, all but the 75°F figures including the creep rupture curve (A = 0).

There is considerable scatter in these data, particularly at A = 1.0. This scatter may be due partly to some bending stresses resulting from slight curvature of the specimens. The sheets from which the specimens were cut were slightly warped. Calculations of the effect of this curvature indicated that the bending stresses would not exceed 5% of the applied stresses. Furthermore, no correlation could be discerned between low points and specimens with more initial curvature. On the other hand, the bending-stress argument is supported by the fact that there is somewhat less dispersion in the data for $A = \infty$, where buckling restrainers would tend to reduce bending effects. Also, the lesser scatter of the data for aged specimens, which were much straighter, gives additional credence to the bending-stress explanation.

4.4.2 The Constant-Life Diagrams for annealed sheet specimens are given in Figs. 24 through 26. Again, the average ultimate tensile strength was plotted along the A = 0 line at 75°F. The unnotched curves for 600°F and 800°F are nearly straight lines, or even slightly concave upward. This is in contrast to the usual behavior which is quite concave downward for smooth specimens. The notched curves (dashed) are quite typical, being concave upward in the high A range and crossing over the unnotched curves in the low A region.

4.5 Creep of Annealed Sheet Specimens

Figure 27 gives the static creep-time curves for annealed sheet specimens at 800°F. No data were obtained on this material at other temperatures. The inversion of the 80,000 psi and 100,000 psi curves from 0 to 20 hours is probably the result of scatter in the data rather than the real behavior of the material.

In Fig. 28, the creep strength design curves are given for a number of levels of creep strain.

4.6 Fatigue of Aged Bar Specimens

4.6.1 The S-N and Creep Rupture Diagrams for aged bar specimens are given in Figs. 29 through 34 for the conditions indicated in the captions. Considerable scatter is evident, and it is felt that the variable aging of the bars, discussed in Section III, is primarily responsible for this dispersion.

Figure 35 gives a comparison of the S-N Curves for $A = \infty$ for the various test temperatures. Considering the scatter, there does not appear to be much effect of temperature, in this range, on the fatigue life for $A = \infty$.

4.6.2 The Constant-Life Diagrams for bar specimens are given in Figs. 36 and 37 for the three test temperatures. The average ultimate tensile strength was plotted along the $A = 0$ line at 75°F.

These curves are quite normal in appearance, the notched curves crossing the unnotched ones in the low A range, indicating that creep is predominant in this region.

4.7 Discussion

The fatigue curves are, in general, quite normal in appearance and shape. It is worth noting that the S-N diagrams are quite flat, especially at elevated temperatures. Stresses only 10 to 15% above the fatigue limit may cause failure in just a few thousand cycles. The creep rupture curves, in particular, are very flat.

As a means of gaining over-all comparisons of results on the different material conditions, temperature effects, and the effect of notches, data on fatigue strengths at $A = \infty$ and 10^7 cycles are listed in Table IX. One observation is that the fatigue strength at the elevated temperatures is almost as high as at room temperatures. This result is probably due in part to some aging of the annealed specimens which occurs at elevated temperatures during the tests. Some additional aging also takes place in the aged specimens, which were only partially aged prior to testing (12 hours at 900°F).

Comparing the data for annealed and aged specimens, it is evident that the fatigue strength of aged material is not much higher than that of the annealed sheet. This result, again, is probably due to some aging of the annealed material during the test.

The fatigue notch factor, K_f, is also listed in Table IX. This value is the ratio of the fatigue strength of an unnotched specimen to that of a notched specimen at the same test conditions. It appears that the annealed sheet is slightly more notch sensitive than the aged material.

The fatigue strength of the aged sheet is considerably less than that of the bar stock. This observation is to be expected for two primary reasons. First, the bar stock was aged more completely (72 hours compared to 12 for the sheet). Second, the fatigue strength of round bar specimens is generally higher than that of sheet specimens of the same material. The sharp corners of sheet specimens are weak spots for crack nucleation, and more rapid crack propagation occurs in sheet specimens.

V. CONCLUDING REMARKS

This testing program was undertaken primarily for the purpose of obtaining fatigue design data on titanium alloy B120-VCA sheet material in both the solution-treated and the aged conditions at room and elevated temperatures. The results are given in the form of S-N diagrams and constant-life diagrams. It is important that users recognize that the curves presented are the best representation of the material properties that can be determined from the data obtained. There is considerable scatter in the data, however, and this fact should be well recognized when the curves are used for design purposes.

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TABLE I

Test Program

Test Temperature (^oF)	75		600		800	
Specimen K_t	1.0	3.0	1.0	3.0	1.0	3.0
Stress Ratio A = ∞	AN AG CB	AN AG CB	AN AG CB	AN AG CB	AN AG CB	AN AG CB
1.0	AN AG CB	AN AG CB	AN AG CB	AN AG CB	AN AG CB	AN AG CB
0.25	- - -	- - -	CB - -	CB - -	CB - -	CB - -
0.0	- - -	- - -	AN AG CB	AN AG CB	AN AG CB	AN AG CB

AN - Annealed Sheet, 0.043" Thickness

AG - Aged Sheet, 0.043" Thickness

CB - Aged Bar, 0.600" Diameter

TABLE II

Chemical Composition, Heat Treatment, and Source of Test Materials

Type of Alloy	Ti-13V-11Cr-3Al sheet (B120-VCA)	B120-VCA Bar (Ti-13V-11Cr-3Al)
Source	Titanium Metals Corp. of America	Crucible Steel Co. of America Titanium Division
Chemical Composition	C 0.029 Fe 0.14 N 0.028 AI 3.0 Va 13.5 Cr 11.2 H 0.010 Ti Balance (72+)	C 0.04 N 0.02 AI 3.7 Va 12.5 Cr 10.7 H_2 0.0090 Ti Balance (73+)
Received as	0.043" Sheet	0.6" dia. bar
Heat Treatment	a) S.T. at 1450°F for 30 min., Air cool. b) S.T. as above + Age at 900°F for 12 hrs. in Vacuum.	S.T. at 1400°F for 30 min., Air cool; + Age at 900°F for 72 hrs. in Argon
Specimen Preparation	University of Minnesota	University of Minnesota

TABLE III

Tensile Test Data for Aged Sheet

Temperature °F	UTS (ksi)	0.2% YS (ksi)	Elong. (%)	Reduction of Area(%)	E (10^6 psi)
75	174.2	156.4	6.6	15.0	15.4
75	174.8	158.4	7.6	16.3	15.1
75	174.4	155.4	7.6	15.9	15.6
600	154.5	124.8	6.3	9.0	14.6
600	157.4	127.8	7.1	13.5	14.9
600	157.1	128.4	8.9	18.7	14.9
800	150.4	121.8	10.2	20.0	13.7
800	148.5	122.0	7.1	17.9	13.8
800	149.2	123.3	9.2	22.6	13.9

TABLE IV

Tensile Test Data for Annealed Sheet

Temperature °F	UTS (ksi)	0.2% YS (ksi)	Elong. (%)	Reduction of Area (%)	E (10^6 psi)
75	141.7	134.1	15.91	29.6	13.7
75	136.2	131.2	15.10	28.5	14.8
75	137.8	133.2	18.33	31.3	13.9
600	116.4	102.4	18.38	28.2	13.3
600	115.5	102.9	15.65	30.3	13.4
800	115.7	98.1	14.04	26.7	12.4
800	115.2	98.4	14.20	28.9	11.9
800	116.5	99.4	14.86	25.0	12.8

TABLE V

Tensile Test Data for Aged Bar

Temperature °F	UTS (ksi)	0.2% YTS (ksi)	Elong. (%)	Reduction of Area(%)	E (10^6 psi)
75	203.2	185.9	3.00	18.3	15.8
75	193.2	178.1	0.76	5.8	15.7
75	186.5	171.5	2.02	19.2	16.0
75	209.9	195.2	2.08	16.0	16.5
75	207.3	189.8	2.60	18.2	15.8

TABLE VI

Fatigue Test Data For Aged Sheet

Test Temperature 75°F

Spec. No.	Spec. K_t	Stress Ratio	Applied Stress, KSI S_m	S_a	S_c	Time to Rupture Hours	Kilocycles	
9310	1.0	∞	0	37.50	37.50	112.40	24,280.0	T.S.
9313	1.0	∞	0	40.00	40.00	120.18	25,960.0	T.S.
9332	1.0	∞	0	42.50	42.50	0.43	93.5	
9130	1.0	∞	0	42.50	42.50	0.50	108.0	
9318	1.0	∞	0	45.00	45.00	0.23	49.7	
9319	1.0	∞	0	45.00	45.00	0.27	58.1	
9416	1.0	∞	0	50.00	50.00	0.25	54.0	
9362	1.0	∞	0	60.00	60.00	0.12	25.3	
9361	1.0	∞	0	60.00	60.00	0.12	25.5	
9229	3.0	∞	0	20.00	20.00	117.69	25,420.0	T.S.
9289	3.0	∞	0	21.00	21.00	0.28	61.1	
9148	3.0	∞	0	21.50	21.50	0.30	64.8	
9489	3.0	∞	0	23.00	23.00	113.07	24,420.0	T.S.
9159	3.0	∞	0	24.00	24.00	0.28	60.5	
9136	3.0	∞	0	24.00	24.00	10.29	2,223.0	
9457	3.0	∞	0	25.00	25.00	0.22	47.5	
9176	3.0	∞	0	26.00	26.00	0.18	37.8	
9160	3.0	∞	0	27.50	27.50	0.13	28.8	
9419	1.0	1.0	25.00	25.00	50.00	114.51	24,730.0	T.S.
9259	1.0	1.0	27.50	27.50	55.00	118.56	25,610.0	T.S.
9382	1.0	1.0	28.75	28.75	57.50	0.25	54.0	
9371	1.0	1.0	30.0	30.0	60.0	0.20	43.2	
9373	1.0	1.0	30.0	30.0	60.0	0.20	43.2	
9494	1.0	1.0	30.0	30.0	60.0	0.17	36.1	
9113	1.0	1.0	32.5	32.5	65.0	0.25	54.0	
9177	1.0	1.0	32.5	32.5	65.0	0.15	32.4	
9337	1.0	1.0	35.0	35.0	70.0	0.19	41.0	
9354	1.0	1.0	40.0	40.0	80.0	0.08	16.2	
9341	1.0	1.0	47.5	47.5	95.0	0.06	10.8	
9363	1.0	1.0	55.0	55.0	110.0	0.03	7.1	

T.S. - Test Stopped

TABLE VI (Continued)

Fatigue Test Data for Aged Sheet

Test Temperature 75°F

Spec. No.	Spec. K_t	Stress Ratio	Applied Stress, KSI S_m	S_a	S_c	Time to Rupture Hours	Kilocycles	
9276	3.0	1.0	13.75	13.75	27.50	282.33	60,980.0	T.S.
9118	3.0	1.0	14.25	14.25	28.50	0.28	61.1	
9215	3.0	1.0	14.25	14.25	28.50	143.06	30,900.0	T.S.
9143	3.0	1.0	15.00	15.00	30.00	39.69	8,573.0	
9232	3.0	1.0	15.00	15.00	30.00	0.17	36.1	
9404	3.0	1.0	15.00	15.00	30.00	0.26	56.2	
9295	3.0	1.0	15.00	15.00	30.00	0.21	45.4	
9155	3.0	1.0	16.00	16.00	32.00	0.17	36.1	
9475	3.0	1.0	16.00	16.00	32.00	0.15	32.4	
9133	3.0	1.0	17.00	17.00	34.00	0.15	32.4	

Test Temperature 600°F

Spec. No.	Spec. K_t	Stress Ratio	Applied Stress, KSI S_m	S_a	S_c	Time to Rupture Hours	Kilocycles	
9346	1.0	∞	0	37.50	37.50	120.00	25,920.0	T.S.
9473	1.0	∞	0	40.00	40.00	101.65	21,960.0	
9350	1.0	∞	0	42.50	42.50	33.61	7,260.0	
9355	1.0	∞	0	42.50	42.50	47.57	10,270.0	
9317	1.0	∞	0	45.00	45.00	0.12	26.1	
9265	1.0	∞	0	45.00	45.00	117.15	25,300.0	
9320	1.0	∞	0	47.50	47.50	0.14	30.0	
9365	1.0	∞	0	47.50	47.50	49.82	10,760.0	
9339	1.0	∞	0	47.50	47.50	33.95	7,333.0	
9497	1.0	∞	0	47.50	47.50	0.17	36.1	
9123	1.0	∞	0	50.00	50.00	0.15	32.4	
9405	1.0	∞	0	50.00	50.00	0.13	28.7	
9298	1.0	∞	0	50.00	50.00	0.11	23.7	
9470	1.0	∞	0	55.00	55.00	0.13	28.7	
9471	1.0	∞	0	55.00	55.00	0.09	19.9	
9261	1.0	∞	0	60.00	60.00	0.09	18.4	

T.S. - Test Stopped

TABLE VI (Continued)

Fatigue Test Data for Aged Sheet

Test Temperature 600^oF

Spec. No.	Spec. K_t	Stress Ratio	Applied Stress, KSI S_m	S_a	S_c	Time to Rupture Hours	Kilocycles	
9485	3.0	∞	0	20.0	20.0	113.80	24,580.0	T.S.
9482	3.0	∞	0	21.5	21.5	117.08	25,290.0	T.S.
9156	3.0	∞	0	23.0	23.0	0.22	46.9	
9162	3.0	∞	0	23.0	23.0	140.85	30,430.0	T.S.
9151	3.0	∞	0	24.0	24.0	0.18	39.5	
9487	3.0	∞	0	24.0	24.0	35.19	7,601.0	
9228	3.0	∞	0	24.0	24.0	0.17	36.1	
9206	3.0	∞	0	24.0	24.0	0.17	37.2	
9293	3.0	∞	0	25.0	25.0	0.20	43.2	
9221	3.0	∞	0	26.0	26.0	19.49	4,210.0	
9140	3.0	∞	0	26.0	26.0	5.76	1,244.0	
9484	3.0	∞	0	26.0	26.0	10.72	2,313.0	
9132	3.0	∞	0	27.5	27.5	3.79	818.6	
9488	3.0	∞	0	27.5	27.5	31.14	6,726.0	
9158	3.0	∞	0	28.5	28.5	0.63	136.1	
9164	3.0	∞	0	28.5	28.5	0.13	28.7	
9224	3.0	∞	0	30.0	30.0	0.13	27.9	
9139	3.0	∞	0	30.0	30.0	0.10	20.7	
9166	1.0	1.0	25.0	25.0	50.0	113.332	24,480.0	T.S.
9372	1.0	1.0	27.5	27.5	55.0	82.70	17,860.0	
9386	1.0	1.0	30.0	30.0	60.0	0.23	49.7	
9456	1.0	1.0	30.0	30.0	60.0	5.39	1,164.0	
9496	1.0	1.0	32.5	32.5	65.0	1.00	216.0	
9303	1.0	1.0	35.0	35.0	70.0	0.15	32.4	
9345	1.0	1.0	40.0	40.0	80.0	0.09	18.4	

T.S. - Test Stopped

TABLE VI (Continued)

Fatigue Test Data for Aged Sheet

Test Temperature 600°F

Spec. No.	Spec. K_t	Stress Ratio	Applied Stress, KSI S_m	S_a	S_c	Time to Rupture Hours	Kilocycles	
9134	3.0	1.0	15.0	15.0	30.0	135.61	29,290.0	T.S.
9167	3.0	1.0	15.5	15.5	31.0	114.17	24,600.0	T.S.
9212	3.0	1.0	15.5	15.5	31.0	0.15	32.4	
9282	3.0	1.0	16.3	16.3	32.5	0.12	26.4	
9299	3.0	1.0	16.3	16.3	32.5	0.17	36.1	
9491	3.0	1.0	16.3	16.3	32.5	2.07	447.1	
9296	3.0	1.0	17.0	17.0	34.0	0.14	30.2	
9208	3.0	1.0	18.0	18.0	36.0	0.17	36.1	
9422	3.0	1.0	18.0	18.0	36.0	0.17	36.1	
9343	1.0	0	140.0	0	14.0	159.75		T.S.
9467	1.0	0	145.0	0	145.0	135.92		T.S.
9315	1.0	0	150.0	0	150.0	113.00		T.S.
9308	1.0	0	152.5	0	152.5	116.83		T.S.
9383	1.0	0	152.5	0	152.5	117.59		T.S.
9307	1.0	0	155.0	0	155.0	114.78		T.S.
9351	1.0	0	155.0	0	155.0	0	0	
9174	1.0	0	157.5	0	157.5	0	0	
9493	1.0	0	160.0	0	160.0	0	0	
9142	3.0	0	160.0	0	160.0	139.67		T.S.
9455	3.0	0	161.0	0	161.0	138.00		T.S.
9163	3.0	0	162.0	0	162.0	164.08		T.S.
9116	3.0	0	162.5	0	162.5	0		
9226	3.0	0	165.0	0	165.0	0		
9474	3.0	0	170.0	0	170.0	0		

T.S. - Test Stopped

TABLE VI (Continued)

Fatigue Test Data for Aged Sheet

Test Temperature 800°F

Spec. No.	Spec. K_t	Stress Ratio	Applied Stress, KSI S_m	S_a	S_c	Time to Rupture Hours	Kilocycles	
9257	1.0	∞	0	42.5	42.5	113.91	24,600.0	T.S.
9256	1.0	∞	0	45.0	45.0	117.79	25,440.0	T.S.
9129	1.0	∞	0	47.5	47.5	10.19	2,195.0	
9385	1.0	∞	0	47.5	47.5	8.69	1,877.0	
9414	1.0	∞	0	50.0	50.0	0.08	17.9	
9490	1.0	∞	0	50.0	50.0	8.14	1,758.0	
9359	1.0	∞	0	50.0	50.0	32.24	6,964.0	
9114	1.0	∞	0	52.5	52.5	73.36	15,840.0	
9347	1.0	∞	0	52.5	52.5	5.51	1,190.0	
9316	1.0	∞	0	52.5	52.5	0.10	22.5	
9413	1.0	∞	0	55.0	55.0	0.05	10.8	
9357	1.0	∞	0	55.0	55.0	0.05	11.7	
9236	1.0	∞	0	55.0	55.0	2.75	594.0	
9125	1.0	∞	0	57.5	57.5	0.59	128.1	
9263	1.0	∞	0	60.0	60.0	0.05	10.8	
9111	1.0	∞	0	65.0	65.0	0.05	10.8	
9243	3.0	∞	0	21.5	21.5	115.77	25,010.0	T.S.
9179	3.0	∞	0	23.0	23.0	116.21	25,100.0	T.S.
9152	3.0	∞	0	24.0	24.0	0.15	32.4	
9304	3.0	∞	0	24.0	24.0	0.17	36.1	
9137	3.0	∞	0	25.0	25.0	33.11	7,152.0	
9460	3.0	∞	0	26.0	26.0	0.10	21.6	
9463	3.0	∞	0	27.5	27.5	0.14	29.3	
9223	3.0	∞	0	30.0	30.0	0.08	16.2	
9369	1.0	1.0	22.5	22.5	45.0	115.10	24,860.0	T.S.
9126	1.0	1.0	25.0	25.0	50.0	1.33	288.0	
9401	1.0	1.0	25.0	25.0	50.0	158.97	34,330.0	T.S.
9124	1.0	1.0	26.0	26.0	52.0	1.29	279.0	
9270	1.0	1.0	26.3	26.3	52.5	1.72	372.0	
9495	1.0	1.0	27.5	27.5	55.0	136.00	29,380.0	T.S.
9408	1.0	1.0	27.5	27.5	55.0	1.52	328.0	
9420	1.0	1.0	27.5	27.5	55.0	2.25	486.0	
9356	1.0	1.0	28.8	28.8	57.5	40.71	8,793.0	
9465	1.0	1.0	30.0	30.0	60.0	0.17	36.1	
9366	1.0	1.0	30.0	30.0	60.0	0.12	31.0	
9327	1.0	1.0	30.0	30.0	60.0	0.20	43.2	
9417	1.0	1.0	32.5	32.5	65.0	0.11	23.8	

T.S. - Test Stopped

TABLE VI (Continued)

Fatigue Test Data for Aged Sheet

Test Temperature 800°F

Spec. No.	Spec. K_t	Stress Ratio	Applied Stress, KSI S_m	S_a	S_c	Time to Rupture Hours	Kilocycles	
9476	3.0	1.0	13.8	13.8	27.5	141.66	30,600.0	T.S.
9147	3.0	1.0	14.5	14.5	29.0	110.83	23,940.0	
9203	3.0	1.0	15.0	15.0	30.0	0.18	38.9	
9333	3.0	1.0	15.5	15.5	31.0	125.59	27,130.0	
9231	3.0	1.0	16.3	16.3	32.5	0.05	10.8	
9173	3.0	1.0	16.3	16.3	32.5	0.10	21.6	
9145	3.0	1.0	17.5	17.5	35.0	0.08	17.9	
9464	1.0	0	110.0	0	110.0	119.10		T.S.
9262	1.0	0	120.0	0	120.0	84.75		
9099	1.0	0	130.0	0	130.0	27.95		
9255	1.0	0	135.0	0	135.0	9.25		
9309	1.0	0	140.0	0	140.0	5.80		
9331	1.0	0	140.0	0	140.0	1.72		
9349	1.0	0	145.0	0	145.0	0.72		
9424	1.0	0	147.8	0	147.8	0.33		
9406	1.0	0	150.0	0	150.0	0		
9478	3.0	0	120.0	0	120.0	115.38		T.S.
9461	3.0	0	130.0	0	130.0	36.63		
9274	3.0	0	130.0	0	130.0	23.73		
9168	3.0	0	140.0	0	140.0	5.23		
9458	3.0	0	150.0	0	150.0	2.50		
9210	3.0	0	155.0	0	155.0	0.80		

T.S. - Test Stopped

TABLE VII

Fatigue Test Data for Annealed Sheet

Test Temperature 75°F

Spec. No.	Spec. K_t	Stress Ratio	Applied Stress, KSI S_m	S_a	S_c	Time to Rupture Hours	Kilocycles	
9241	1.0	∞	0	35.00	35.00	117.51	25,380.0	T.S.
9190	1.0	∞	0	36.00	36.00	5.04	1,089.0	
9438	1.0	∞	0	37.50	37.50	2.49	538.0	
9195	1.0	∞	0	40.00	40.00	0.32	69.1	
9194	1.0	∞	0	42.50	42.50	0.38	82.1	
9388	1.0	∞	0	50.00	50.00	0.18	39.5	
9423	1.0	∞	0	60.00	60.00	0.10	21.6	
9453	3.0	∞	0	15.00	15.00	118.22	25,620.0	T.S.
9451	3.0	∞	0	16.00	16.00	139.19	30,060.0	T.S.
9448	3.0	∞	0	17.50	17.50	143.00	30,900.0	T.S.
9245	3.0	∞	0	19.00	19.00	63.09	13,630.0	
9446	3.0	∞	0	20.00	20.00	0.57	123.0	
9120	3.0	∞	0	20.00	20.00	5.16	1,114.0	
9280	3.0	∞	0	21.50	21.50	0.30	64.8	
9450	3.0	∞	0	22.50	22.50	0.73	157.7	
9452	3.0	∞	0	25.00	25.00	0.24	51.8	
9153	3.0	∞	0	27.00	27.00	0.14	30.7	
9235	1.0	1.0	27.50	27.50	55.00	116.49	25,160.0	T.S.
9394	1.0	1.0	30.00	30.00	60.00	122.28	26,410.0	T.S.
9233	1.0	1.0	30.00	30.00	60.00	30.59	6,608.0	
9193	1.0	1.0	32.50	32.50	65.00	113.36	24,500.0	T.S.
9106	1.0	1.0	32.50	32.50	65.00	21.75	4,698.0	
9266	1.0	1.0	32.50	32.50	65.00	15.94	3,443.0	
9219	1.0	1.0	32.50	32.50	65.00	4.90	1,058.0	
9387	1.0	1.0	35.00	35.00	70.00	13.07	2,823.0	
9187	1.0	1.0	35.00	35.00	70.00	9.63	2,080.0	
9498	1.0	1.0	35.00	35.00	70.00	9.22	1,992.0	
9502	1.0	1.0	35.00	35.00	70.00	8.79	1,899.0	
9397	1.0	1.0	35.00	35.00	70.00	6.31	1,363.0	
9506	1.0	1.0	36.50	36.50	73.00	7.62	1,646.0	
9421	1.0	1.0	37.50	37.50	75.00	18.04	3,897.0	
9201	1.0	1.0	37.50	37.50	75.00	0.91	197.0	
9199	1.0	1.0	37.50	37.50	75.00	0.31	67.0	
9284	1.0	1.0	37.50	37.50	75.00	0.27	58.3	
9185	1.0	1.0	37.50	37.50	75.00	0.27	57.7	

T.S. - Test Stopped

TABLE VII (Continued)

Fatigue Test Data for Annealed Sheet

Test Temperature 75°F

Spec. No.	Spec. K_t	Stress Ratio	Applied Stress, KSI S_m	S_a	S_c	Time to Rupture Hours	Kilocycles	
9267	1.0	1.0	37.50	37.50	75.00	0.25	54.0	
9301	1.0	1.0	37.50	37.50	75.00	0.24	51.8	
9505	1.0	1.0	38.00	38.00	76.00	4.34	937.0	
9238	1.0	1.0	40.00	40.00	80.00	0.17	36.0	
9503	1.0	1.0	41.25	41.25	82.50	5.58	1,205.0	
9191	1.0	1.0	43.75	43.75	87.50	0.16	34.6	
9122	3.0	1.0	11.25	11.25	22.50	30.05	6,491.0	
9291	3.0	1.0	11.25	11.25	22.50	115.47	24,940.0	
9445	3.0	1.0	12.00	12.00	24.00	0.77	166.0	
9444	3.0	1.0	12.50	12.50	25.00	177.20	38,270.0	
9292	3.0	1.0	13.00	13.00	26.00	8.21	1,773.0	
9121	3.0	1.0	13.75	13.75	27.50	0.24	51.8	
9275	3.0	1.0	13.75	13.75	27.50	5.82	1,257.0	
9204	3.0	1.0	13.75	13.75	27.50	80.75	17,440.0	
9442	3.0	1.0	15.00	15.00	30.00	0.45	97.2	
9440	3.0	1.0	15.00	15.00	30.00	0.45	97.2	
9165	3.0	1.0	15.00	15.00	30.00	135.86	30,000.0	
9294	3.0	1.0	17.00	17.00	34.00	0.34	73.4	
			Test Temperature 600°F					
9377	1.0	∞	0	37.50	37.50	231.53	50,010.0	T.S.
9469	1.0	∞	0	42.50	42.50	47.43	10,250.0	
9368	1.0	∞	0	45.00	45.00	23.26	5,024.0	
9364	1.0	∞	0	50.00	50.00	6.32	1,365.0	
9342	1.0	∞	0	55.00	55.00	1.32	285.0	
9358	1.0	∞	0	60.00	60.00	0.06	13.0	
9222	3.0	∞	0	19.00	19.00	114.09	24,640.0	T.S.
9230	3.0	∞	0	20.00	20.00	0.58	126.0	
9146	3.0	∞	0	20.00	20.00	207.68	44,860.0	T.S.
9138	3.0	∞	0	21.50	21.50	105.30	22,750.0	
9169	3.0	∞	0	23.00	23.00	0.10	21.6	
9154	3.0	∞	0	23.00	23.00	0.12	25.3	
9225	3.0	∞	0	23.00	23.00	21.24	459.0	
9454	3.0	∞	0	24.00	24.00	0.29	62.6	
9220	3.0	∞	0	26.00	26.00	0.08	18.0	

T. S. - Test Stopped

TABLE VII (Continued)

Fatigue Test Data for Annealed Sheet

Test Temperature 600°F

Spec. No.	Spec. K_t	Stress Ratio	Applied Stress, KSI S_m	S_a	S_c	Time to Rupture Hours	Kilocycles	
9374	1.0	1.0	23.75	23.75	47.50	121.49	26,240.0	T.S.
9348	1.0	1.0	25.00	25.00	50.00	63.69	13,760.0	
9466	1.0	1.0	27.50	27.50	55.00	82.80	17,880.0	
9407	1.0	1.0	30.00	30.00	60.00	18.06	3,901.0	
9415	1.0	1.0	32.50	32.50	65.00	0.83	180.0	
9175	1.0	1.0	32.50	32.50	65.00	4.56	985.0	
9360	1.0	1.0	35.00	35.00	70.00	0.55	119.0	
9376	1.0	1.0	40.00	40.00	80.00	0.11	23.3	
9297	3.0	1.0	13.00	13.00	26.00	117.35	25,350.0	T.S.
9249	3.0	1.0	13.75	13.75	27.50	8.62	1,862.0	
9462	3.0	1.0	14.25	14.25	28.50	0.13	28.7	
9141	3.0	1.0	14.25	14.25	28.50	22.39	4,836.0	
9481	3.0	1.0	14.25	14.25	28.50	65.51	14,150.0	
9161	3.0	1.0	15.00	15.00	30.00	26.18	5,655.0	
9273	3.0	1.0	15.00	15.00	30.00	139.13	30,050.0	T.S.
9214	3.0	1.0	15.33	15.33	30.67	0.17	36.1	
9244	3.0	1.0	16.00	16.00	32.00	22.03	4,759.0	
9480	3.0	1.0	17.00	17.00	34.00	0.26	56.2	
9240	1.0	0	105.00	0	105.00	159.93		T.S.
9108	1.0	0	112.13	0	112.13	120.18		T.S.
9253	1.0	0	113.00	0	113.00	195.28		T.S.
9336	1.0	0	113.30	0	113.30	0.42		
9186	1.0	0	115.00	0	115.00	0.08		
9441	3.0	0	120.00	0	120.00	184.20		T.S.
9131	3.0	0	121.50	0	121.50	136.92		T.S.
9283	3.0	0	123.00	0	123.00	*		
9335	3.0	0	125.00	0	125.00	*		

T.S. - Test Stopped

* - Fracture Prior to Full Load

TABLE VII (Continued)

Fatigue Test Data for Annealed Sheet

Test Temperature 800°F

Spec. No.	Spec. K_t	Stress Ratio	Applied Stress, KSI S_m	S_a	S_c	Time to Rupture Hours	Kilocycles	
9501	1.0	∞	0	21.20	21.20	114.46	24,700.0	T.S.
9258	1.0	∞	0	30.00	30.00	35.96	7,767.0	
9400	1.0	∞	0	32.50	32.50	115.23	24,890.0	T.S.
9200	1.0	∞	0	42.50	42.50	118.85	25,670.0	T.S.
9216	1.0	∞	0	45.00	45.00	18.35	3,963.0	
9183	1.0	∞	0	47.50	47.50	30.58	6,606.0	
9264	1.0	∞	0	47.50	47.50	0.37	79.3	
9287	1.0	∞	0	47.50	47.50	0.10	21.6	
9184	1.0	∞	0	50.00	50.00	4.65	1,004.0	
9218	1.0	∞	0	50.00	50.00	1.22	263.0	
9250	1.0	∞	0	52.50	52.50	3.85	829.0	
9344	1.0	∞	0	55.00	55.00	1.44	311.0	
9384	1.0	∞	0	60.00	60.00	0.05	10.8	
9188	1.0	∞	0	70.00	70.00	0.00	0.0	
9150	3.0	∞	0	19.00	19.00	44.23	9,554.0	
9477	3.0	∞	0	19.50	19.50	113.19	24,450.0	T.S.
9227	3.0	∞	0	20.00	20.00	0.18	39.5	
9459	3.0	∞	0	21.50	21.50	88.66	19,150.0	
9247	3.0	∞	0	23.00	23.00	117.57	25,390.0	T.S.
9117	3.0	∞	0	23.00	23.00	17.75	3,834.0	
9486	3.0	∞	0	24.00	24.00	0.18	38.8	
9288	3.0	∞	0	26.00	26.00	0.05	10.8	
9396	1.0	1.0	19.00	19.00	38.00	162.88	35,180.0	T.S.
9234	1.0	1.0	21.25	21.25	42.50	62.02	13,400.0	
9182	1.0	1.0	21.25	21.25	42.50	49.32	10,650.0	
9353	1.0	1.0	23.75	23.75	47.50	59.53	12,860.0	
9100	1.0	1.0	25.00	25.00	50.00	57.04	12,320.0	
9242	1.0	1.0	25.00	25.00	50.00	20.80	4,493.0	
9260	1.0	1.0	25.00	25.00	50.00	4.58	989.0	
9105	1.0	1.0	27.50	27.50	55.00	38.51	8,318.0	
9198	1.0	1.0	27.50	27.50	55.00	19.64	4,238.0	
9109	1.0	1.0	30.00	30.00	60.00	27.45	5,929.0	
9399	1.0	1.0	30.00	30.00	60.00	0.17	36.7	
9237	1.0	1.0	30.00	30.00	60.00	0.15	32.4	
9202	1.0	1.0	32.50	32.50	65.00	45.13	9,748.0	
9102	1.0	1.0	32.50	32.50	65.00	10.45	2,257.0	
9252	1.0	1.0	33.75	33.75	67.50	0.19	41.0	
9391	1.0	1.0	34.00	34.00	68.00	2.05	443.0	
9352	1.0	1.0	37.50	37.50	75.00	0.05	10.8	

T.S. - Test Stopped

TABLE VII (Continued)

Fatigue Test Data for Annealed Sheet

Test Temperature 800°F

Spec. No.	Spec. K_t	Stress Ratio	Applied Stress, KSI S_m	S_a	S_c	Time to Rupture Hours	Kilocycles	Elong %
9443	3.0	1.0	11.25	11.25	22.50	114.51	24,730.0	T.S.
9172	3.0	1.0	12.00	12.00	24.00	99.72	21,540.0	
9135	3.0	1.0	12.50	12.50	25.00	44.77	9,670.0	
9370	3.0	1.0	13.00	13.00	26.00	0.83	179.0	
9483	3.0	1.0	13.73	13.73	27.45	0.25	54.0	
9281	3.0	1.0	13.75	13.75	27.50	0.10	21.6	
9209	3.0	1.0	15.00	15.00	30.00	0.12	25.3	
9472	1.0	0	80.00	0	80.00	114.25		T.S.(6.64)
9239	1.0	0	100.00	0	100.00	115.90		T.S.(7.53)
9192	1.0	0	107.50	0	107.50	68.10		
9500	1.0	0	107.50	0	107.50	4.10		
9103	1.0	0	110.00	0	110.00	109.93		15.8
9197	1.0	0	112.00	0	112.00	88.30		
9504	1.0	0	115.00	0	115.00	9.70		
9189	1.0	0	120.00	0	120.00	*		
9180	3.0	0	105.00	0	105.00	208.08		T.S.
9144	3.0	0	110.00	0	110.00	55.95		
9278	3.0	0	115.00	0	115.00	63.00		
9277	3.0	0	117.50	0	117.50	21.80		T.S.main power off
9447	3.0	0	121.00	0	121.00	19.55		
9305	3.0	0	123.00	0	123.00	9.95		
9272	3.0	0	124.00	0	124.00	27.40		
9119	3.0	0	126.00	0	126.00	*		

T.S. - Test Stopped

* - Fracture Prior to Full Load

TABLE VIII

Fatigue Test Data for Aged Bar

Test Temperature 75^{o}F

Specimen Number	Ratio A	Applied S_m	Stress, KSI S_a	S_c	Time to Rupture Hours	Kilocycles	
CB 6926 AK	∞	0	52.0	52.0	106.71	23,050	
6921	∞	0	55.0	55.0	24.52	5,296	
7051	∞	0	58.0	58.0	60.37	13,040	
7033	∞	0	60.0	60.0	39.30	8,489	
6959	∞	0	60.0	60.0	3.36	726	
7019	∞	0	63.0	63.0	140.24	30,290	
7042	∞	0	65.0	65.0	8.17	1,765	
6961	∞	0	70.0	70.0	28.70	6,199	
6971	∞	0	70.0	70.0	19.76	4,268	
7018	∞	0	70.0	70.0	1.03	222	
7017	∞	0	75.0	75.0	0.90	194	
7044	∞	0	90.0	90.0	0.12	25	
CB 7085 BU	∞	0	26.0	26.0	142.80	30,830	T.S.
7067	∞	0	28.0	28.0	90.54	19,550	
7061	∞	0	30.0	30.0	67.35	14,550	
7063	∞	0	31.0	31.0	98.75	21,330	
7059	∞	0	33.0	33.0	0.48	104	
7055	∞	0	34.0	34.0	93.28	20,150	
7182	∞	0	35.0	35.0	62.59	13,520	
7175	∞	0	35.0	35.0	14.75	3,186	
7155	∞	0	35.0	35.0	0.68	148	
7056	∞	0	35.0	35.0	0.37	80	
7054	∞	0	37.0	37.0	0.42	90	
7052	∞	0	40.0	40.0	0.22	47	
CB 6898 AK	1.0	33.5	33.5	67.0	120.67	26,470	T.S.
7040	1.0	36.5	36.5	73.0	181.79	39,270	
6920	1.0	37.5	37.5	75.0	13.38	2,890	
7070	1.0	40.0	40.0	80.0	23.45	5,065	
6897	1.0	40.0	40.0	80.0	20.48	4,424	
6901	1.0	40.0	40.0	80.0	15.51	3,350	
6962	1.0	42.5	42.5	85.0	28.94	6,271	
6956	1.0	42.5	42.5	85.0	18.72	4,043	
7039	1.0	42.5	42.5	85.0	12.36	2,670	
7034	1.0	42.5	42.5	85.0	9.01	1,946	
7041	1.0	45.0	45.0	90.0	3.78	817	
7038	1.0	50.0	50.0	100.0	4.45	961	
7032	1.0	55.0	55.0	110.0	1.59	343	

T.S. - Test Stopped
P.S. - Prior Stress History

TABLE VIII (Continued)

Fatigue Test Data for Aged Bar

Test Temperature 75°F

Specimen Number	Ratio A	Applied Stress, KSI S_m	S_a	S_c	Time to Rupture Hours	Kilocycles	
CB 7087 BU	1.0	17.5	17.5	35.0	159.52	34,450	T.S.
7084	1.0	18.5	18.5	37.0	50.10	10,820	
7089	1.0	20.0	20.0	40.0	34.09	7,364	
7071	1.0	20.0	20.0	40.0	7.78	1,680	
7082	1.0	21.5	21.5	43.0	7.80	1,685	
7090	1.0	22.5	22.5	45.0	2.93	633	
7066	1.0	25.0	25.0	50.0	0.55	119	
CB 6922 AK	0.25	74.4	18.6	93.0	140.54	30,350	T.S.
6899	0.25	78.4	19.6	98.0	163.13	35,240	T.S.
6919	0.25	84.0	21.0	105.0	43.39	9,372	
6900	0.25	92.0	23.0	115.0	97.72	21,100	
6918	0.25	92.0	23.0	115.0	17.21	3,717	
6963	0.25	104.0	26.0	130.0	28.11	6,072	
7005	0.25	104.0	26.0	130.0	6.59	1,423	
7021	0.25	120.0	30.0	150.0	6.14	1,326	
6923	0.25	128.0	32.0	160.0	0.37	79	
CB 7081 BU	0.25	44.0	11.0	55.0	138.26	29,870	T.S.
7075	0.25	48.0	12.0	60.0	37.31	8,059	
7064	0.25	48.0	12.0	60.0	31.39	6,780	
7065	0.25	56.0	14.0	70.0	5.96	1,287	
7176	0.25	56.0	14.0	70.0	1.33	287	
7077	0.25	56.0	14.0	70.0	0.30	65	
7062	0.25	61.6	15.4	77.0	0.23	50	
7060	0.25	72.0	18.0	90.0	0.12	26	
7058	0.25	84.0	21.0	105.0	0.05	11	

T.S. - Test Stopped

TABLE VIII (Continued)

Fatigue Test Data for Aged Bar

Test Temperature 600°F

Specimen Number	Ratio A	Applied S_m	Stress, KSI S_a	S_c	Time to Rupture Hours	Kilocycles	
CB 7035 AK	∞	0	60.0	60.0	101.17	21,860	T.S.
6933	∞	0	62.5	62.5	25.09	5,420	
7163	∞	0	65.0	65.0	21.80	4,709	
6931	∞	0	65.0	65.0	11.03	2,383	
7020	∞	0	70.0	70.0	45.82	9,897	
6932	∞	0	70.0	70.0	16.90	3,650	
6912	∞	0	75.0	75.0	0.88	191	
7043	∞	0	80.0	80.0	3.06	661	
6934	∞	0	90.0	90.0	0.07	15	
CB 7083 BU	∞	0	30.0	30.0	125.38	27,080	T.S.
7114	∞	0	31.0	31.0	138.53	29,920	T.S.
7076	∞	0	33.0	33.0	94.90	20,500	
7121	∞	0	35.0	35.0	93.50	20,200	
7094	∞	0	35.0	35.0	0.25	54	
7097	∞	0	35.0	35.0	0.17	36	
7111	∞	0	37.0	37.0	92.49	19,980	
7148	∞	0	37.0	37.0	0.21	45	
7130	∞	0	40.0	40.0	0.17	36	
7142	∞	0	42.0	42.0	0.22	47	
7154	∞	0	43.0	43.0	0.09	19	
7140	∞	0	50.0	50.0	0.08	16	
CB 6907 AK	1.0	35.0	35.0	70.0	112.31	24,250	T.S.
6952	1.0	37.5	37.5	75.0	145.15	31,350	
6906	1.0	37.5	37.5	75.0	27.93	6,033	
6953	1.0	40.0	40.0	80.0	94.56	20,420	
6910	1.0	40.0	40.0	80.0	80.96	17,490	
6925	1.0	40.0	40.0	80.0	10.54	2,277	
6903	1.0	45.0	45.0	90.0	18.82	4,065	
6924	1.0	50.0	50.0	100.0	2.04	441	
6911	1.0	57.5	57.5	115.0	1.97	427	
CB 7120 BU	1.0	18.5	18.5	37.0	186.52	40,290	T.S.
7137	1.0	20.0	20.0	40.0	144.52	31,210	P.S.
7095	1.0	20.0	20.0	40.0	48.75	10,530	
7119	1.0	20.0	20.0	40.0	13.56	2,929	
7116	1.0	22.5	22.5	45.0	10.54	2,277	
7078	1.0	25.0	25.0	50.0	5.09	1,099	
7100	1.0	25.0	25.0	50.0	0.13	27	
7115	1.0	27.5	27.5	55.0	0.12	25	

T.S. - Test Stopped
P.S. - Prior Stress History

TABLE VIII (Continued)

Fatigue Test Data for Aged Bar

Test Temperature 600°F

Specimen Number	Ratio A	Applied Stress, KSI S_m	S_a	S_c	Time to Rupture Hours	Kilocycles	
CB 6954 AK	0.25	96.0	24.0	120.0	141.50	30,560	T.S.
6929	0.25	100.0	25.0	125.0	32.10	6,934	
6904	0.25	104.0	26.0	130.0	140.14	30,490	T.S.
6909	0.25	112.0	128.0	140.0	119.56	25,820	T.S.
6928	0.25	112.0	128.0	140.0	18.88	4,078	
6927	0.25	120.0	30.0	150.0	5.80	1,253	
6950	0.25	124.0	31.0	155.0	7.00	1,512	
6908	0.25	128.0	32.0	160.0	0.11	23	
CB 7088 BU	0.25	44.0	11.0	55.0	139.85	30,210	T.S.
7134	0.25	52.0	13.0	65.0	136.0	29,380	T.S.
7074	0.25	52.0	13.0	65.0	76.18	16,460	
7132	0.25	56.0	14.0	70.0	59.96	12,950	
7122	0.25	56.0	14.0	70.0	54.9	11,860	
7135	0.25	61.6	15.4	77.0	71.01	15,340	
7118	0.25	61.6	15.4	77.0	0.22	48	
7138	0.25	65.6	16.4	82.0	0.08	18	
7133	0.25	72.0	18.0	90.0	0.017	3.7	
CB 6902 AK	0	130.0	0	130.0	121.38		T.S.
6905	0	170.0	0	170.0	120.00		T.S.
7001	0	184.3	0	184.3	120.27		T.S.
7000	0	185.0	0	185.0	133.58		T.S.
6939	0	187.5	0	187.5	*		
6951	0	190.0	0	190.0	*		
6938	0	195.0	0	195.0	*		
6998	0	200.0	0	200.0	*		
7002	0	210.0	0	210.0	*		
CB 7112 BU	0	225.0	0	225.0	136.00		T.S.
7096	0	230.0	0	230.0	15.48		T.S.-P.S.
7124	0	260.0	0	260.0	*		
7139	0	238.0	0	238.0	135.75		T.S.
7099	0	240.0	0	240.0	*		
7103	0	242.0	0	242.0	136.72		T.S.
7104	0	246.0	0	246.0	162.18		T.S.
7117	0	248.0	0	248.0	*		
7106	0	250.0	0	250.0	188.85		T.S.
7102	0	250.0	0	250.0	*		
7101	0	235.0	0	235.0	33.00		T.S.

T.S. - Test Stopped
P.S. - Prior Stress History
* - Fracture Prior to Full Load

TABLE VIII(Continued)

Fatigue Test Data for Aged Bar

Test Temperature 800°F

Specimen Number	Ratio A	Applied S_m	Stress, KSI S_a	S_c	Time to Rupture Hours	Kilocycles	
CB 7026 AK	∞	0	53.0	53.0	135.48	29,270	T.S.
6964	∞	0	57.0	57.0	62.21	13,440	
6970	∞	0	60.0	60.0	104.17	22,500	
7006	∞	0	65.0	65.0	8.86	1,914	
6965	∞	0	70.0	70.0	7.66	1,654	
7025	∞	0	70.0	70.0	7.28	1,572	
7028	∞	0	70.0	70.0	6.50	1,404	
6917	∞	0	75.0	75.0	3.07	663	
7026	∞	0	80.0	80.0	0.67	144	P.S.
7029	∞	0	85.0	85.0	0.12	25	
	∞						
CB 7150 BU	∞	0	30.0	30.0	182.53	39,750	
7152	∞	0	33.0	33.0	28.23	6,120	
7194	∞	0	33.0	33.0	15.80	3,413	
7158	∞	0	35.0	35.0	0.18	40	
7345	∞	0	37.0	37.0	13.52	2,920	
7126	∞	0	40.0	40.0	2.25	486	
7153	∞	0	43.0	43.0	0.09	19	
CB 6966 AK	1.0	36.0	36.0	72.0	234.06	50,550	
6969	1.0	36.0	36.0	72.0	75.92	16,400	T.S.
6914	1.0	40.0	40.0	80.0	69.26	14,960	
7027	1.0	42.5	42.5	85.0	44.87	9,691	
6975	1.0	45.0	45.0	90.0	8.70	1,879	
6913	1.0	50.0	50.0	100.0	6.71	1,449	
6941	1.0	55.0	55.0	110.0	1.70	367	
7022	1.0	60.0	60.0	120.0	0.07	15	
CB 7170 BU	1.0	18.5	18.5	37.0	119.62	25,840	
7157	1.0	18.5	18.5	37.0	112.29	24,250	T.S.
7346	1.0	20.0	20.0	40.0	35.86	7,746	
7184	1.0	21.5	21.5	43.0	23.42	5,058	
7151	1.0	22.5	22.5	45.0	0.17	37	

T.S. - Test Stopped
P.S. - Prior Stress History

TABLE VIII (Continued)

Fatigue Test Data for Aged Bar

Test Temperature 800°F

Specimen Number	Ratio A	Applied S_m	Stress, KSI S_a	S_c	Time to Rupture Hours	Kilocycles	
CB 6916 AK	0.25	84.0	21.0	105.0	123.55	26,690	T.S.
6974	0.25	96.0	24.0	120.0	115.49	25,950	
7050	0.25	100.0	25.0	125.0	28.64	6,186	
6936	0.25	100.0	25.0	125.0	22.45	4,859	
6976	0.25	112.0	28.0	140.0	29.16	6,299	
7037	0.25	112.0	28.0	140.0	10.09	2,179	
6967	0.25	116.0	29.0	145.0	15.51	3,350	
6955	0.25	116.0	29.0	145.0	3.27	706	
6937	0.25	120.0	30.0	150.0	0.05	11	
CB 7344 BU	0.25	49.6	12.4	62.0	147.35	31,830	
7149	0.25	52.0	13.0	65.0	118.47	25,590	T.S.
7171	0.25	53.6	13.4	67.0	126.44	27,310	
7186	0.25	53.6	13.4	67.0	98.11	21,190	
7131	0.25	56.0	14.0	70.0	0.17	36	
7174	0.25	57.6	14.4	72.0	0.22	48	
CB 7049 AK	0	130.0	0	130.0	137.50		T.S.
7003	0	140.0	0	140.0	73.00		
6935	0	150.0	0	150.0	15.26		
6996	0	160.0	0	160.0	3.33		
6915	0	170.0	0	170.0	2.68		
6973	0	174.0	0	174.0	*		
6940	0	180.0	0	180.0	*		
CB 7092 BU	0	200.0	0	200.0	182.88		T.S.
7128	0	215.0	0	215.0	60.05		
7145	0	220.0	0	220.0	59.17		
7107	0	240.0	0	240.0	9.68		
7141	0	248.0	0	248.0	0.75		
7129	0	255.0	0	255.0	0.10		
7110	0		0		*		

T.S. - Test Stopped
* - Fracture Prior to Full Load

TABLE IX

Fatigue Strength (KSI) of B120-VCA Sheet

at 10^7 Cycles

Conditions	Annealed			Aged		
	K_t = 1.0	K_t = 3.0	K_f	1.0	3.0	K_f
75° A = 0						
75° 1.0	67	25	2.67	56	28	2.00
75° ∞	35	17	2.05	41	22	1.86
600° 0	120	130	0.92	152	160	0.95
600° 1.0	52	29	1.79	54	31.5	1.72
600° ∞	42	22	1.92	46	24	1.92
800° 0	120	140	0.86	125	128	.98
800° 1.0	52	24	2.17	49	29	1.69
800° ∞	45	22	2.05	48	24	2.00

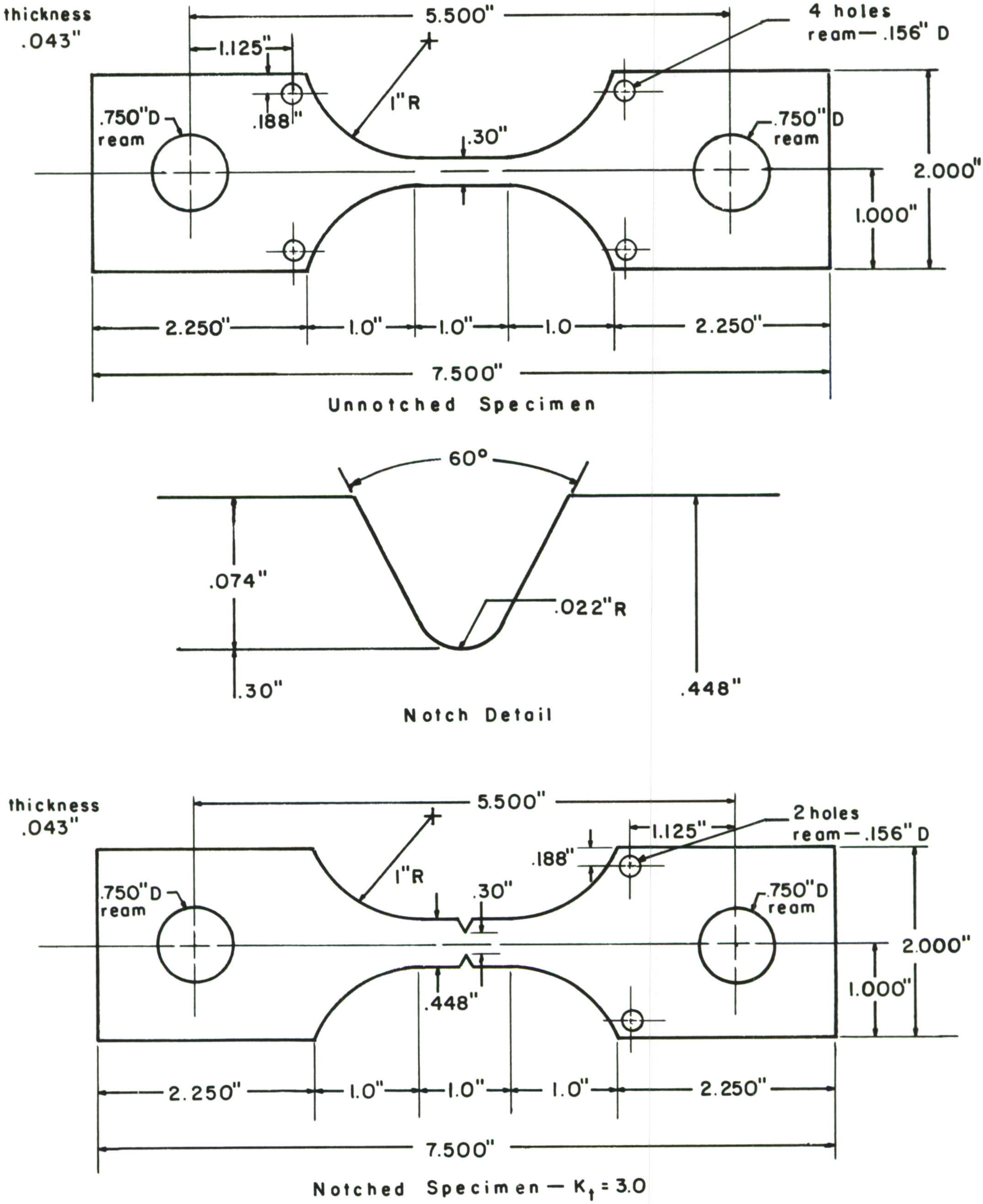

Figure 1 Diagram of Sheet Specimens.

9115	9132	9149	9166	9183	9200	9217	9234	9251	9268	9285	9302
9114	9131	9148	9165	9182	9199	9216	9233	9250	9267	9284	9301
9113	9130	9147	9164	9181	9198	9215	9232	9249	9266	9283	9300
9112	9129	9146	9163	9180	9197	9214	9231	9248	9265	9282	9299
9111	9128	9145	9162	9179	9196	9213	9230	9247	9264	9281	9298
9110	9127	9144	9161	9178	9195	9212	9229	9246	9263	9280	9297
9109	9126	9143	9160	9177	9194	9211	9228	9245	9262	9279	9296
9108	9125	9142	9159	9176	9193	9210	9227	9244	9261	9278	9295
9107	9124	9141	9158	9175	9192	9209	9226	9243	9260	9277	9294
9106	9123	9140	9157	9174	9191	9208	9225	9242	9259	9276	9293
9105	9122	9139	9156	9173	9190	9207	9224	9241	9258	9275	9292
9104	9121	9138	9155	9172	9189	9206	9223	9240	9257	9274	9291
9103	9120	9137	9154	9171	9188	9205	9222	9239	9256	9273	9290
9102	9119	9136	9153	9170	9187	9204	9221	9238	9255	9272	9289
9101	9118	9135	9152	9169	9186	9203	9220	9237	9254	9271	9288
9100	9117	9134	9151	9168	9185	9202	9219	9236	9253	9270	9287
9099	9116	9133	9150	9167	9184	9201	9218	9235	9252	9269	9286

Figure 2 Location of Specimen Blanks, Sheet No. 2.

9319	9336	9353	9370	9387	9404	9421	9438	9455	9472	9489	9506
9318	9335	9352	9369	9386	9403	9420	9437	9454	9471	9488	9505
9317	9334	9351	9368	9385	9402	9419	9436	9453	9470	9487	9504
9316	9333	9350	9367	9384	9401	9418	9435	9452	9469	9486	9503
9315	9332	9349	9366	9383	9400	9417	9434	9451	9468	9485	9502
9314	9331	9348	9365	9382	9399	9416	9433	9450	9467	9484	9501
9313	9330	9347	9364	9381	9398	9415	9432	9449	9466	9483	9500
9312	9329	9346	9363	9380	9397	9414	9431	9448	9465	9482	9499
9311	9328	9345	9362	9379	9396	9413	9430	9447	9464	9481	9498
9310	9327	9344	9361	9378	9395	9412	9429	9446	9463	9480	9497
9309	9326	9343	9360	9377	9394	9411	9428	9445	9462	9479	9496
9308	9325	9342	9359	9376	9393	9410	9427	9444	9461	9478	9495
9307	9324	9341	9358	9375	9392	9409	9426	9443	9460	9477	9494
9306	9323	9340	9357	9374	9391	9408	9425	9442	9459	9476	9493
9305	9322	9339	9356	9373	9390	9407	9424	9441	9458	9475	9492
9304	9321	9338	9355	9372	9389	9406	9423	9440	9457	9474	9491
9303	9320	9337	9354	9371	9388	9405	9422	9439	9456	9473	9490

Figure 3 Location of Specimen Blanks, Sheet No. 3.

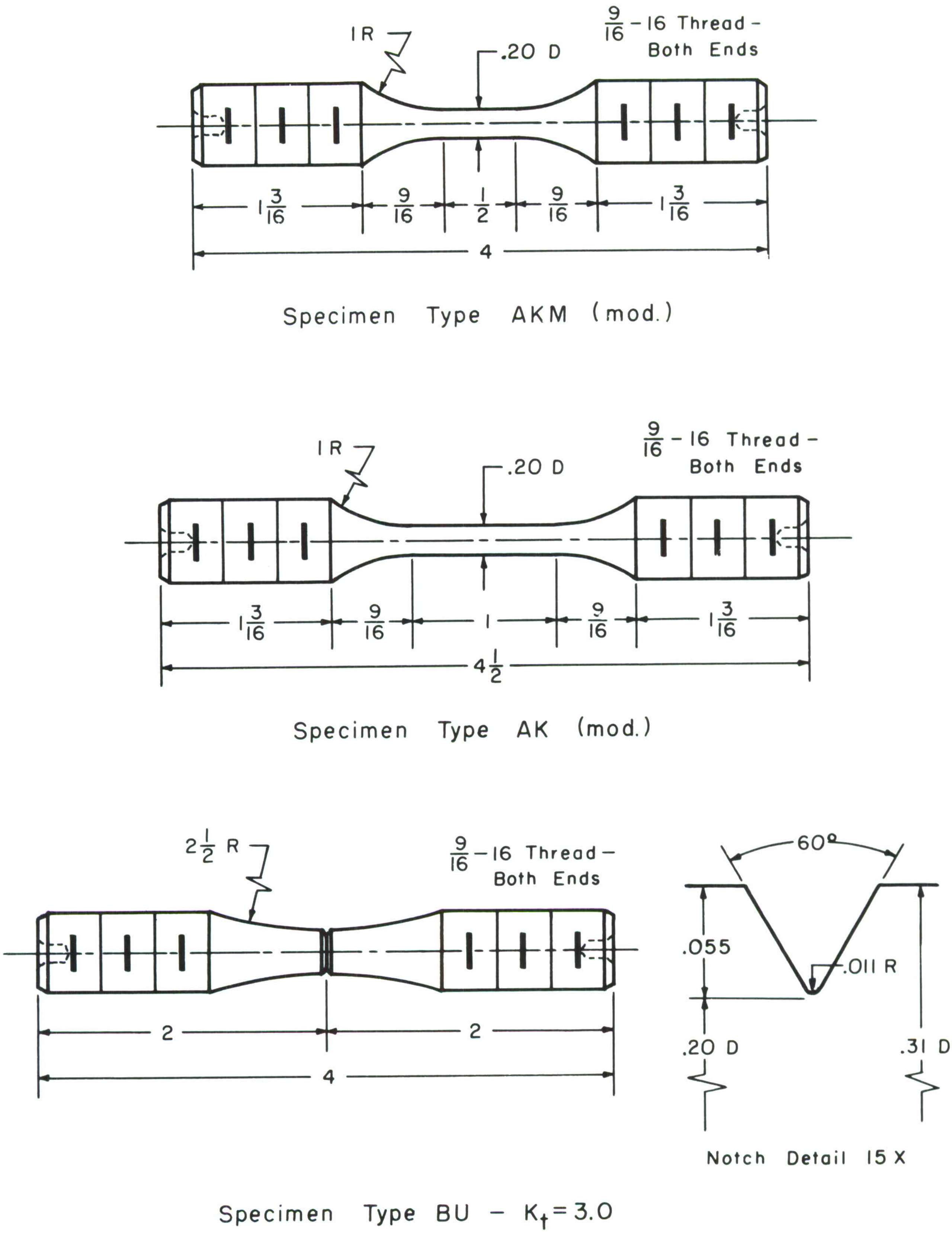

Figure 4 Diagram of Bar Specimens.

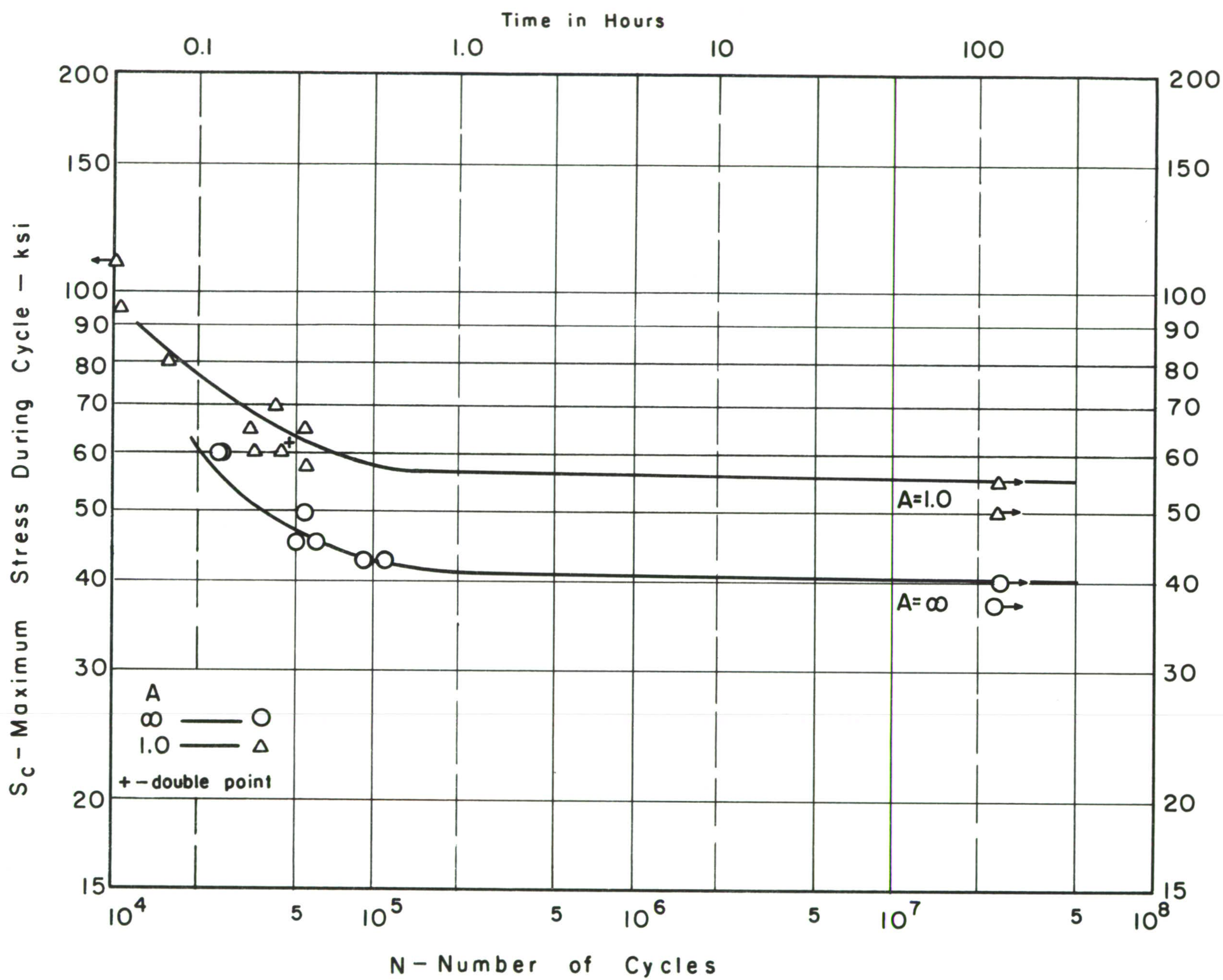

Figure 5 S-N Fatigue Diagrams for Unnotched Specimens of Aged Sheet at 75°F.

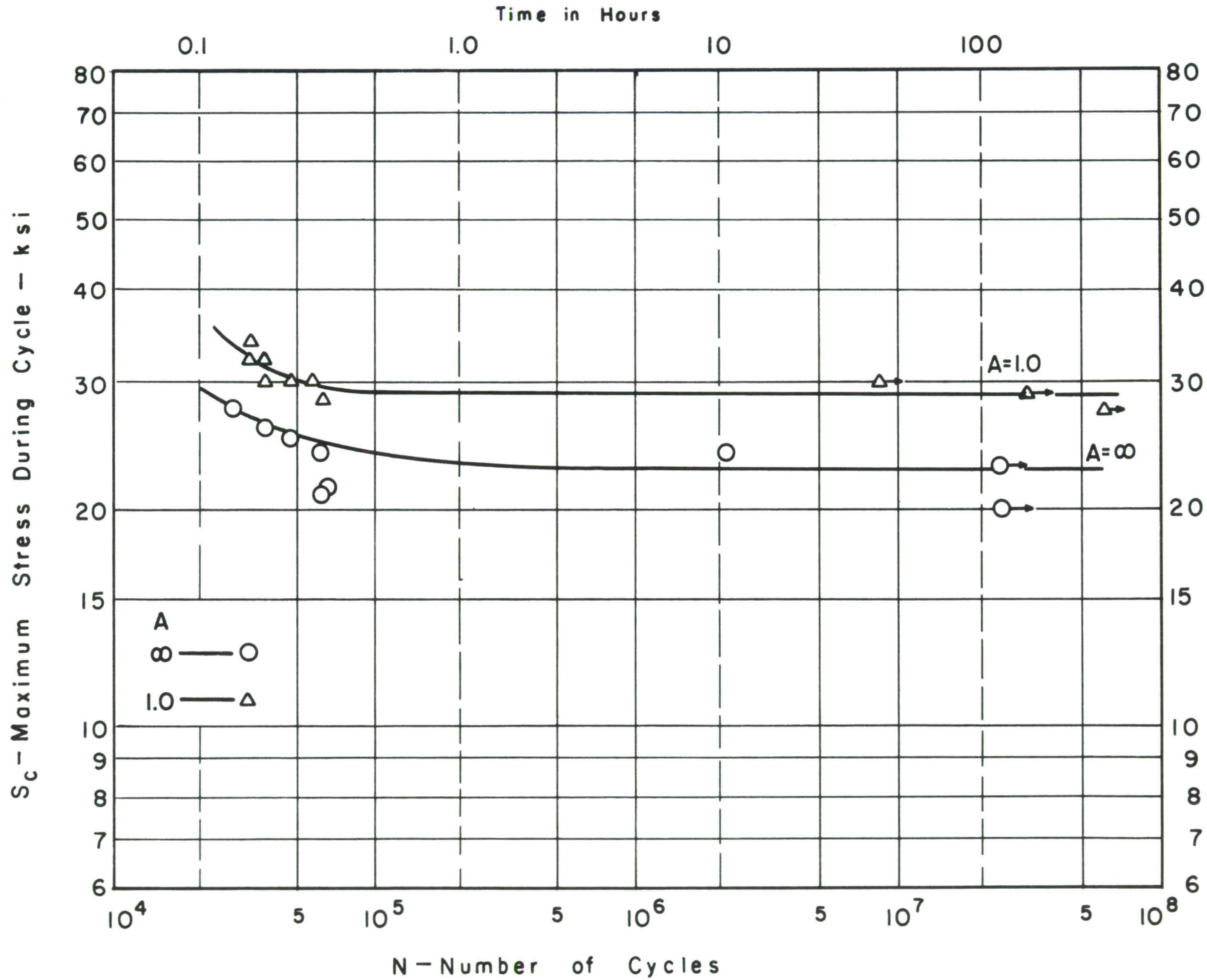

Figure 6 S-N Fatigue Diagrams for Notched Specimens of Aged Sheet at 75°F.

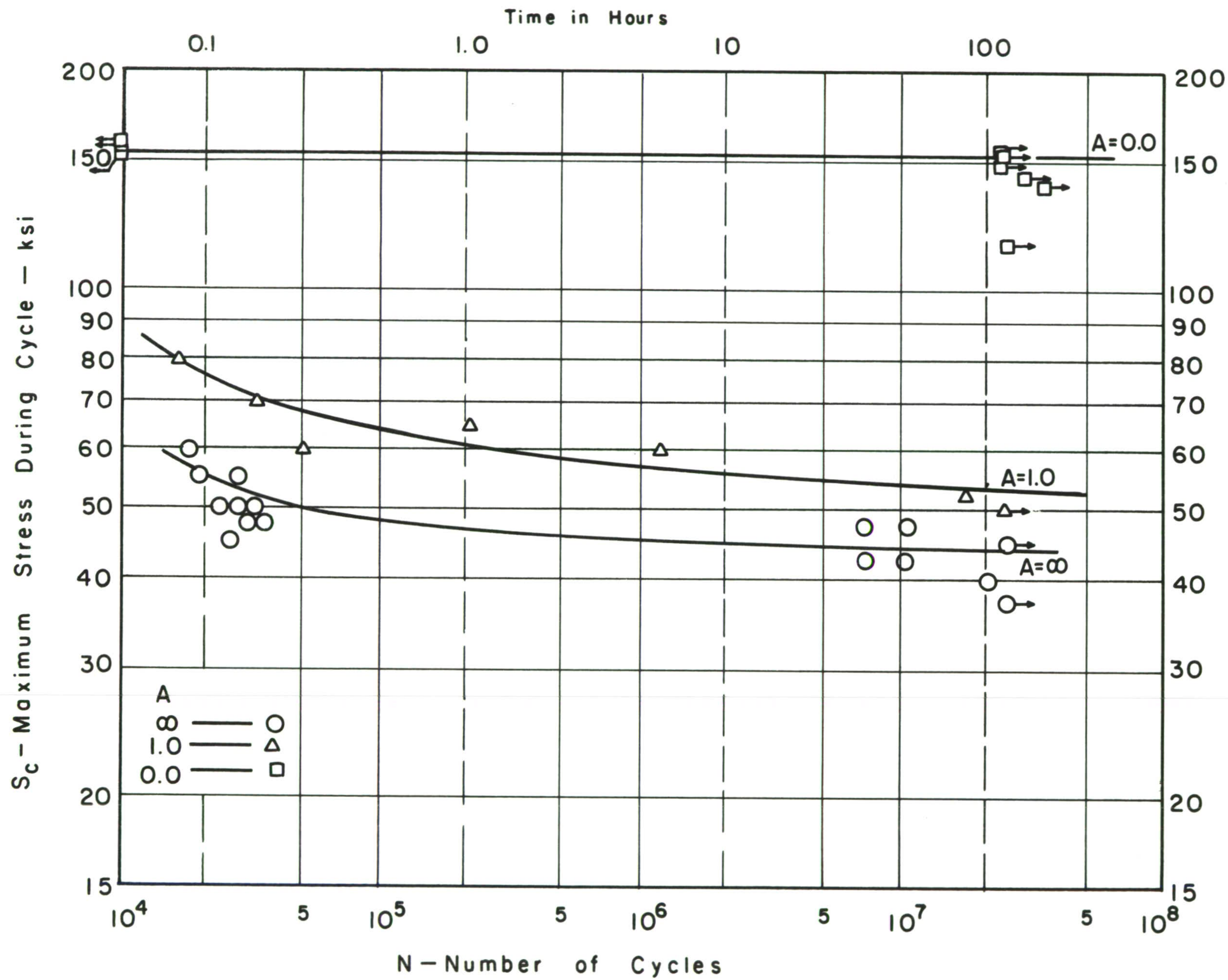

Figure 7 S-N Fatigue and Creep Rupture Diagrams for Unnotched Specimens of Aged Sheet at 600°F.

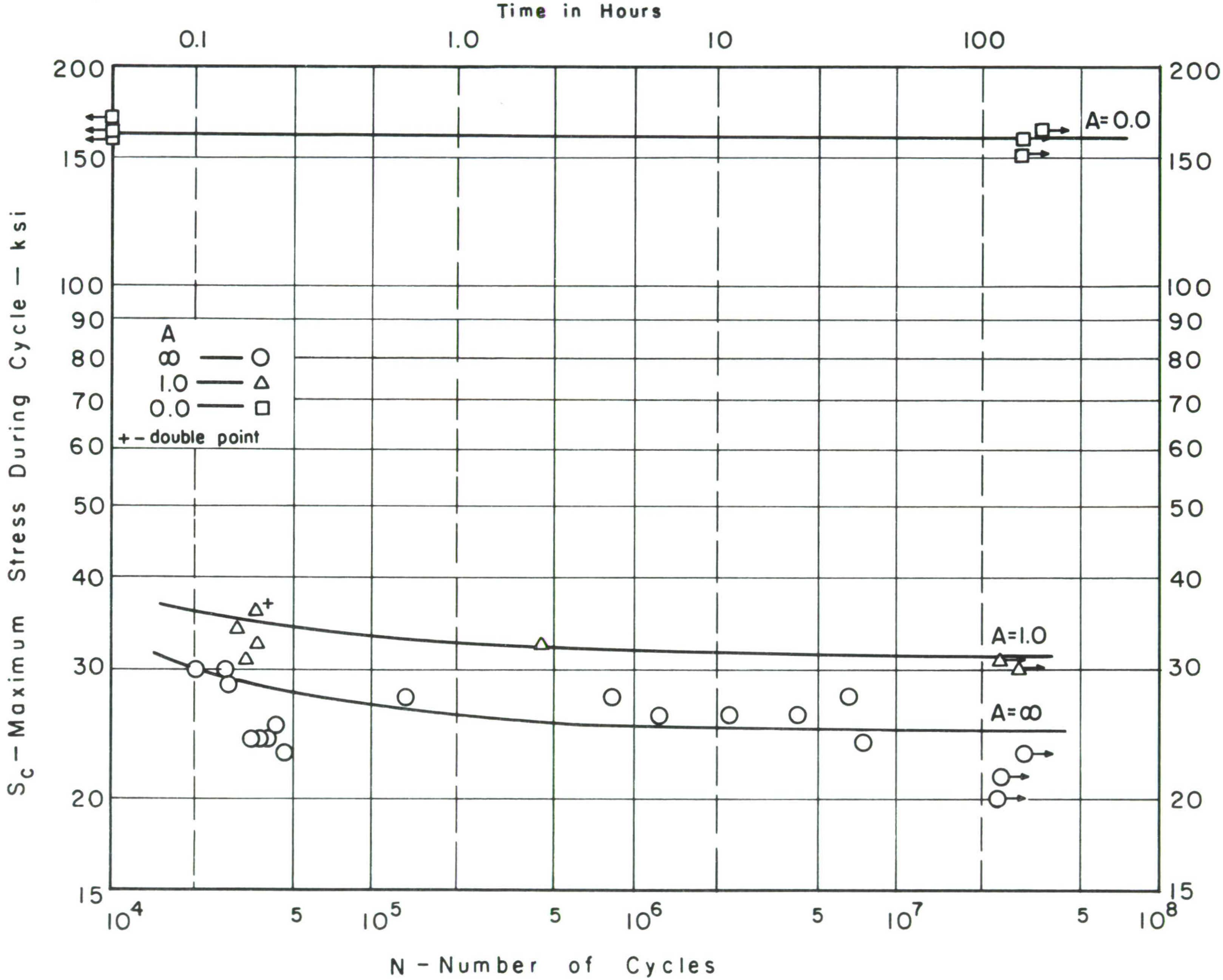

Figure 8 S-N Fatigue and Creep Rupture Diagrams for Notched Specimens of Aged Sheet at 600°F.

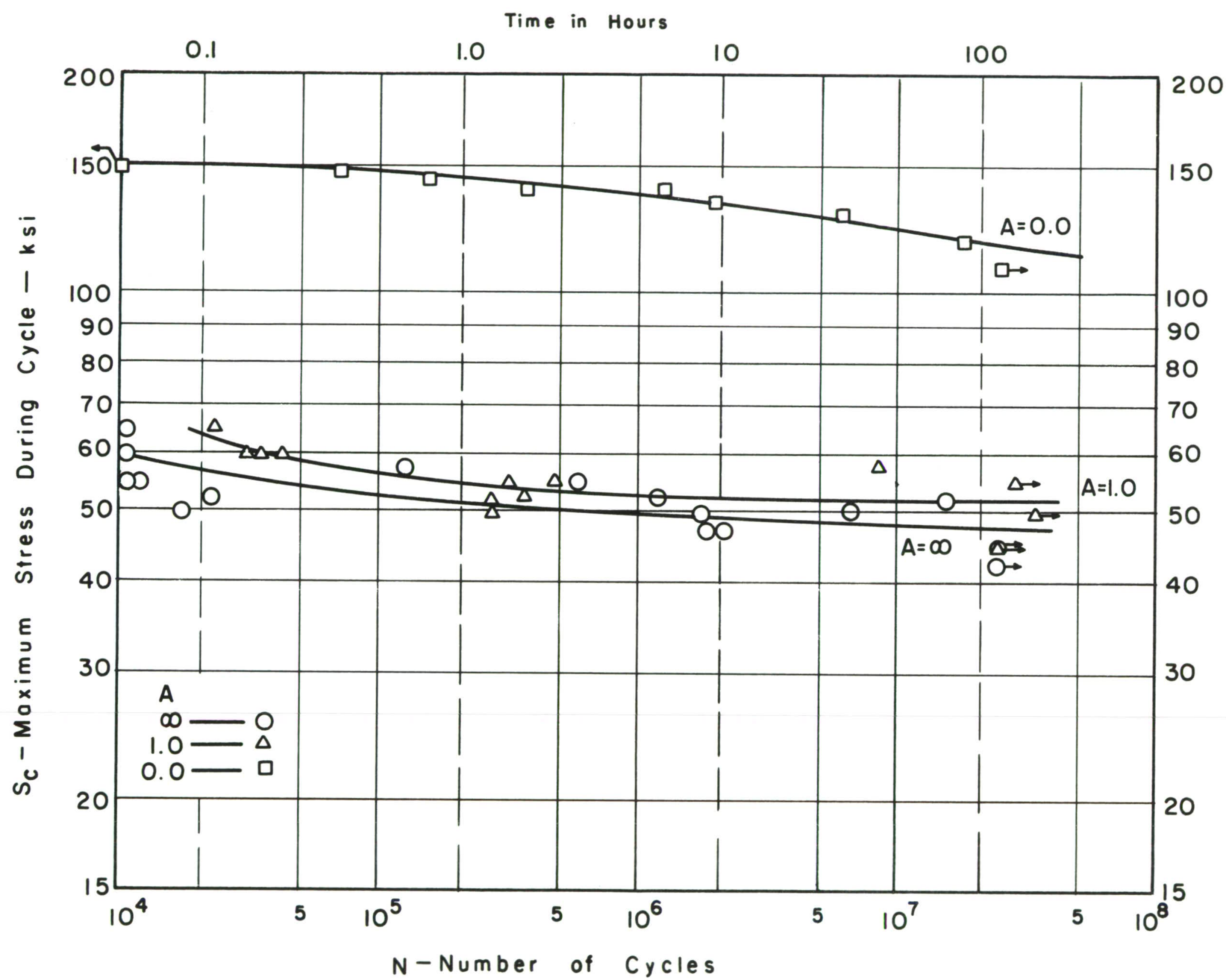

Figure 9 S-N Fatigue and Creep Rupture Diagrams for Unnotched Specimens of Aged Sheet at 800°F.

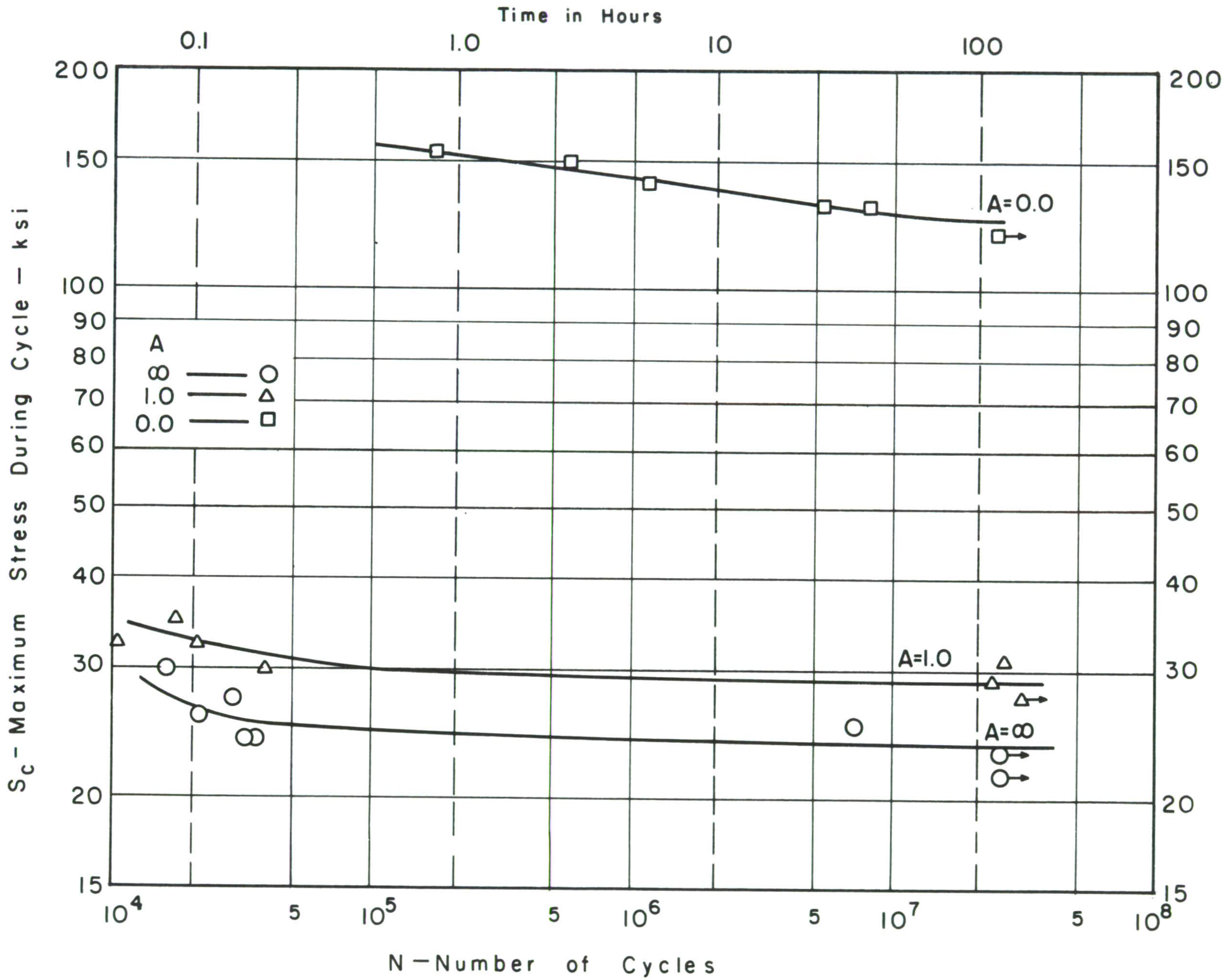

Figure 10 S-N Fatigue and Creep Rupture Diagrams for Notched Specimens of Aged Sheet at 800°F.

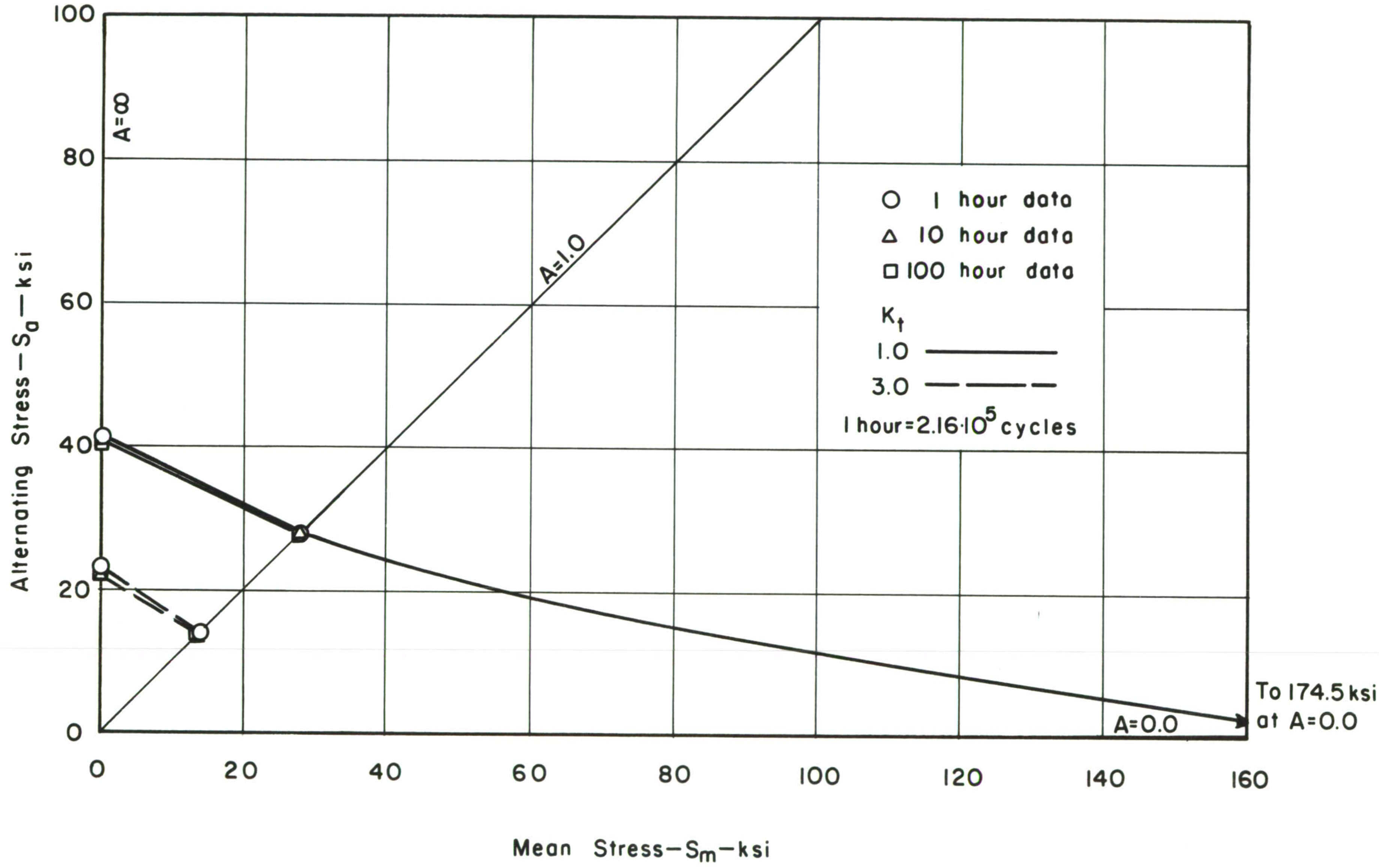

Figure 11 Constant-Life Diagrams for Aged Sheet Specimens at 75°F.

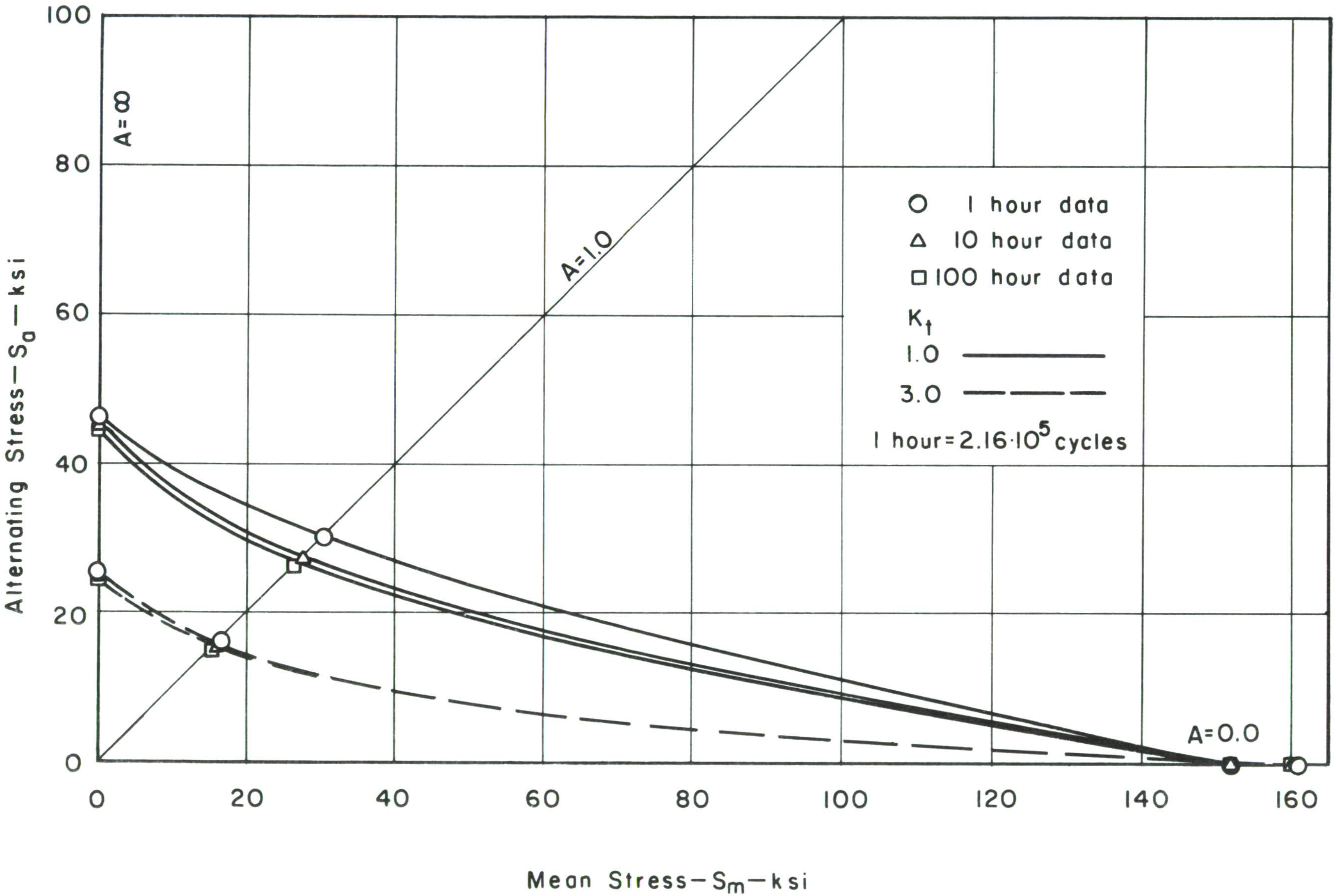

Figure 12 Constant-Life Diagrams for Aged Sheet Specimens at 600°F.

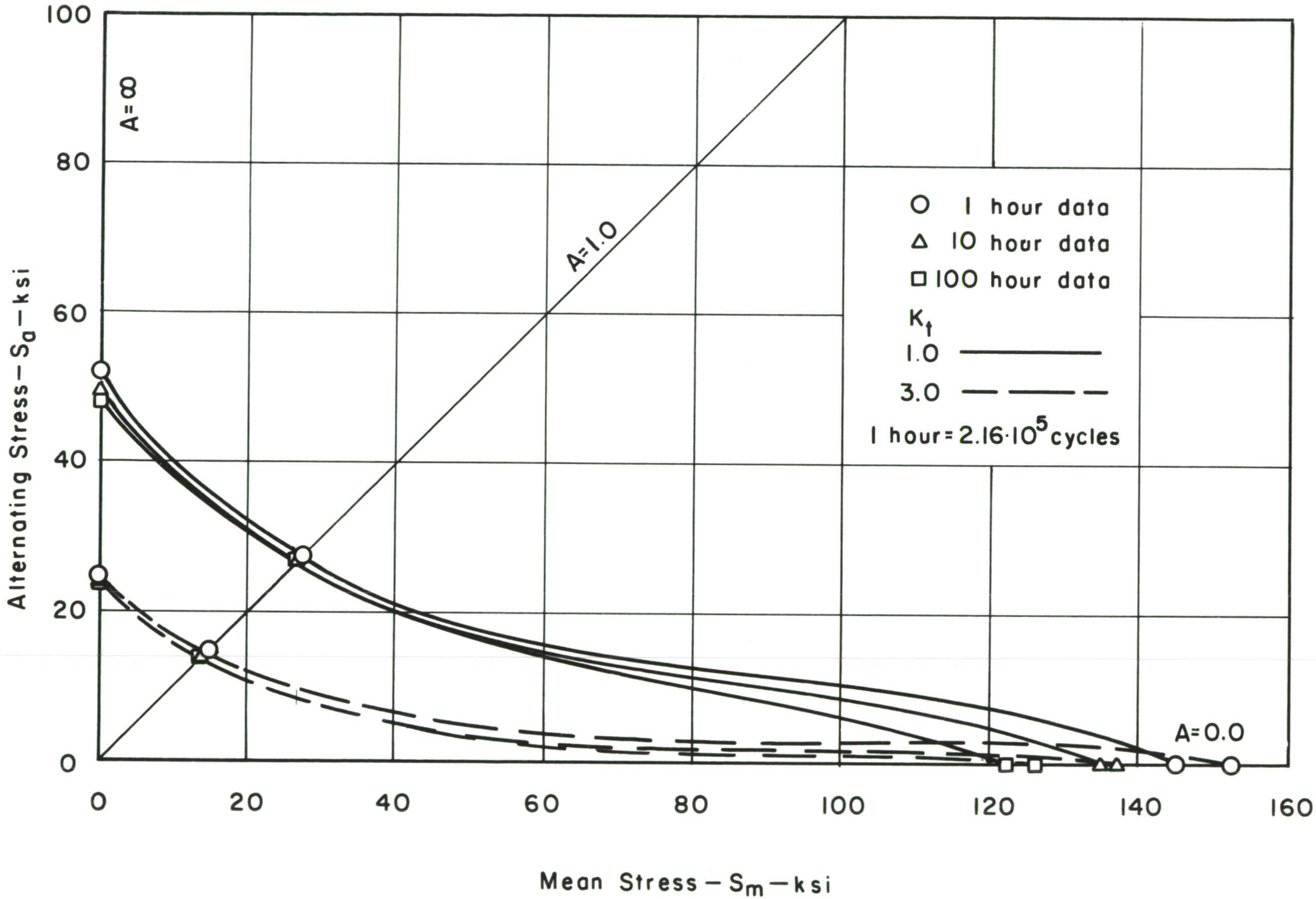

Figure 13 Constant-Life Diagrams for Aged Sheet Specimens at 800°F.

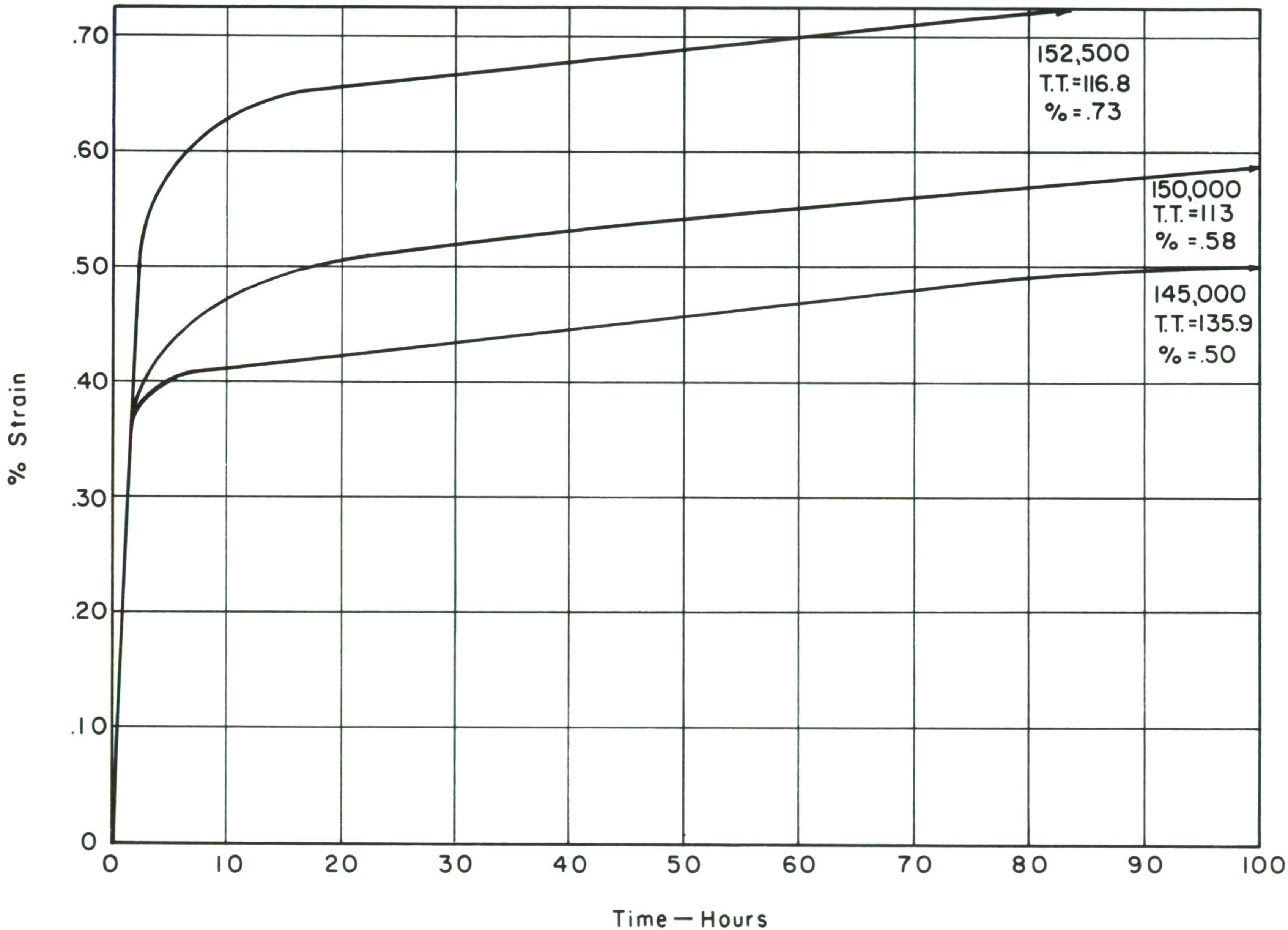

Figure 14 Static Creep Curves for Aged Sheet at $600^{O}F$.

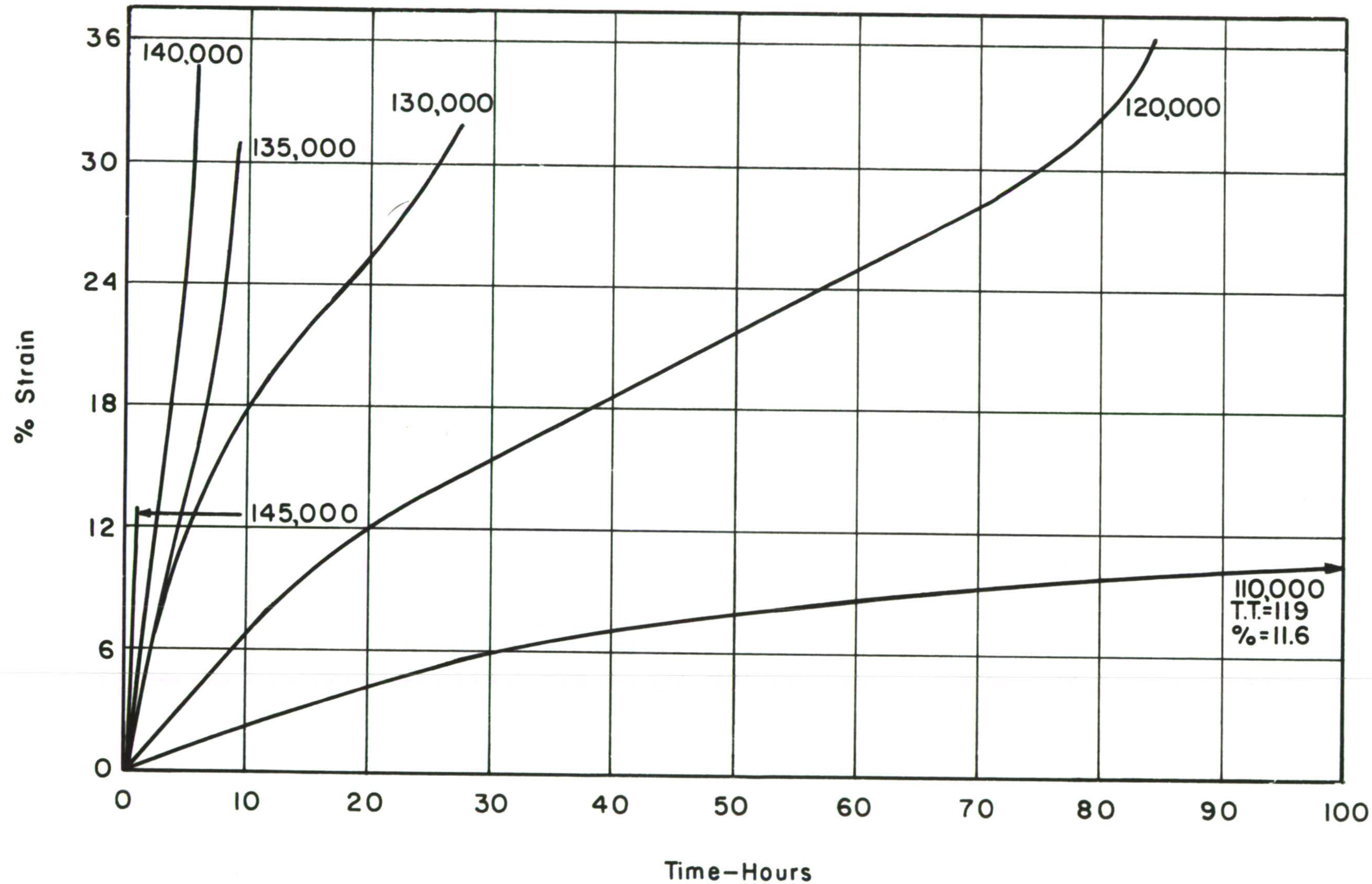

Figure 15 Static Creep Curves for Aged Sheet at 800°F.

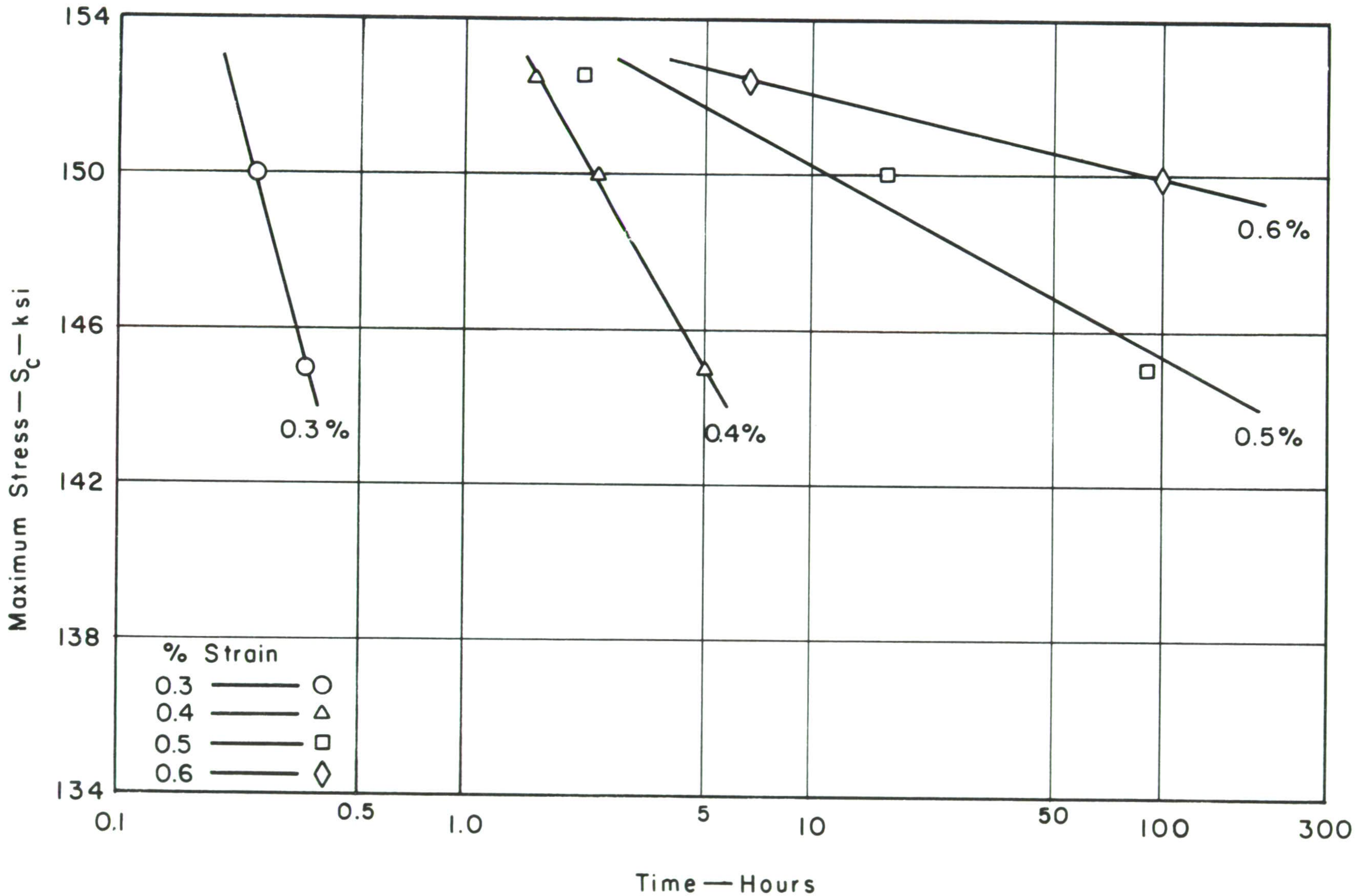

Figure 16 Creep Strength Design Curves for Aged Sheet at 600°F.

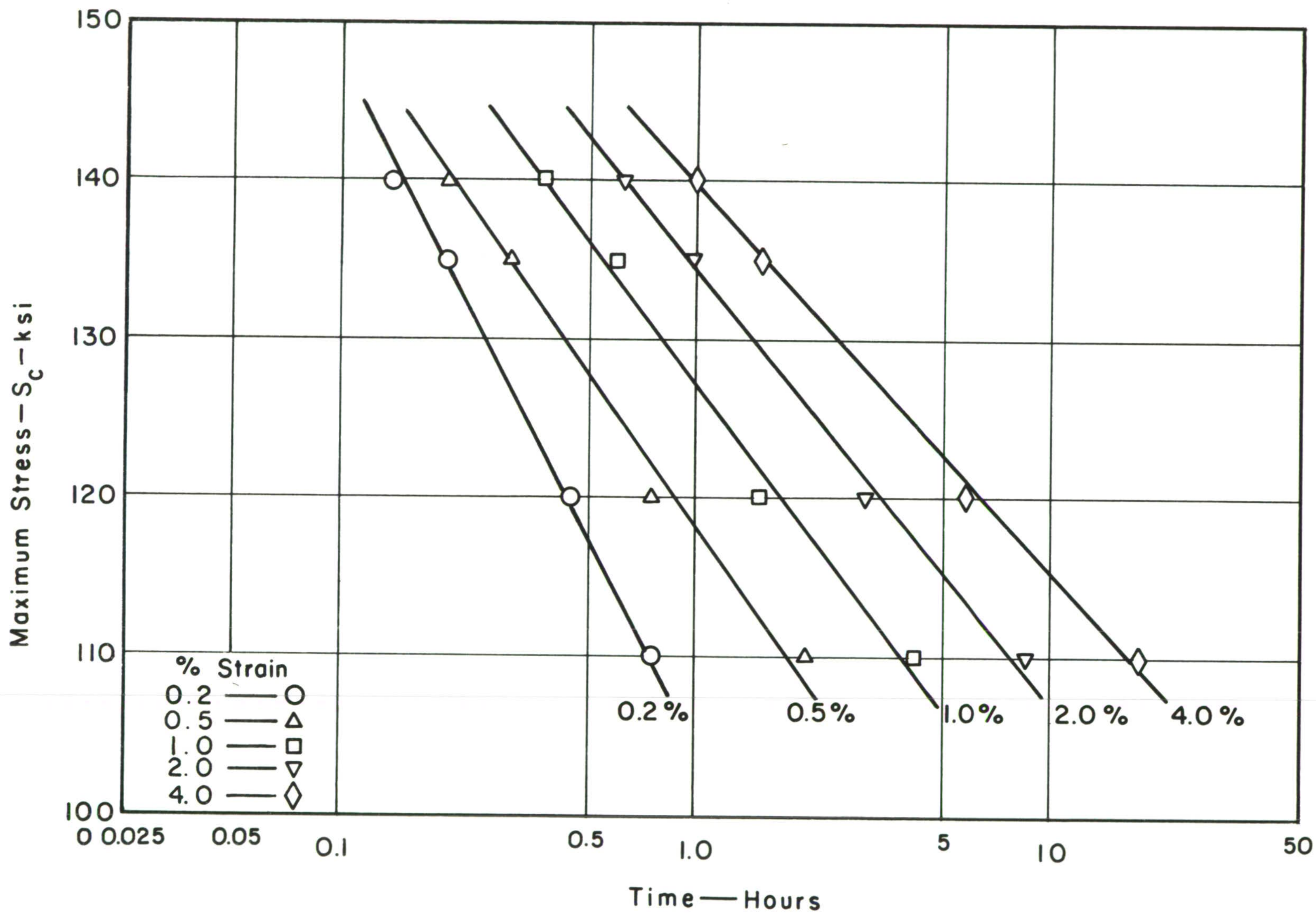

Figure 17 Creep Strength Design Curves for Aged Sheet at 800°F.

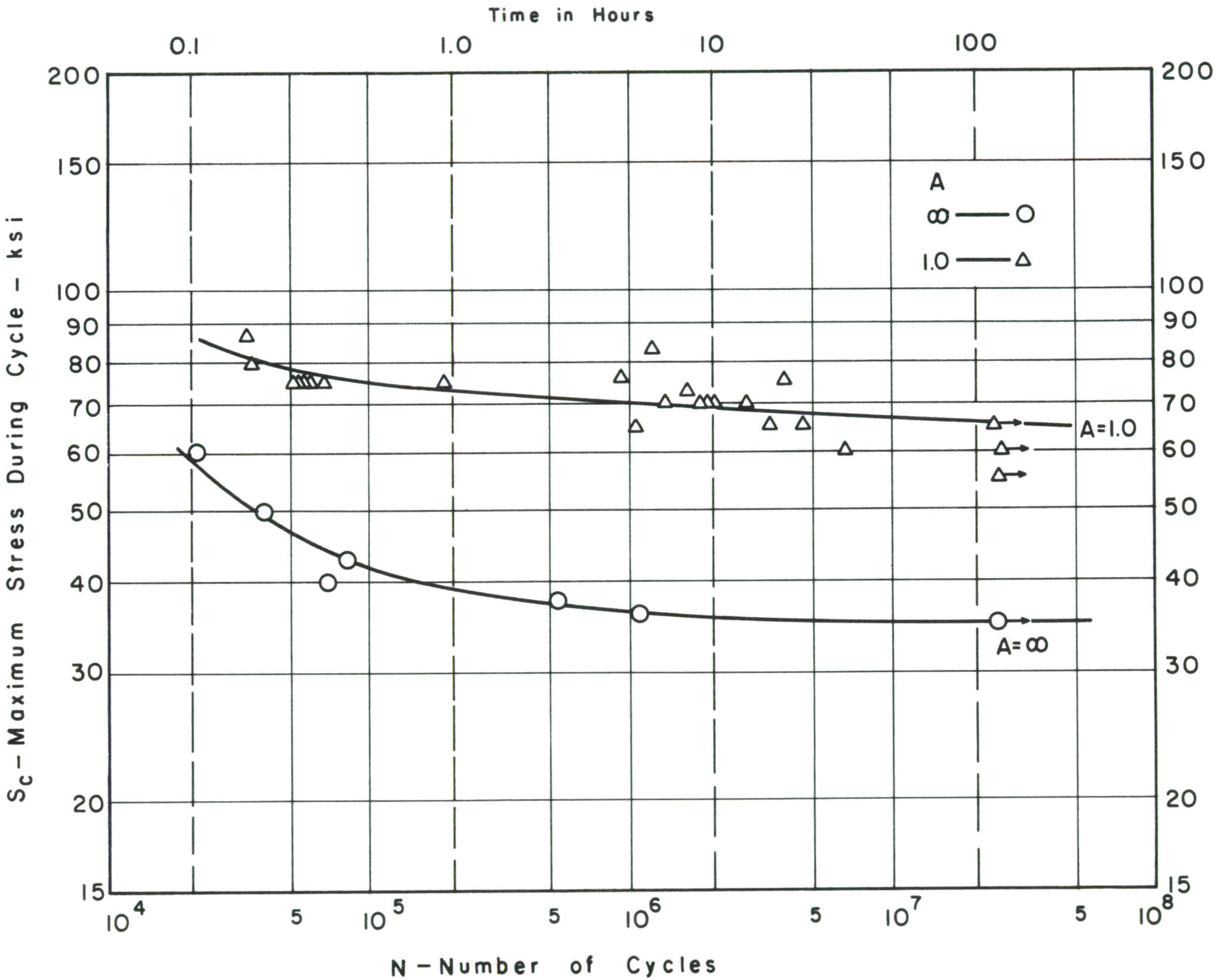

Figure 18 S-N Fatigue Diagrams for Unnotched Specimens of Annealed Sheet at 75°F.

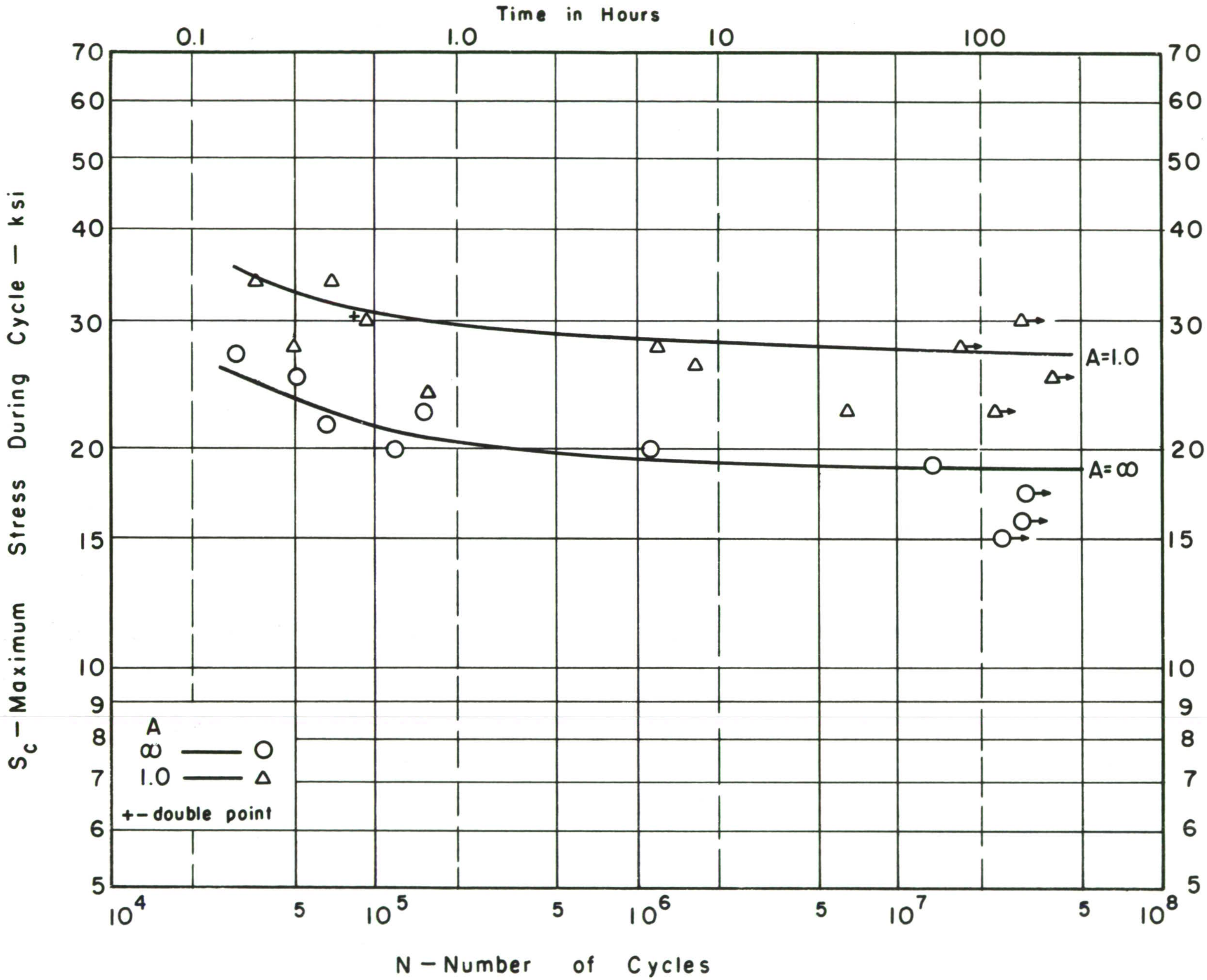

Figure 19 S-N Fatigue Diagrams for Notched Specimens of Annealed Sheet at 75°F.

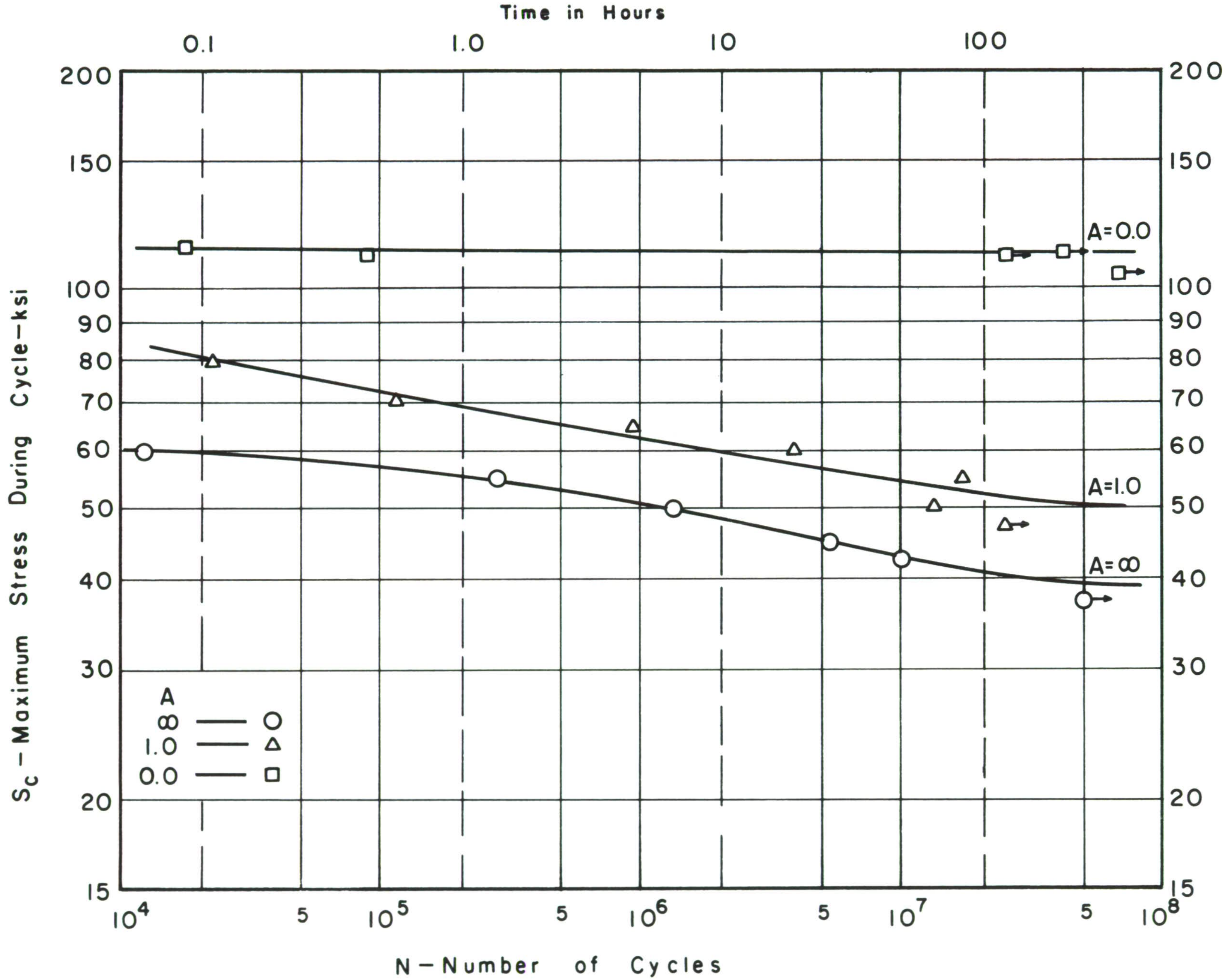

Figure 20 S-N Fatigue and Creep Rupture Diagrams for Unnotched Specimens of Annealed Sheet at 600°F.

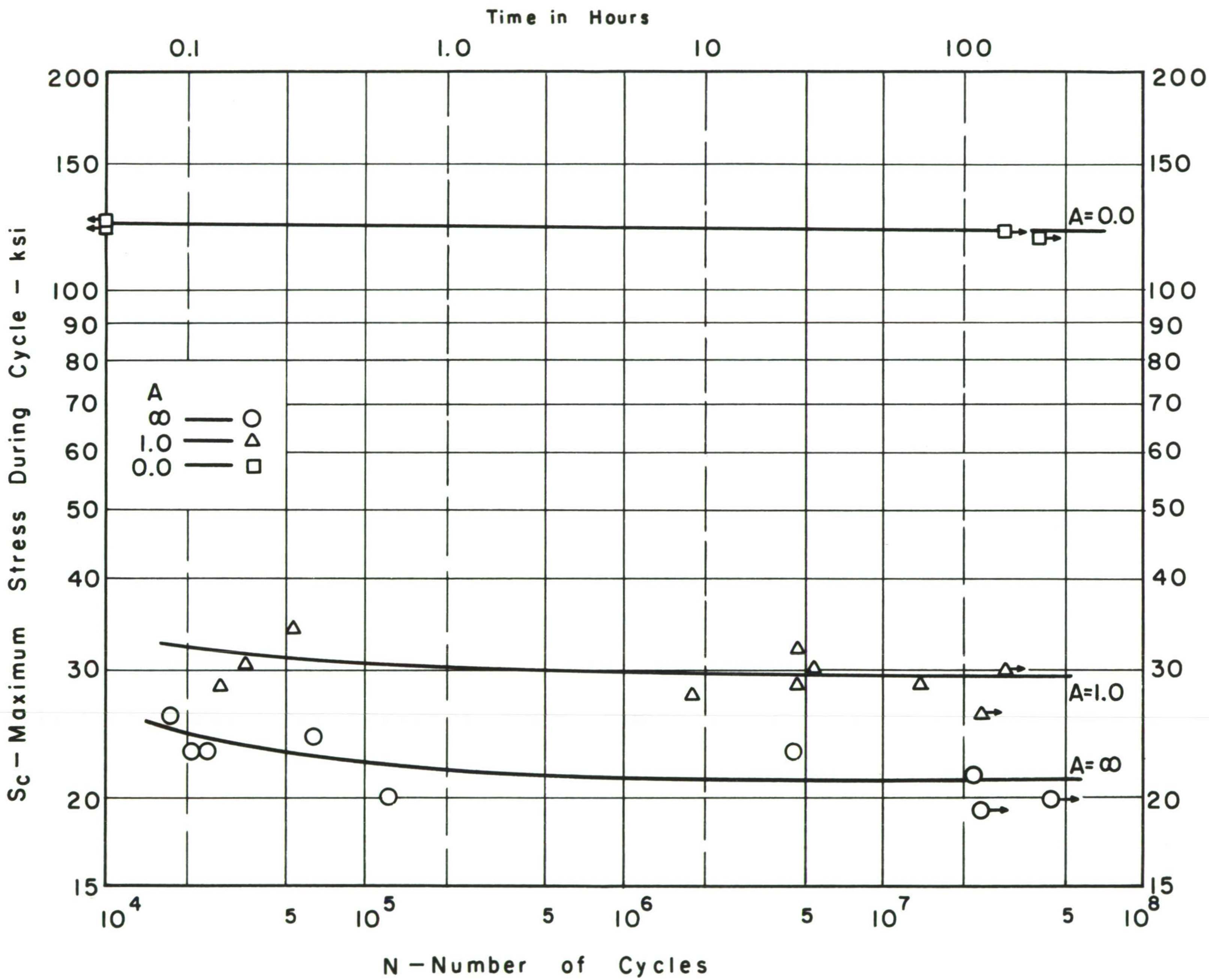

Figure 21 S-N Fatigue and Creep Rupture Diagrams for Notched Specimens of Annealed Sheet at 600°F.

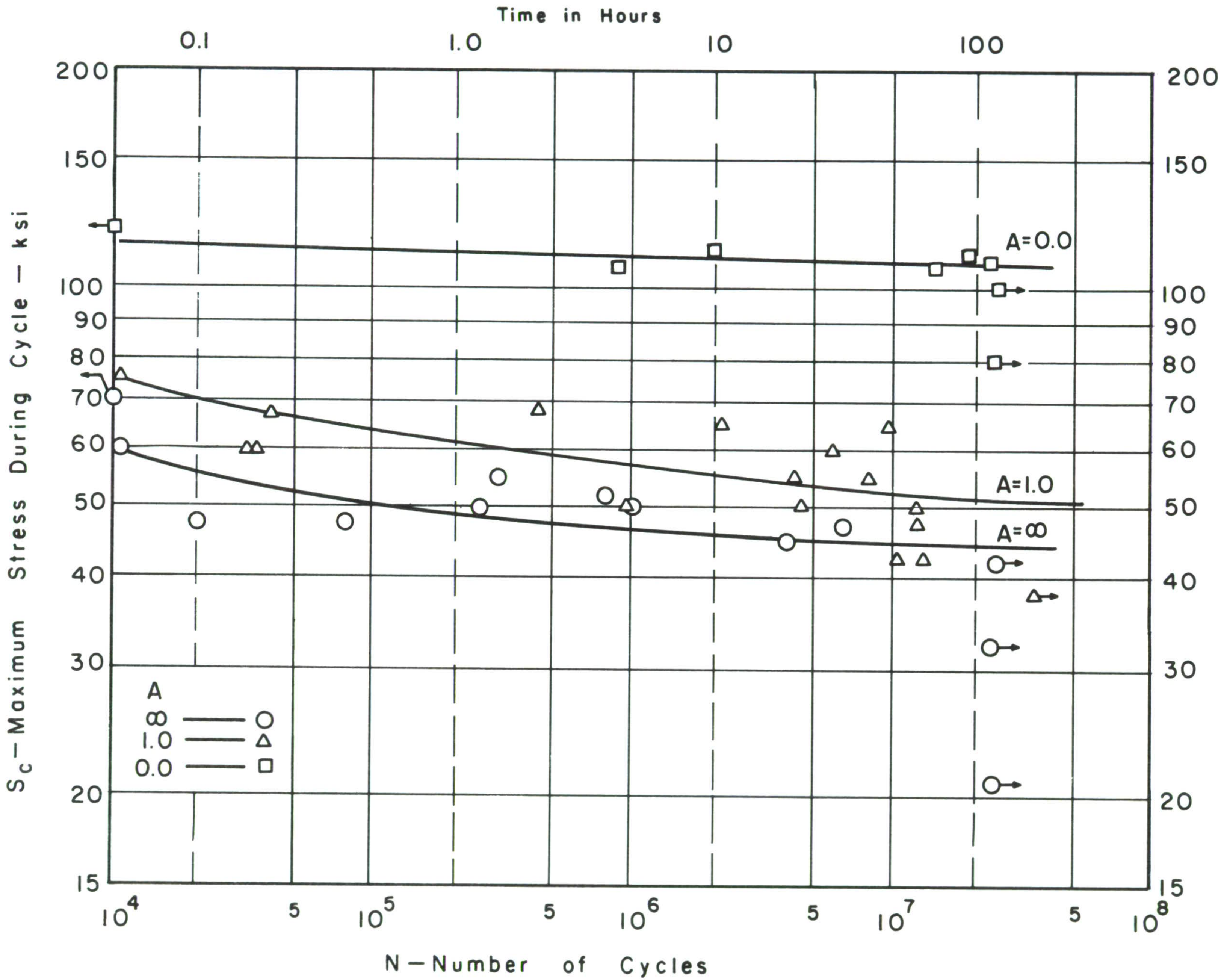

Figure 22 S-N Fatigue and Creep Rupture Diagrams for Unnotched Specimens of Annealed Sheet at 800°F.

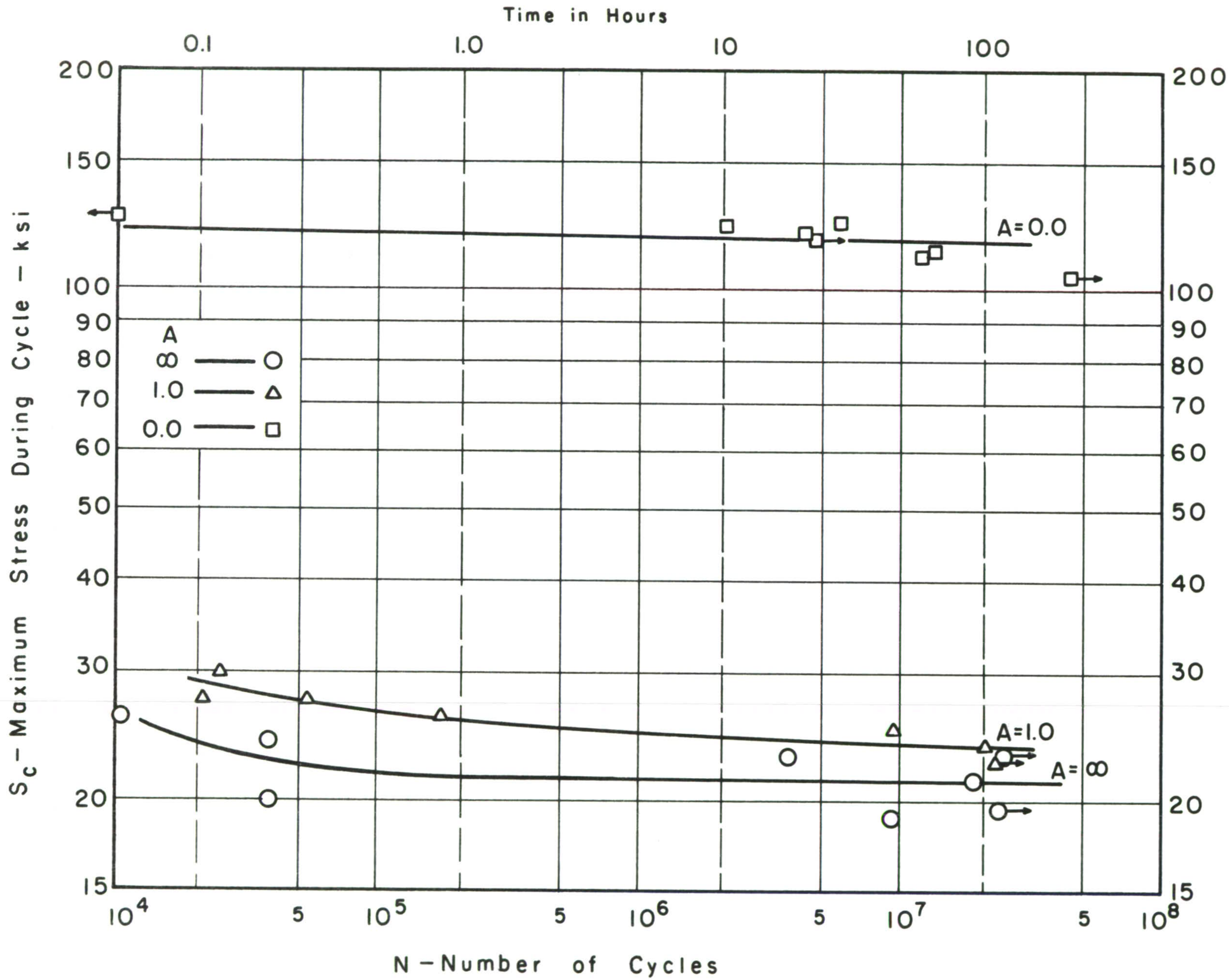

Figure 23 S-N Fatigue and Creep Rupture Diagrams for Notched Specimens of Annealed Sheet at 800°F.

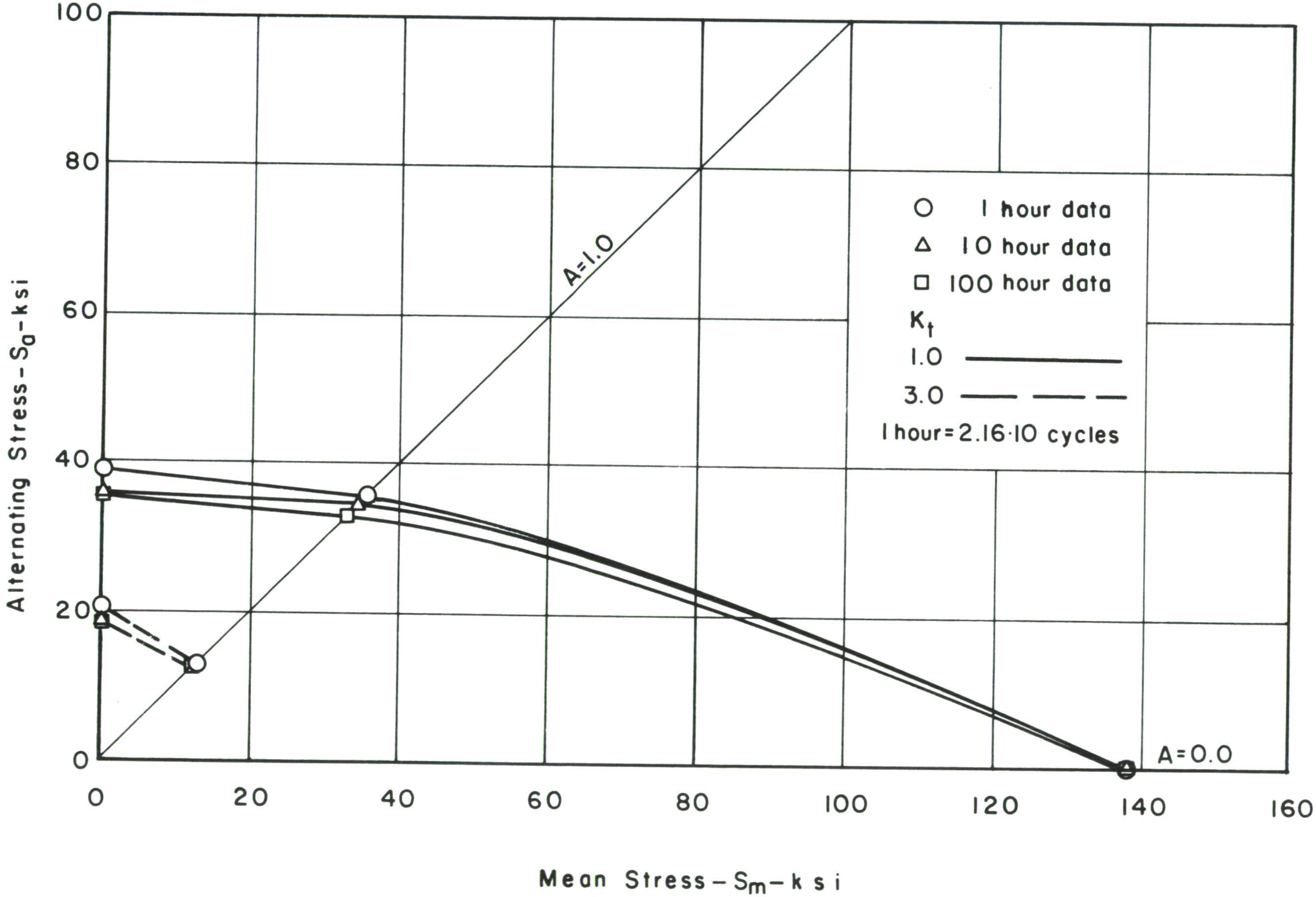

Figure 24 Constant-Life Diagrams for Annealed Sheet at 75°F.

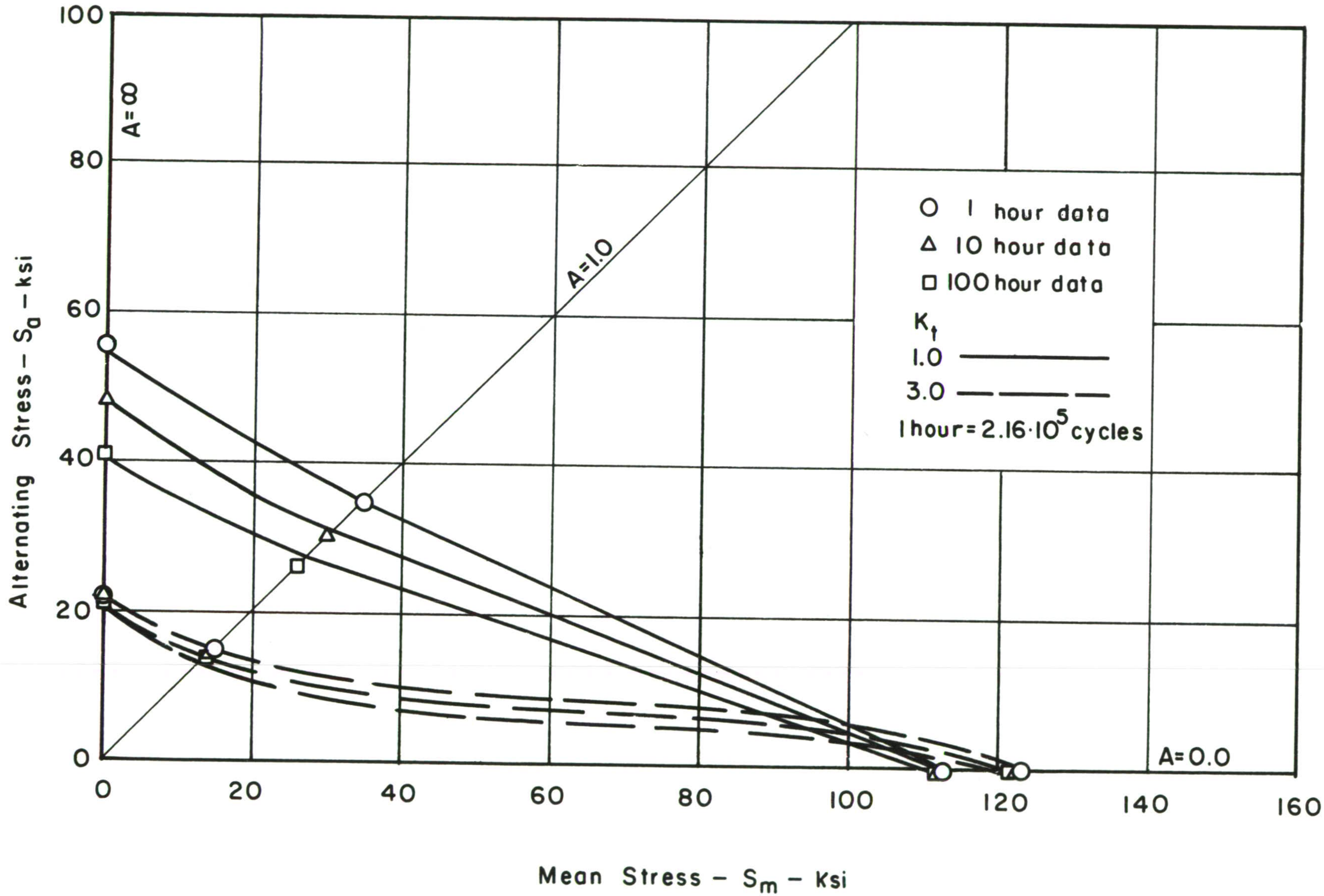

Figure 25 Constant-Life Diagrams for Annealed Sheet at 600°F.

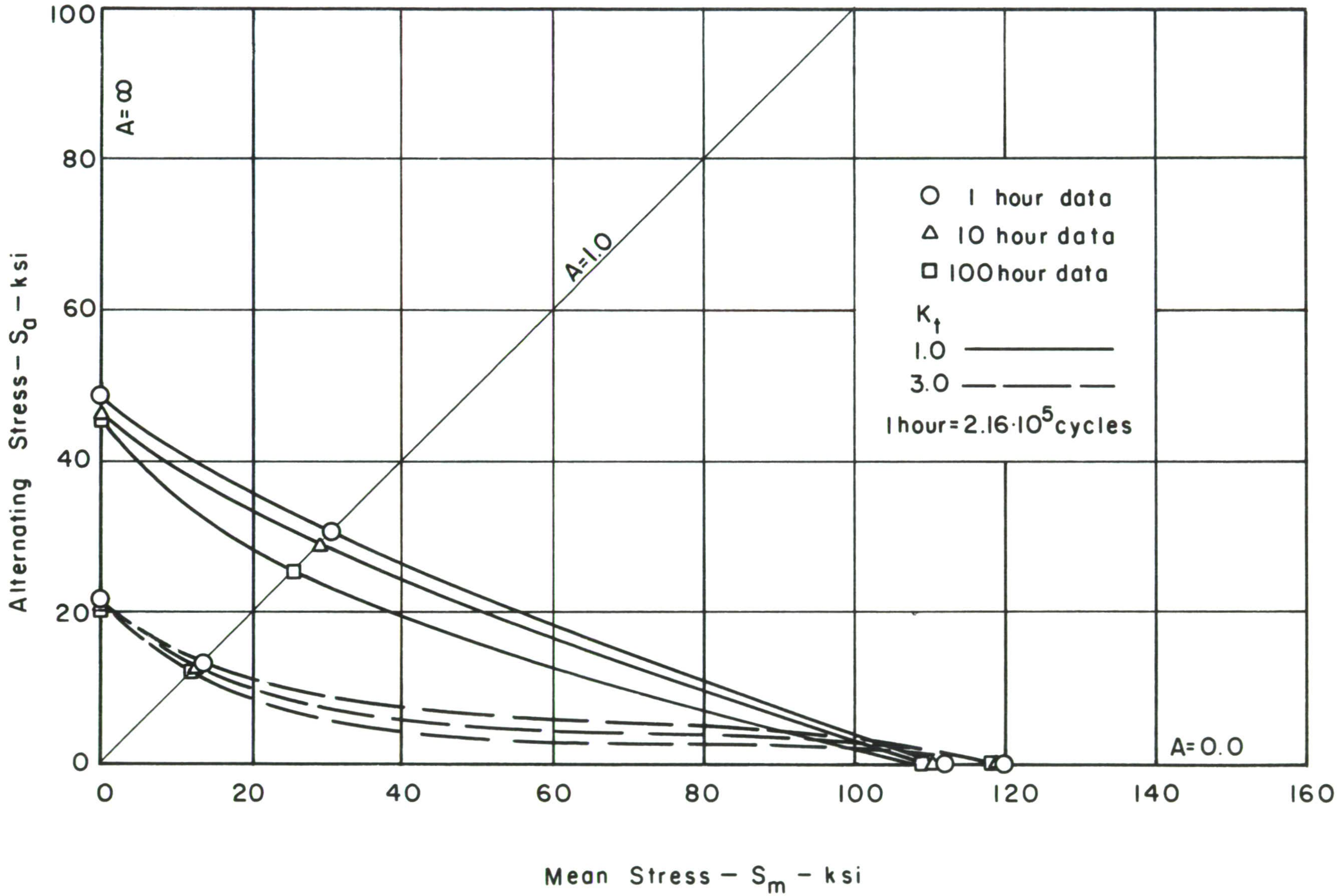

Figure 26 Constant-Life Diagrams for Annealed Sheet at 800°F.

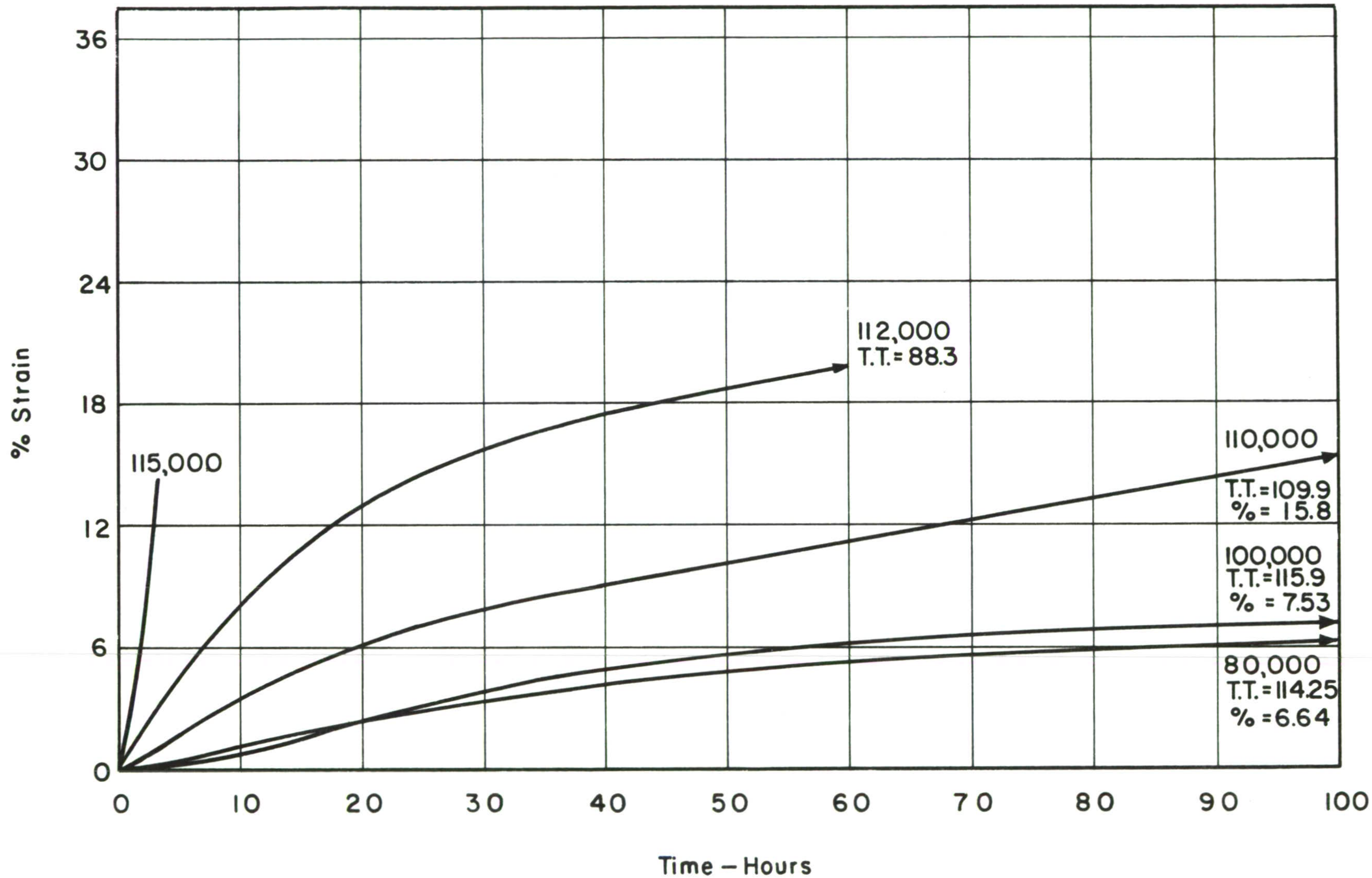

Figure 27 Static Creep Curves for Annealed Sheet at 800°F.

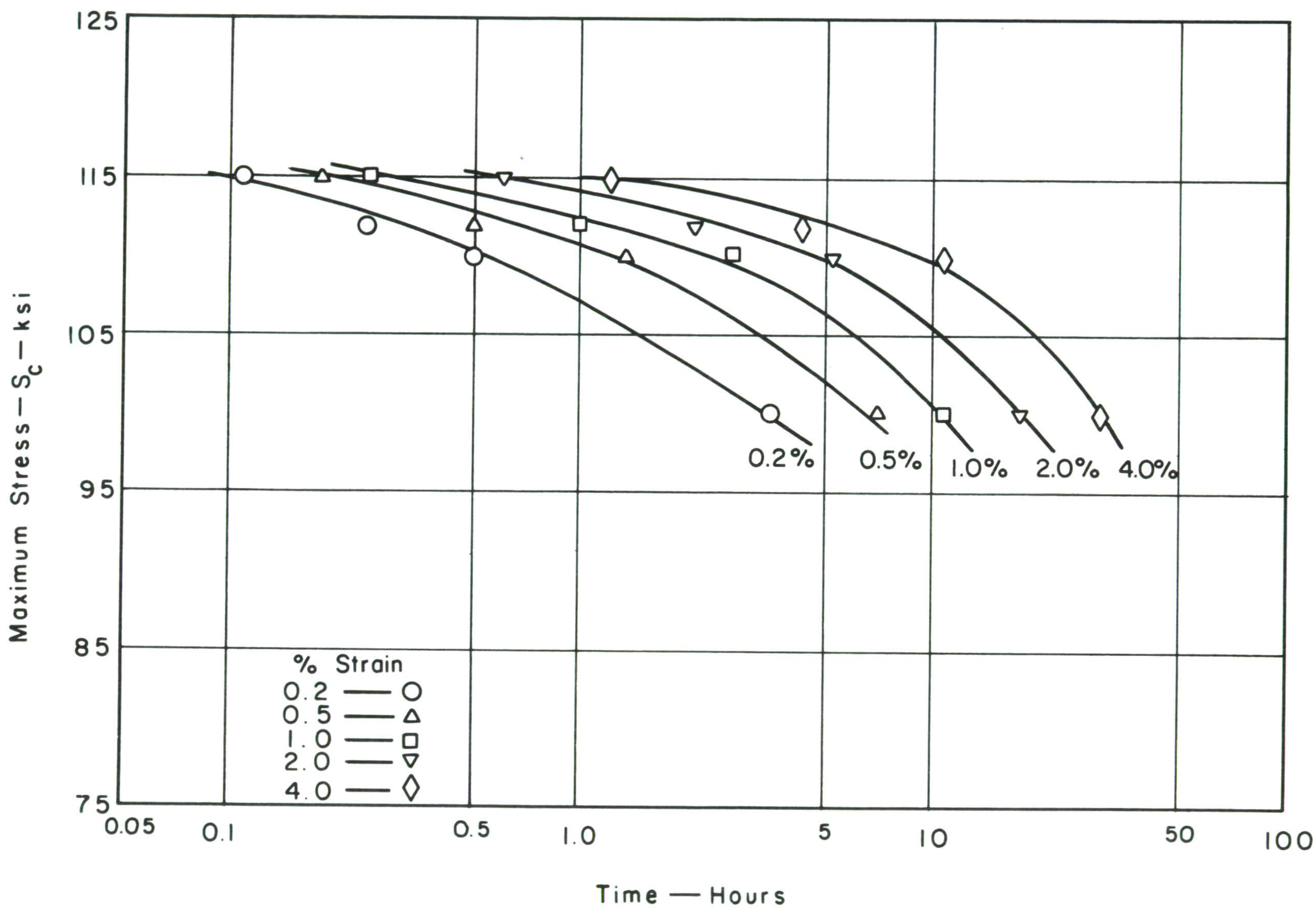

Figure 28 Creep Strength Design Curves for Annealed Sheet at 800°F.

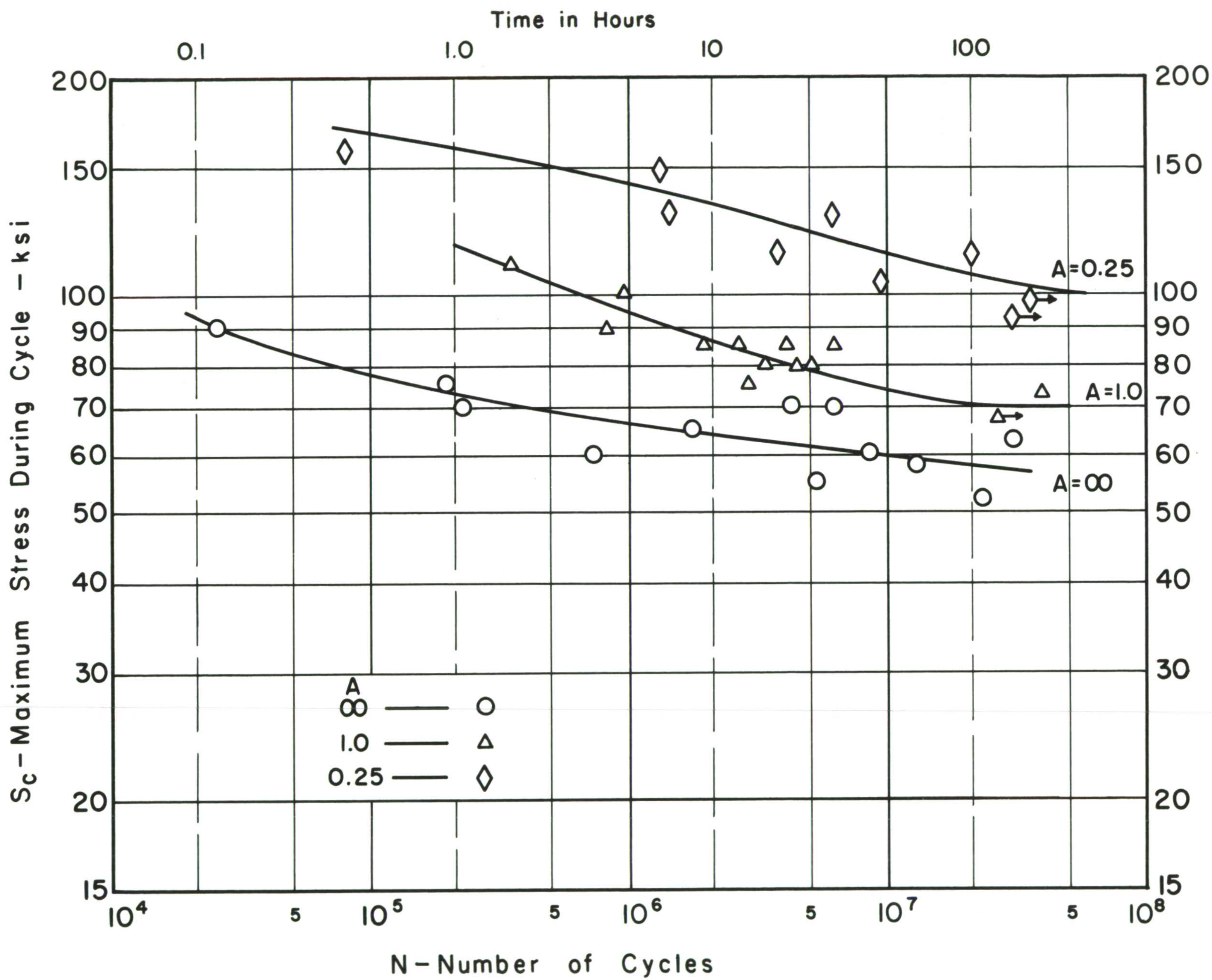

Figure 29 S-N Fatigue Diagrams for Unnotched Specimens of Aged Bar at 75°F.

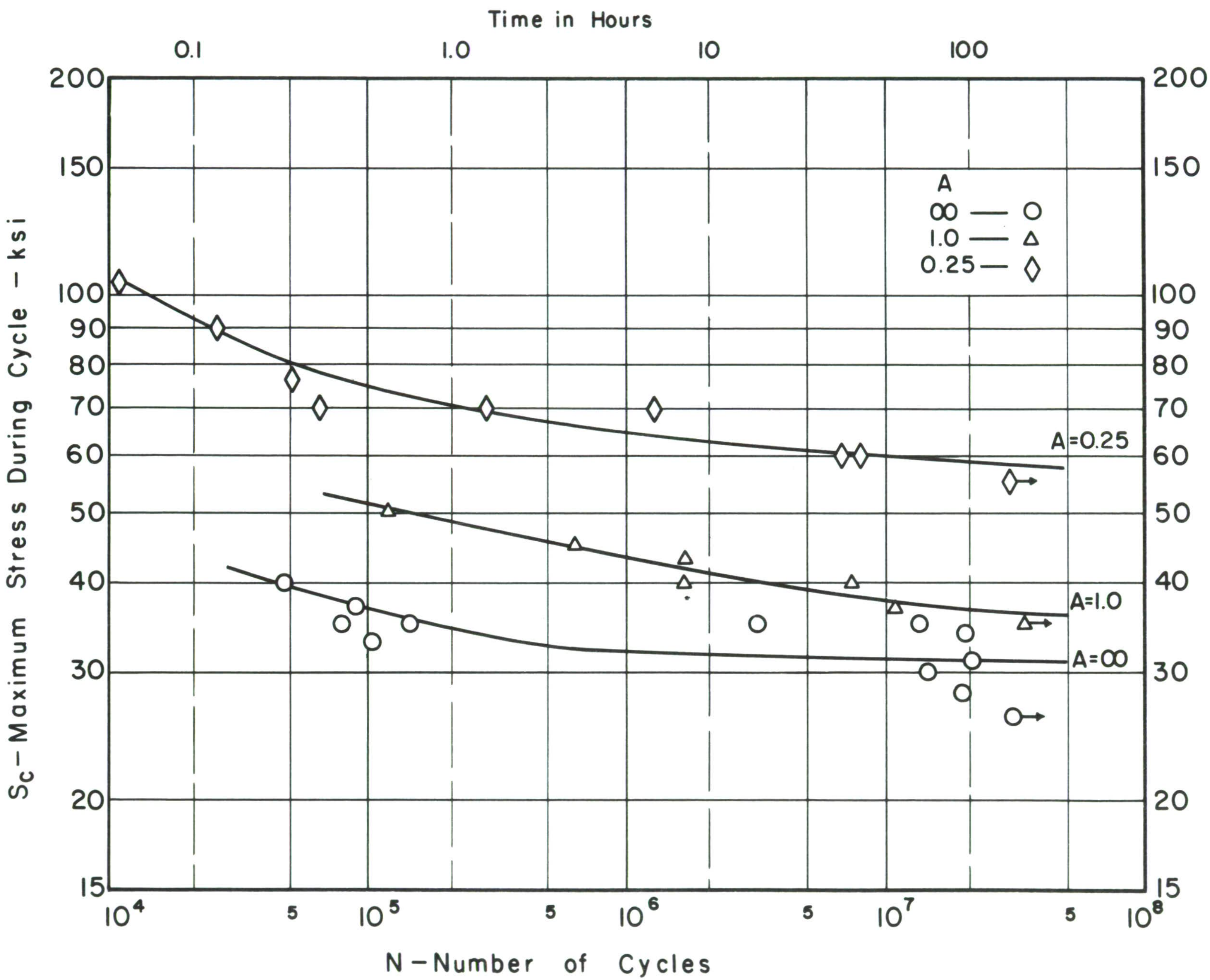

Figure 30 S-N Fatigue Diagrams for Notched Specimens of Aged Bar at 75°F.

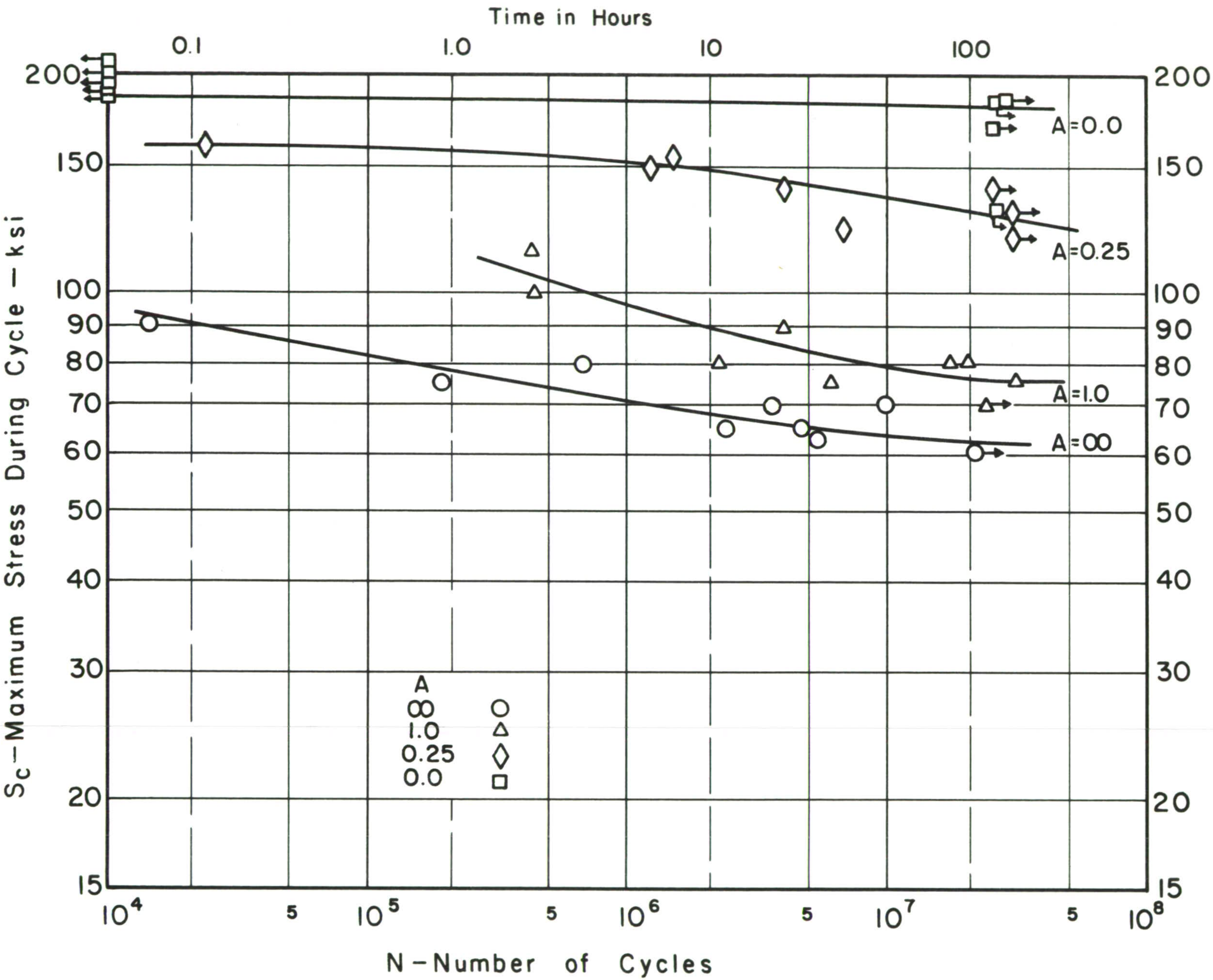

Figure 31 S-N Fatigue and Creep Rupture Diagrams for Unnotched Specimens of Aged Bar at 600°F.

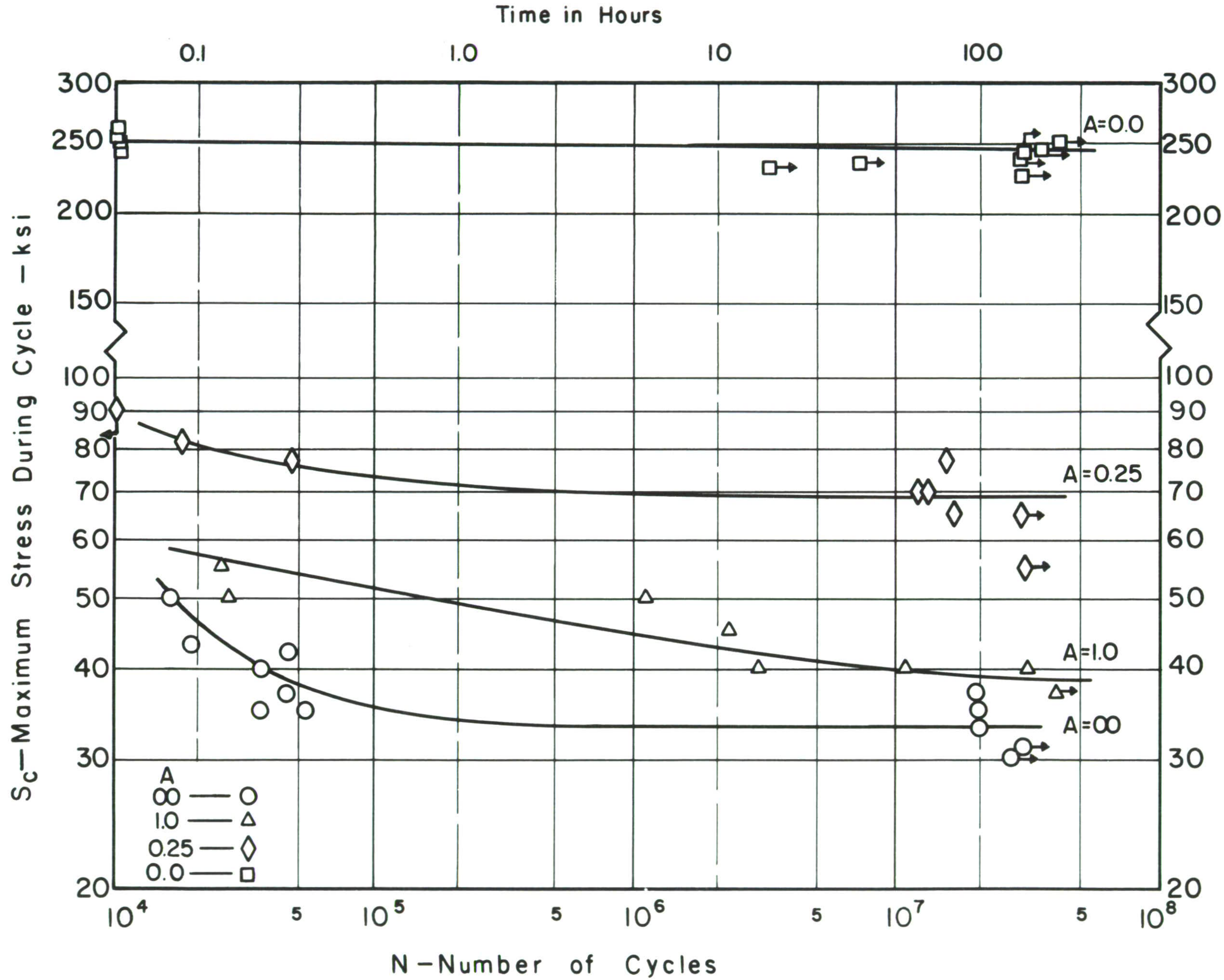

Figure 32 S-N Fatigue and Creep Rupture Diagrams for Notched Specimens of Aged Bar at 600°F.

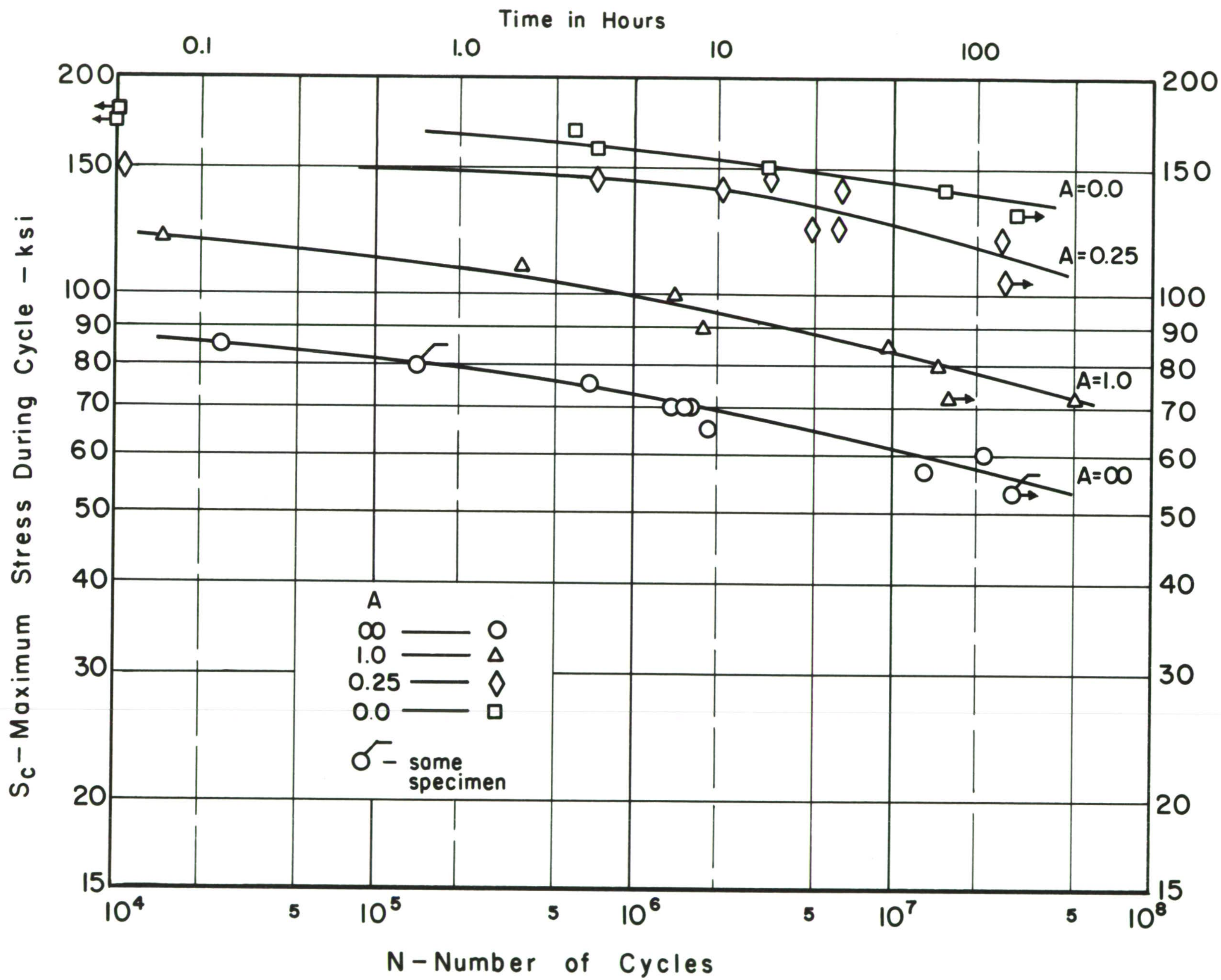

Figure 33 S-N Fatigue and Creep Rupture Diagrams for Unnotched Specimens of Aged Bar at 800°F.

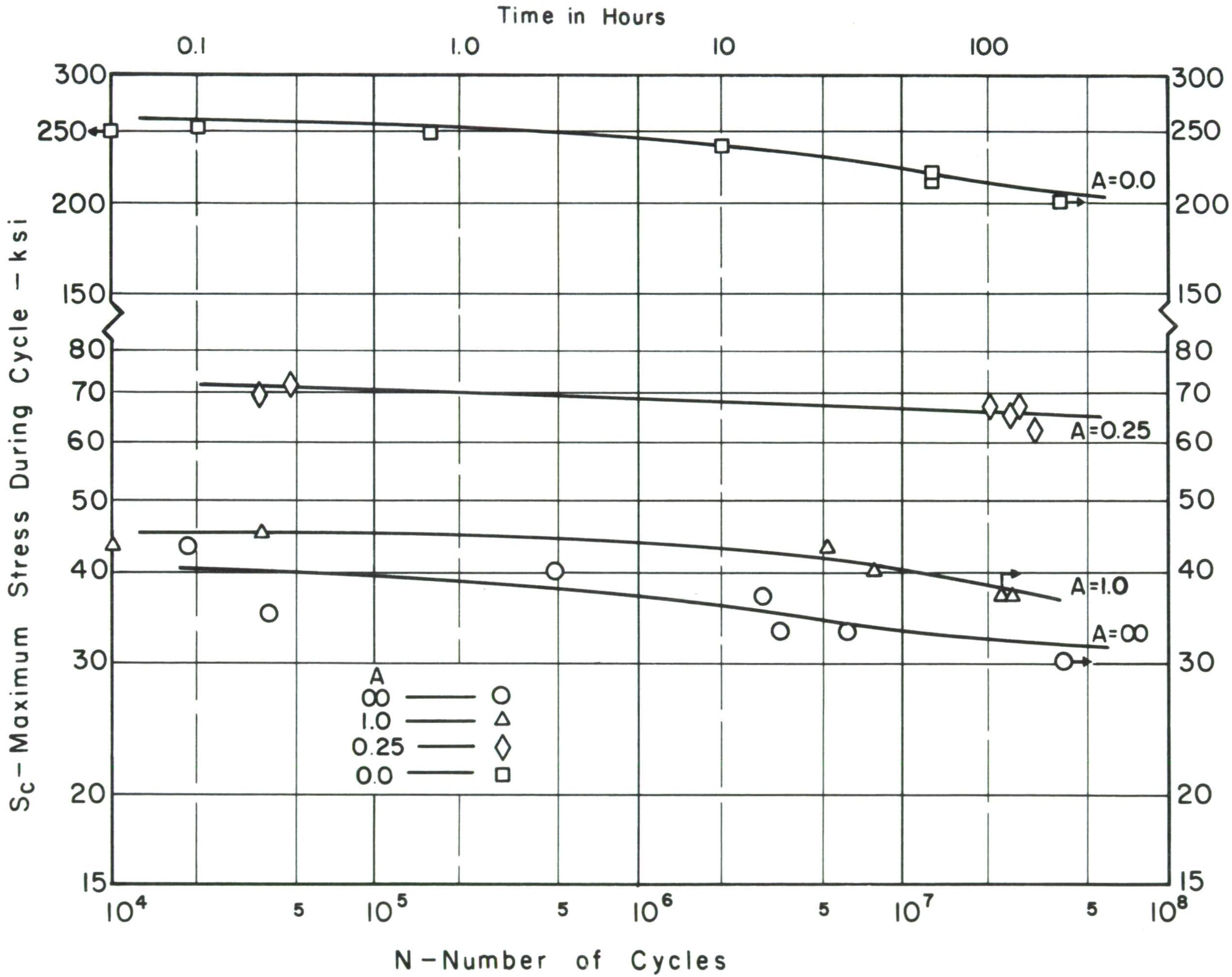

Figure 34 S-N Fatigue and Creep Rupture Diagrams for Notched Specimens of Aged Bar at 800°F.

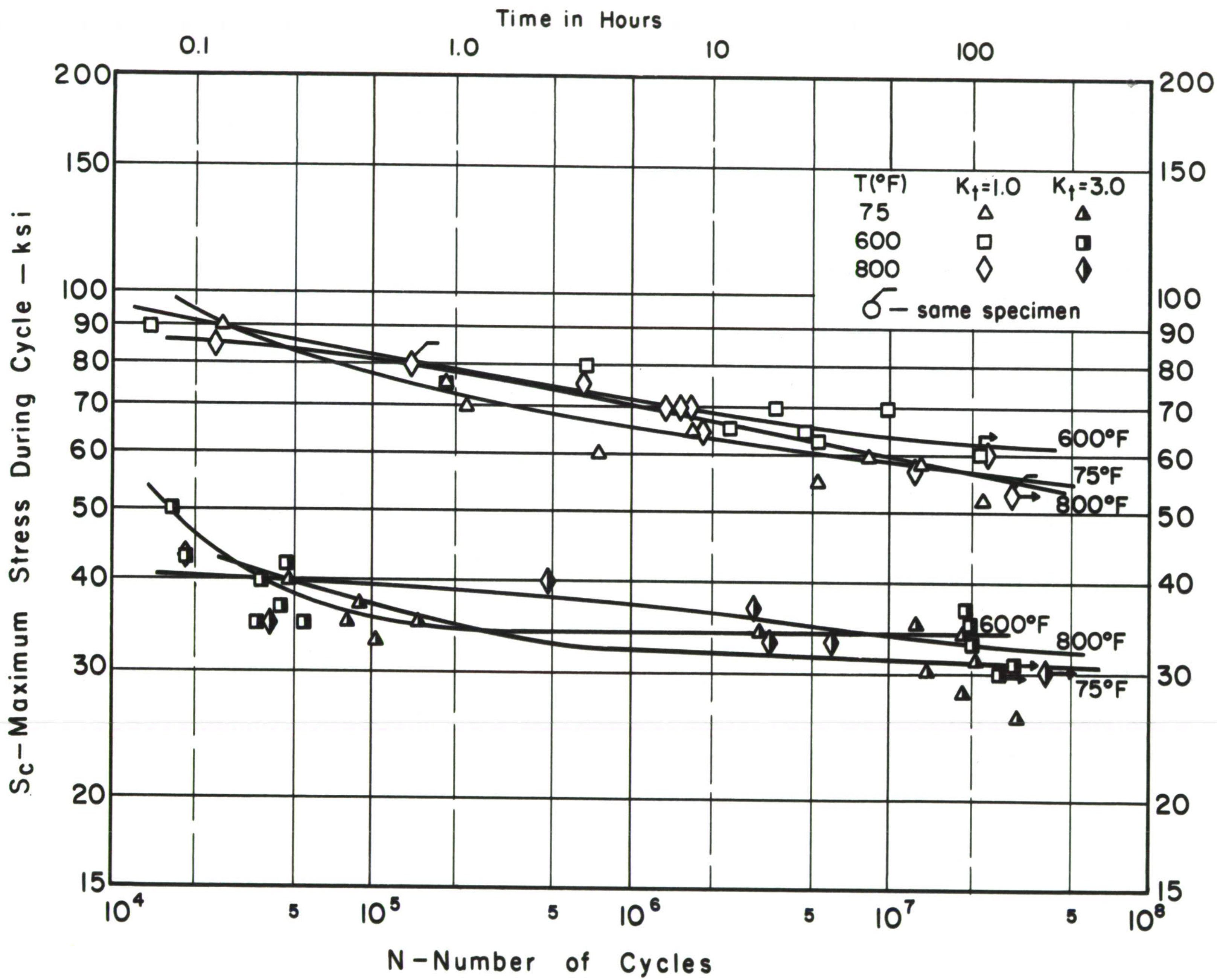

Figure 35 S-N Fatigue Diagrams for Aged Bar at A = ∞ for all Temperatures.

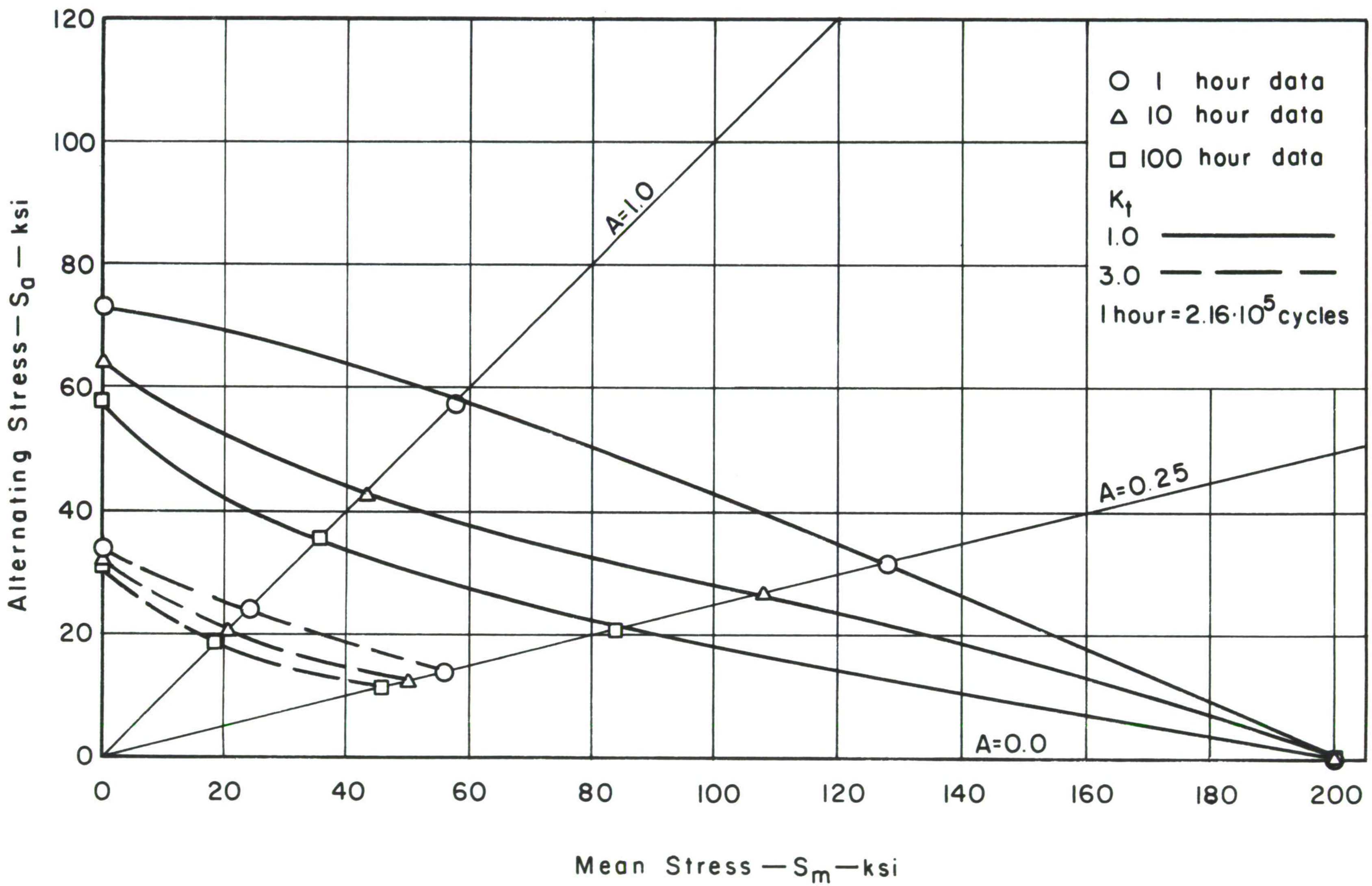

Figure 36 Constant-Life Diagrams for Aged Bar at 75°F.

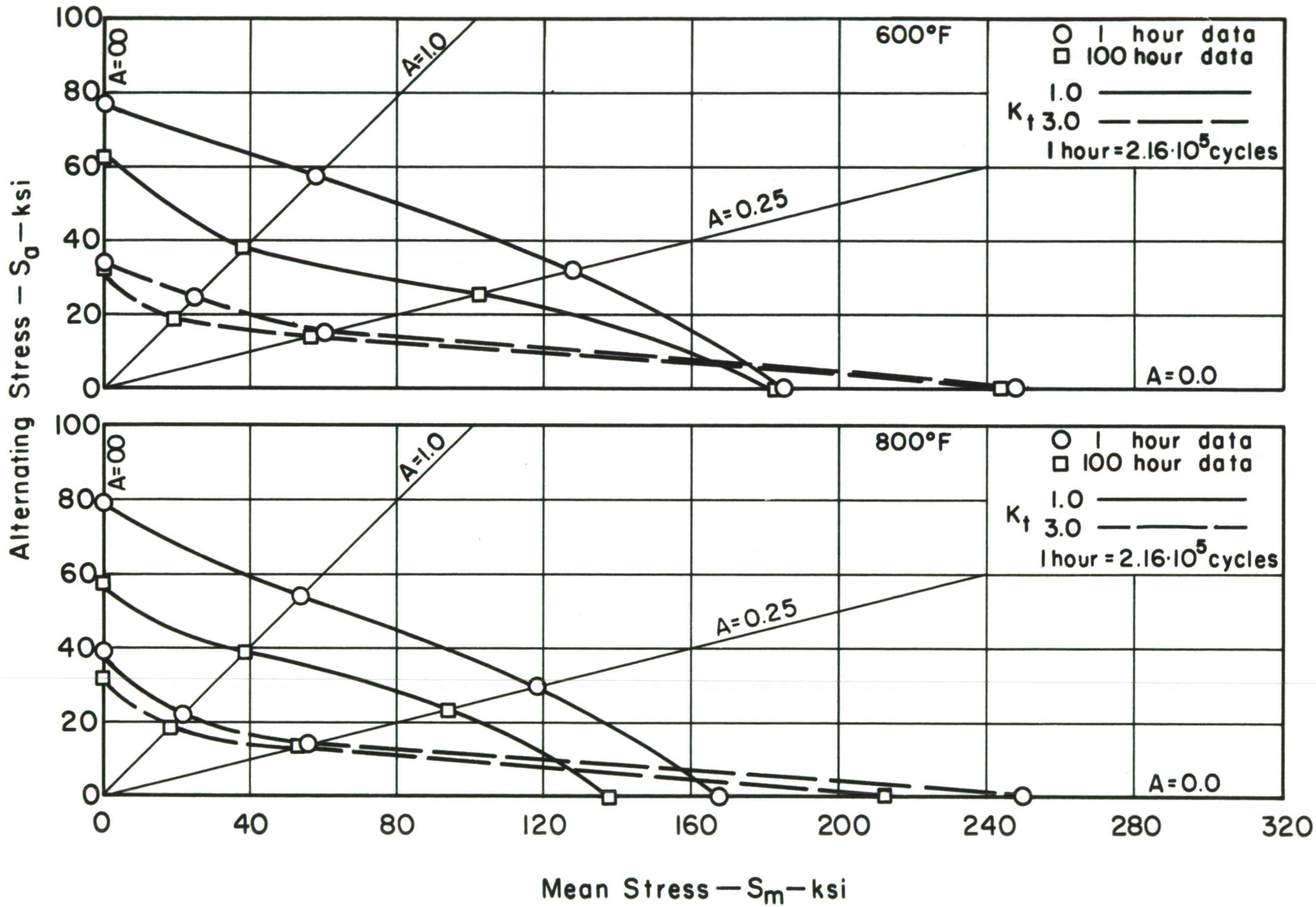

Figure 37 Constant-Life Diagrams for Aged Bar at 600°F and 800°F.

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2b. GROUP

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Air Force Materials Laboratory
Research Technology Division
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13. ABSTRACT

A fatigue and creep-rupture testing program was conducted on solution-treated and aged sheet specimens of titanium alloy B-120VCA at room and elevated temperatures. Data on aged bar stock, previously tested, are also included for comparison. All tests were conducted in axial-stress machines with various combinations of alternating and mean stresses. Notched as well as smooth specimens were used.

The data are presented in the form of S-N and creep rupture diagrams, and the effect of various combinations of alternating and mean stresses is shown by means of constant-life diagrams. Creep data are given in the form of creep-time curves, and for design purposes, creep strength curves are presented.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Fatigue						
Creep						
Titanium Alloy						
Elevated-temperature						
Design data						
Stress rupture						

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