T. & A. M. Report No. 318

EFFECTS OF MEAN STRESS AND PRESTRAIN ON FATIGUE DAMAGE SUMMATION

by

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Sponsored by

Aeronautical Structures Laboratory
Naval Air Engineering Center
Contract No. N00-156-67-C-1875

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Urbana, Illinois

August 1968

ABSTRACT

A cumulative damage procedure based on smooth specimen tests of 2024-T4 aluminum alloy and aircraft quality SAE 4340 steel is formulated in which the effects of prestrain and mean stress on fatigue life are investigated separately. It is assumed that life reductions due to prestrain or mean stress at a given strain level may be separately incorporated into a simple cycle ratio damage summation.

Small plastic prestrains are shown to cause considerable life reductions. Larger prestrains appear to have little additional adverse effect. It was found possible to adequately correlate results with and without mean stress by a parametric representation of mean stress and strain amplitude.

Analysis of arbitrary stress-strain sequences indicates that the proposed damage summation procedure gives adequate life predictions. Cycle ratio summations were close to one for both stress controlled and strain controlled tests in which sequence, number of blocks, fraction of life at mean stress, and the life fraction at which plastic straining occurred were all varied.

ACKNOWLEDGMENT

This investigation was conducted in the H. F. Moore Fracture Research Laboratory of the Department of Theoretical and Applied Mechanics, University of Illinois in cooperation with the Aeronautical Structures Department of the Naval Air Development Center under Contract No. N00-156-67-C-1875.

Messrs. M. S. Rosenfeld and R. E. Vining acted as technical liaison for the Navy and Professors JoDean Morrow and T. J. Dolan furnished administrative guidance and many technical suggestions. Some of the data analyzed was taken from earlier work on mean stress performed by Mr. R. B. Wilson as a part of his MS thesis. Mr. S. Stadnick and Professor T. Endo also furnished test results which are included in this report. Mrs. H. Corray typed the manuscript.

INTRODUCTION

This work is part of a broad research program aimed at predicting the fatigue life of notched spectrum loaded structural components. Analytical methods have been developed for determining the local stress-strain history at the critical location in terms of the geometry of the component, the applied load history, and the stress-strain response of the metal of which the component is made. Fatigue life of the most severely stressed region should be predictable by employing an appropriate cumulative damage procedure and fatigue properties of the metal.

Previous papers reported cyclic stress-strain and fatigue properties of four representative aircraft metals(1) and a method for determining(2) and simulating(3) the non linear stress-strain response of the metal at a notch root. The latter two papers pointed out the problem of evaluating mean stress levels when nominally elastic service loads result in inelastic material behavior at notches. Residual stresses following inelastic straining and hence subsequent mean stresses can be determined only by following the stress-strain history at the stress raiser.

Another paper(4) showed that, if all strain levels are high enough to cause significant repeated plastic straining, mean stresses are rapidly relaxed and damage summations (based on fully reversed constant amplitude strain-life data) are close to one. When large inelastic strain levels are followed by essentially elastic strain levels, however, mean stresses persist at the lower levels and damage values vary significantly from one. Damage values are consistently less than one when the mean stresses are tensile and usually greater than one when they are compressive.

In those cases in which a compressive mean stress is associated with damage values less than one the magnitude of the compressive mean stress is small. The reduced life in the presence of a beneficial compressive mean stress may be due to a deterimental effect of prior plastic straining. If the life reduction due to prestraining exceeds the life increase due to a small compressive mean stress then cycle ratio summations less than unity would be obtained.

A similar observation was made by Manson[5] who shows that fully reversed stressing sequences in which inelastic strain is present in the first level but nearly absent in the second level may give cycle ratio summations below unity. He attributes this effect to the initiation of cracks during the first large strain cycle which propagate at the lower strain level. A considerable fraction of the life is required in a constant amplitude test at the lower level to initiate similar cracks.

Another explanation is that inelastic straining removes beneficial surface compressive stresses induced in the specimens during fabrication. Also, for those materials having a yield point, similar reductions in life for low strain levels may be expected when plastic prestraining eliminates the yield point and softens the material.

All of these explanations suggest that a considerable life reduction at nominally elastic strain levels will result from a moderate amount of prior plastic strain but that the amount of plastic straining is probably not significant.

In this paper an attempt is made to separate the effects of mean stress and prior plastic straining on the life at a subsequent low strain amplitude. The following three test series at constant strain amplitudes serve as a basis for subsequent damage summations. In the first series there was no prior plastic straining and the mean stress was zero. In the second series, plastic straining preceded testing at zero mean stress, and in the third series plastic prestraining was followed by testing at various tensile mean stresses.

A damage summation procedure is developed which includes the effects of strain amplitude, prior plastic deformation and mean stress, and is applied to a variety of arbitrary stress-strain sequences to check its validity.

MATERIAL AND SPECIMENS

A 2024-T4 aluminum alloy and a heat treated condition of aircraft quality SAE 4340 steel were used. The composition and mechanical properties and fatigue response of these materials are given in Ref. 1. The 0.2% offset yield was 44 ksi for the 2024-T4 and 171 ksi for the SAE 4340. Ultimate strengths were 69 ksi for the 2024-T4 and 180 ksi for the SAE 4340. Specimens had a 0.60 in long 0.25 in diameter reduced section.

TEST EQUIPMENT

Testing was done in a closed loop servo controlled axial hydraulic test system. Strains were measured on the test section by a one half inch clip gage. Load and displacement outputs were recorded continuously. Hysteresis loops were plotted on an X-Y recorder at logarithmic cyclic increments.

TEST PROGRAM

The program for testing 2024-T4 aluminum and SAE 4340 steel is outlined below:

Constant Amplitude Strain Control

The following strain controlled tests were used to examine separately the effects of plastic prestrain and mean stress on fatigue life.

1. Fully reversed tests on virgin samples.
2. Tests in which the mean strain was adjusted to give an initial mean stress of zero after initial cyclic plastic straining.
3. Tests in which the mean strain was adjusted to give various initial mean stresses after cyclic plastic deformation.

Stress Controlled Tests

In all stress controlled tests the first application of the mean stress caused plastic straining. These tests were performed on 2024-T4 aluminum only.

1. Constant stress amplitude with a constant mean stress.
2. Constant stress amplitude with a mean stress applied for varying life fractions at the beginning of the test.
3. Constant stress amplitude at zero mean stress for varying life fractions followed by application of a mean stress for the remainder of the test.
4. Varying numbers of blocks, each including fully reversed stressing and cycling about a mean stress level.

Strain Contolled Step Tests

Two level strain controlled step tests with various numbers of blocks were performed. Each block contained inelastic and elastic strain levels resulting in tensile or compressive mean stresses at the lower strain level.

DISCUSSION

Fully reversed constant amplitude strain-life data with and without prior plastic strain for 2024-T4 are given in Table 1 and plotted in Fig. 1. Reduced lives at low strain levels are found for specimens subjected to prior plastic strain. This reduction in life decreases with increasing strain amplitude and becomes insignificant at the level where the elastic and total strain-life curves diverge. At higher strain levels inelastic strain occurs throughout the test and any prior plastic strain has an insignificant effect on life.

Less scatter is observed at all strain levels for prestrained 2024-T4 specimens compared to those in which the strains remained nearly elastic throughout the life. While the curve for virgin samples continues smoothly to a life of ten million cycles, the life curve for specimens with a prior plastic strain abruptly flattens at about three million cycles.

Similar fully reversed constant amplitude strain-life data for SAE 4340 steel with and without prestrain are given in Table 2 and plotted in Fig. 2. As in the case of the aluminum alloy, reduced lives are found at low strain levels for prestrained samples. Again, this reduction in life becomes negligible where the total and elastic strain-life curves diverge and significant repeated plastic strain occurs throughout the test. For the steel, both the curve for prestrained samples and that for virgin samples abruptly flatten at a life of about 300, 000 cycles.

It is of interest to note that the life reduction for specimens prestrained ten cycles at an amplitude of ± 0.02 is no greater than the life reduction for specimens prestrained one cycle at an amplitude of ± 0.01. Both sets of data fall into a single band.

Table 3 lists strain controlled tests with a tensile mean stress for 2024-T4 specimens subjected to previous plastic deformation. The decrease in life with tensile mean stress is shown in Fig. 3. All curves have the same pronounced flattening at long lives as found for zero mean stress tests. In contrast to the behavior found by Landgraf[6] for some steels, the log-log plots of stress amplitude vs life with a mean stress present are not parallel to the curve for zero mean stress.

Data for strain controlled tests with a tensile mean stress of prestrained SAE 4340 specimens are given in Table 4. The reduction in life with tensile mean stress is shown in Fig. 4. The mean stress curves exhibit the same pronounced flattening as found for the zero mean stress curve. As in the case of the aluminum alloy, the SAE 4340 data with a mean stress present are not parallel to the curve for zero mean stress.

Parametric Representation of Mean Stress

Various parameters were investigated in an attempt to correlate the mean stress and fully reversed data. The following equation was found to be reasonably accurate:

$$\frac{\Delta\epsilon^*}{2} = \frac{\Delta\epsilon}{2} + \frac{\sigma_o^\alpha}{E} \qquad \text{------------------} \qquad (1)$$

or for elastic material behavior:

$$\frac{\Delta\sigma^*}{2} = \frac{\Delta\sigma}{2} + \sigma_o^\alpha \qquad \text{-----------------} \qquad (1a)$$

where $\Delta\epsilon^*/2$ is the "equivalent completely reversed strain amplitude" or the fully reversed strain amplitude which would give the same life as a strain amplitude, $\Delta\epsilon/2$, coexisting with a mean stress, σ_o. Similarly, $\Delta\sigma^*/2$ is an "equivalent fully reversed stress amplitude" for a combination of a stress amplitude, $\Delta\sigma/2$, and a mean stress, σ_o. The exponent, α, is approximately equal to 0.73 for 2024-T4 aluminum and 0.89 for SAE 4340 steel.

Mean stress data from Fig. 3 are replotted on the basis of Eq. (1) in Fig. 5a for 2024-T4 aluminum. The line reproduces curve B of Figs. 1 and 3 for zero mean stress. Equation (1) adequately superimposes the mean stress data on this curve for lives below one million cycles. At longer lives where the curves flatten, Eq. (1) is conservative, especially for the highest mean stress.

Similar mean stress data for SAE 4340 steel from Fig. 4 are replotted in Fig. 6 on the basis of Eq. (1). The solid line reproduces the curve from Fig. 4 for overstrained specimens at zero mean stress. Equation (1) shows good agreement at all lives.

Damage Summation

The following damage summation technique is based on the preceding strain controlled tests and Eq. (1). In subsequent analyses, Eq. (1) is applied to both tensile and compressive mean stresses.

1. Damage is taken as the sum of cycle rations, $\Sigma n_i/N_{fi}$, wnere n_i is the number of cycles at a given strain amplitude and mean stress level and N_{fi} is the life to failure for the same combination of strain amplitude and mean stress.
2. All strain cycles prior to plastic straining are evaluated using the strain-life curve for virgin specimens.
3. All strain cycles subsequent to plastic straining are evaluated using the strain-life curve for specimens with a prior plastic strain.
4. For cycles having a mean stress the "equivalent strain amplitude," $\Delta\epsilon^*/2$, given by Eq. (1) is used in place of $\Delta\epsilon/2$ in evaluating N_{fi}.

Application of Damage Summation

Table 5 and Fig. 5b show a comparison of lives predicted by Eq. (1) and actual lives for stress controlled mean stress tests of 2024-T4 aluminum. In spite of mean strains that varied between 0.012 and 0.116, agreement is excellent for both tensile and compressive mean stresses. There is no apparent trend in damage values with the degree of prior plastic straining.

Table 6 lists damage values computed for stress controlled tests on 2024-T4 aluminum. The order of application of mean stress, the fraction of life at a mean stress and the number of blocks are all varied. In each case the damage values are close to one for both tensile and compressive mean stresses. No significant trends are evident to suggest that any of the variables cause damage values to vary significantly from unity. Equation (1) appears to be equally applicable to tensile and compressive mean stresses.

Damage values computed for step strain controlled tests of 2024-T4 giving rise to compressive and tensile mean stresses are given in Table 7. The strain levels at which mean stresses persist are nominally elastic. Mean stresses rapidly relaxed at higher strain levels and their effect at these levels was ignored. Damage values are close to one for both tensile and compressive mean stresses.

Similar step strain controlled tests on SAE 4340 are reported in Table 8. Again, damage values are close to unity despite variations in sequence and number of blocks.

CONCLUSIONS

In the approach used in this investigation the effects of prestrain and mean stress on strain-life behavior have been treated separately. The following conclusions may be drawn from this study:

1. Inelastic prestraining significantly reduces the life at nominally elastic strain levels but not at strain levels causing repeated plastic strain.
2. Within the limits investigated, the amount of plastic prestrain is not significant.
3. Effects of tensile and compressive mean stresses can be adequately represented by an empirical equation.
4. The damage summation procedure outlined adequately predicts fatigue life for all stress-strain sequences examined.

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6. R. W. Landgraf, "Effect of Mean Stress on the Fatigue Behavior of a Hard Steel," M.S. Thesis, Department of Theoretical and Applied Mechanics, 1966. See also, T&AM Report No. 662, University of Illinois, January 1966, pp. 9.

TABLE 1

STRAIN CONTROLLED TESTS ON 2024-T4 ALUMINUM

$\Delta\epsilon/2$	$\Delta\sigma/2$ ksi	N_f
Tests without prior plastic strain		
0.411	92.9	0.5
0.150	85.5	1.1
0.0725	88.5	5
0.0445	86.0	14
0.029	81.0	45
0.0182	76.0	142
0.0122	68.0	310
0.0082	64.5	1000
0.00560	57	4,200
0.00519	53.4	6,400
0.00516	53.1	8,000
0.00490	50.4	8,300
0.00465	49.0	12,400
0.00448	46.1	24,200
0.00437	45.0	25,500
0.00433	44.5	33,000
0.00417	42.9	35,000
0.00411	42.3	51,000
0.00395	40.8	53,000
0.00382	39.3	74,000
0.00365	37.6	86,000
0.00355	36.5	117,000
0.00373	38.4	131,000
0.00321	33.0	172,000
0.00297	30.6	309,000
0.00281	28.9	330,000
0.00296	30.5	430,000
0.00304	31.3	610,000
0.00299	30.8	1,850,000
0.00247	25.4	2,276,000
0.00214	22.0	9,000,000

Table 1 continued

$\Delta\epsilon/2$	$\Delta\sigma/2$ ksi	N_f
Specimens strained 10 cycles at $\Delta\epsilon/2 = \pm 0.02$ prior to testing		
0.00505	49.0	9,500
0.00385	39.8	34,300
0.00380	39.6	38,500
0.00290	30.0	196,000
0.00240	24.8	478,000
0.00192	19.8	1,836,000
0.00170	17.5	9,030,000
0.00150	15.5	21,000,000

TABLE 2

STRAIN CONTROLLED TESTS ON SAE 4340 STEEL

Tests without prior plastic strain

$\Delta\epsilon/2$	$\Delta\sigma/2$	N_f	
0.120	204	10	
0.080	185	17	
0.070		19	
0.040		66	
0.045	178	74	
0.029	162	167	
0.0120	136	477	
0.0105	128	957	
0.0100	135	900	
0.0100		958	
0.0096		1,600	
0.0058		5,300	
0.0050	120	6,500	
0.0049	111	5,360	
0.0040		16,500	
0.0040	112	17,500	
0.0035	105	36,000	
0.0032	82	64,600	
0.0030	90	1,050,000	
0.0025	75	5,000,000	unbroken
Specimens strained 10 cycles at $\Delta\epsilon/2 = \pm 0.02$ prior to testing			
0.0040	94	18,500	
0.0030	82	93,000	
0.00275	78.5	142,000	
0.0025	70	10,250,000	unbroken
Specimens strained 1 cycle at $\Delta\epsilon/2 = \pm 0.01$ prior to testing			
0.0040	100	14,000	
0.0030	85	75,000	
0.0025	75	1,200,000	
0.0020	60	5,000,000	unbroken

TABLE 3

STRAIN CONTROLLED MEAN STRESS TESTS ON 2024-T4 ALUMINUM ALLOY

Note: All specimens were strained 10 cycles at $\Delta\epsilon/2 = \pm 0.02$ prior to testing

Tensile Mean Stress

$\Delta\epsilon/2$	$\Delta\sigma/2$ ksi	σ_o ksi	N_f	
0.00345	35.5	10.4	37,800	
0.00232	23.9	10.4	244,600	
0.00172	17.7	10.4	760,000	
0.00149	15.3	10.3	11,750,000	
0.00410	42.2	20.6	11,000	
0.00303	31.2	20.4	30,000	
0.00254	26.2	20.9	58,500	
0.00198	20.8	20.8	158,000	
0.00148	15.2	20.6	437,100	
0.00121	12.4	20.9	820,000	
0.00112	11.5	20.8	16,600,000	unbroken
0.00101	10.4	20.8	13,600,000	"
0.00250	25.8	42.4	27,700	
0.00149	15.4	42.4	200,000	
0.00149	11.1	41.6	747,000	
0.00101	10.4	41.6	8,235,000	

TABLE 4

STRAIN CONTROLLED MEAN STRESS TESTS ON SAE 4340 STEEL

Note: All specimens were strained 10 cycles at $\Delta\epsilon/2 = \pm 0.02$ prior to testing

Tensile Mean Stress

$\Delta\epsilon/2$	$\Delta\sigma/2$ ksi	σ_o ksi	N_f	
0.0030	81	51	17,000	
0.0025	70.5	51	30,000	
0.00235	68.5	51	36,500	
0.0022	61	51	110,500	
0.0019	54	51	70,800	
0.0019	54	51	91,000	
0.0017	49	51	248,000	
0.0015	45	51	1,200,000	
0.0014	41.5	51	502,000	
0.00125	37.5	51	424,000	
0.0010	30	51	15,500,000	unbroken
0.0030	83.5	21	27,000	
0.0025	71	21	62,000	
0.0022	60.5	21	165,000	
0.0020	58	21	1,640,000	

TABLE 5

STRESS CONTROLLED MEAN STRESS TESTS

Mean Strain	$\Delta\sigma/2$ ksi	σ_o ksi	$\Delta\epsilon^*/2$	N_f	Fraction of Expected Life (Eq. 1)
Constant Tensile Mean Stress					
0.086	48.8	22.2	0.00567	5,100	1.09
0.077	48.4	22.0	0.00561	5,100	1.02
0.116	51.1	23.3	0.00593	5,400	1.46
0.116	49.1	22.3	0.00560	6,200	1.24
0.062	42.0	22.1	0.00500	9,600	1.01
0.050	40.3	23.8	0.00498	12,300	1.29
0.025	41.5	10.4	0.00456	17,500	1.14
0.027	37.9	21.0	0.00457	19,100	1.25
0.024	34.4	20.8	0.00423	20,200	0.86
0.020	37.3	22.0	0.00454	21,800	1.38
0.012	34.6	10.2	0.00389	34,100	1.00
0.019	25.0	25.0	0.00342	35,800	0.48
0.025	34.4	17.7	0.00412	36,600	1.35
0.038	26.7	26.7	0.00366	36,700	0.58
0.020	29.4	21.1	0.00375	48,000	1.07
0.030	20.7	31.1	0.00321	85,000	0.81
0.024	17.0	33.8	0.00298	144,000	0.80
0.021	16.7	33.4	0.00288	201,000	1.00
				ave.	1.09
Constant Compressive Mean Stress					
0.045	43.6	19.8	0.00338	54,400	0.66
0.061	42.4	19.2	0.00328	108,000	1.12
0.096	41.1	18.7	0.00316	127,000	1.08
0.043	39.6	19.8	0.00298	146,000	0.96
0.016	36.6	10.2	0.00302	160,000	1.07
0.033	35.8	16.0	0.00274	267,000	1.03
0.024	36.1	16.1	0.00277	419,000	1.75
0.032	35.8	15.9	0.00275	507,000	2.05
				ave.	1.20

TABLE 6

STEP MEAN STRESS TESTS ON 2024-T4 ALUMINUM ALLOY

No. of Blocks	$\Delta\sigma_1/2$ ksi	σ_o ksi	n_1 per Block	$\Delta\sigma_2/2$ ksi	σ_o ksi	n_2 per Block	Damage $\Sigma n_i/N_{fi}$ (Eq. 1)
(a) Tensile Mean Stress							
hi-lo sequence varying fraction of life at mean stress							
1	42.9	21.0	1	42.9	0	31,000	1.24
"	42.6	21.6	10	42.6	0	36,000	1.33
"	41.2	21.1	300	42.3	0	35,000	1.28
"	40.3	20.2	1000	40.3	0	38,000	1.10
"	43.3	22.0	2000	44.0	0	19,900	1.10
"	43.0	22.0	4000	43.0	0	24,600	1.41
"	42.3	21.7	5000	42.2	0	8,400	0.74
"	41.8	21.4	7000	42.0	0	10,100	0.97
"	40.8	22.3	8000	40.8	0	26,200	1.42
"	37.6	20.9	10,000	38.0	0	33,000	1.13
						ave.	1.17
lo-hi sequence varying fraction of life at mean stress							
1	42.0	0	100	43.0	20.8	10,500	1.05
"	41.6	0	1000	41.9	20.5	11,000	1.00
"	45.9	0	5000	48.2	22.0	3,700	0.79
"	42.2	0	10,000	41.5	20.5	12,000	1.25
"	44.9	0	15,000	46.4	21.0	1,200	0.68
"	39.7	0	25,000	40.5	21.2	6,500	0.86
"	41.8	0	25,000	42.0	20.2	5,900	1.03
"	37.7	0	30,000	38.0	21.1	12,900	1.13
						ave.	0.99
lo-hi sequence varying number of blocks							
3	42.1	0	4000	42.1	22.4	4000	1.08
4	42.7	0	5000	40.0	20.0	1	0.55
4	43.4	0	4000	43.4	22.8	1000	1.00
6	41.7	0	4000	41.7	21.3	1000	1.18
6	41.5	0	5000	41.8	20.9	2	0.93
7	43.7	0	4000	44.3	22.9	2	1.16
7	41.5	0	5000	41.5	21.3	1	0.90
9	42.5	0	3000	42.5	22.4	100	1.04

Table 6 Continued

No. of Blocks	$\Delta\sigma_1/2$ ksi	σ_o ksi	n_1 per Block	$\Delta\sigma_2/2$ ksi	σ_o ksi	n_2 per Block	Damage $\Sigma n_i/N_{fi}$ (Eq. 1)
26	43.1	0	680	43.1	22.8	10	0.72
32	40.5	0	680	40.5	19.8	100	0.88
37	42.1	0	680	42.1	21.6	10	0.92
133	41.7	0	170	41.7	20.3	3	0.83
295	42.5	0	70	42.5	20.3	1	0.80
342	40.8	0	70	40.8	18.8	1	0.73
							ave. 0.91

(b) Compressive Mean Stress

No. of Blocks	$\Delta\sigma_1/2$ ksi	σ_o ksi	n_1 per Block	$\Delta\sigma_2/2$ ksi	σ_o ksi	n_2 per Block	Damage $\Sigma n_i/N_{fi}$ (Eq. 1)
1	44.7	0	15,000	42.3	19.3	52,900	1.05
1	43.9	18.0	50,000	43.9	0	1,880	0.78
2	43.4	19.7	15,000	43.4	0	4,500	0.78
5	41.7	0	10,000	41.7	20.3	10	1.43
34	41.5	0	680	41.5	14.7	10	0.89
							ave. 0.99

TABLE 7

STRAIN CONTROLLED STEP TESTS

No. of Blocks and Sequence	$\Delta\epsilon_1/2$	σ_{o_1} ksi	n_1 per Block	$\Delta\epsilon_2/2$	σ_{o_2} ksi	n_2 per Block	Damage $\Sigma n_i/N_{fi}$ (Eq. 1)
(a) Tensile Mean Stress							
150 lo-hi	0.0054	4	17	0.0102	0	1	0.90
121 lo-hi	0.0046	7	17	0.0100	0	1	0.44
6 hi-lo	0.0102	0	50	0.0050	7	850	1.21
4 hi-10	0.0110	0	50	0.0052	3	850	1.05
3 hi-lo	0.0100	0	50	0.0034	17	5000	0.83
						ave.	0.89
(b) Compressive Mean Stress							
6 hi-lo	0.0104	0	50	0.0050	6	850	0.77
6 hi-lo	0.0102	0	50	0.0035	17	5000	0.63
8 hi-lo	0.0097	0	50	0.0049	15	850	0.94
5 lo-hi	0.0051	9	850	0.0099	0	50	0.70
11 hi-lo	0.0100	0	50	0.0036	30	500	1.02
8 lo-hi	0.0034	29	500	0.0095	0	50	0.71
						ave.	0.80

TABLE 8

STRAIN CONTROLLED STEP TESTS ON SAE 4340 STEEL

No. of Blocks and Sequence	$\Delta\epsilon/2$	σ_{o_1} ksi	n_1 per Block	$\Delta\epsilon/2$	σ_{o_2} ksi	n_2 per Block	Damage $\Sigma n_i/N_{fi}$ (Eq. 1)
<u>Tensile Mean Stress</u>							
1 hi-lo	0.0221	-6	10	0.0044	5	11,400	1.18
1 hi-lo	0.0179	-5	100	0.0025	28	47,000	0.89
1 hi-lo	0.0412	0	5	0.0028	28	38,000	1.08
6 hi-lo	0.0200	0	10	0.0025	41	5,000	0.82
9 lo-hi	0.0025	45	2500	0.0200	0	5	0.77
24 hi-lo	0.0200	0	2	0.0025	50	1,000	0.94
34 lo-hi	0.0025	51	500	0.0200	0	1	0.75
							ave. 0.92

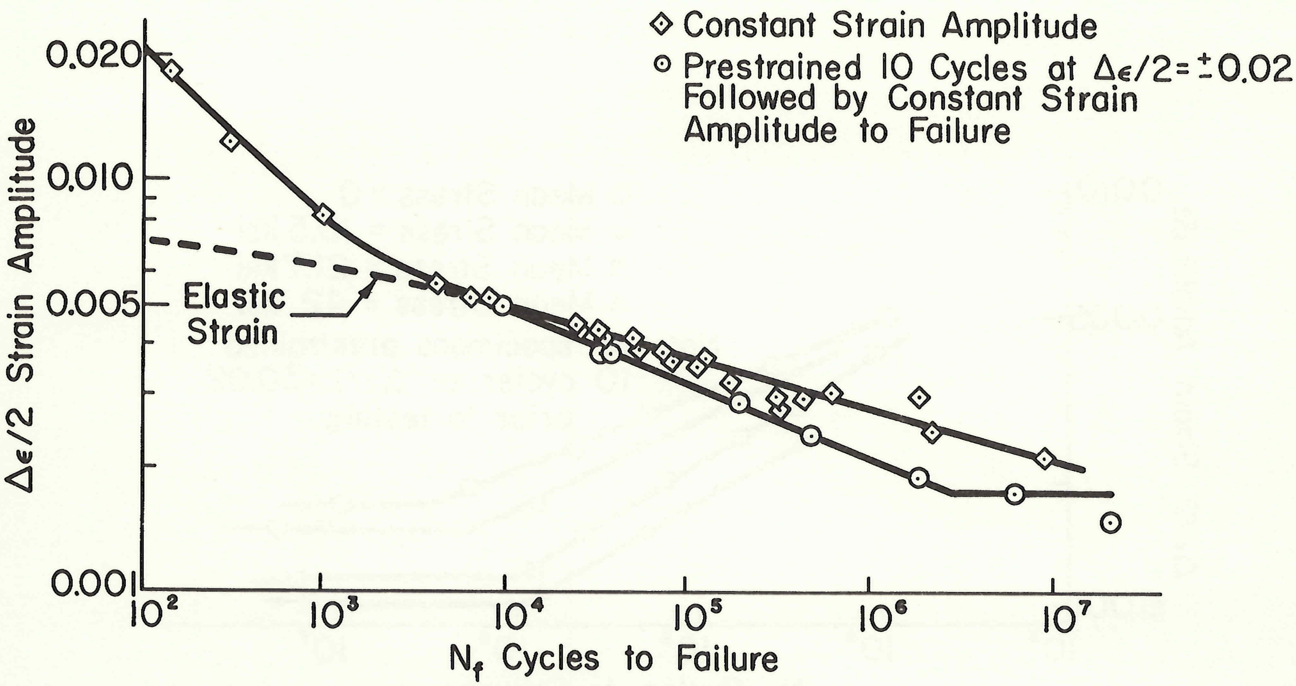

Fig. 1 Effect of a Prestrain on the Strain-Life Behavior of 2024-T4 Aluminum

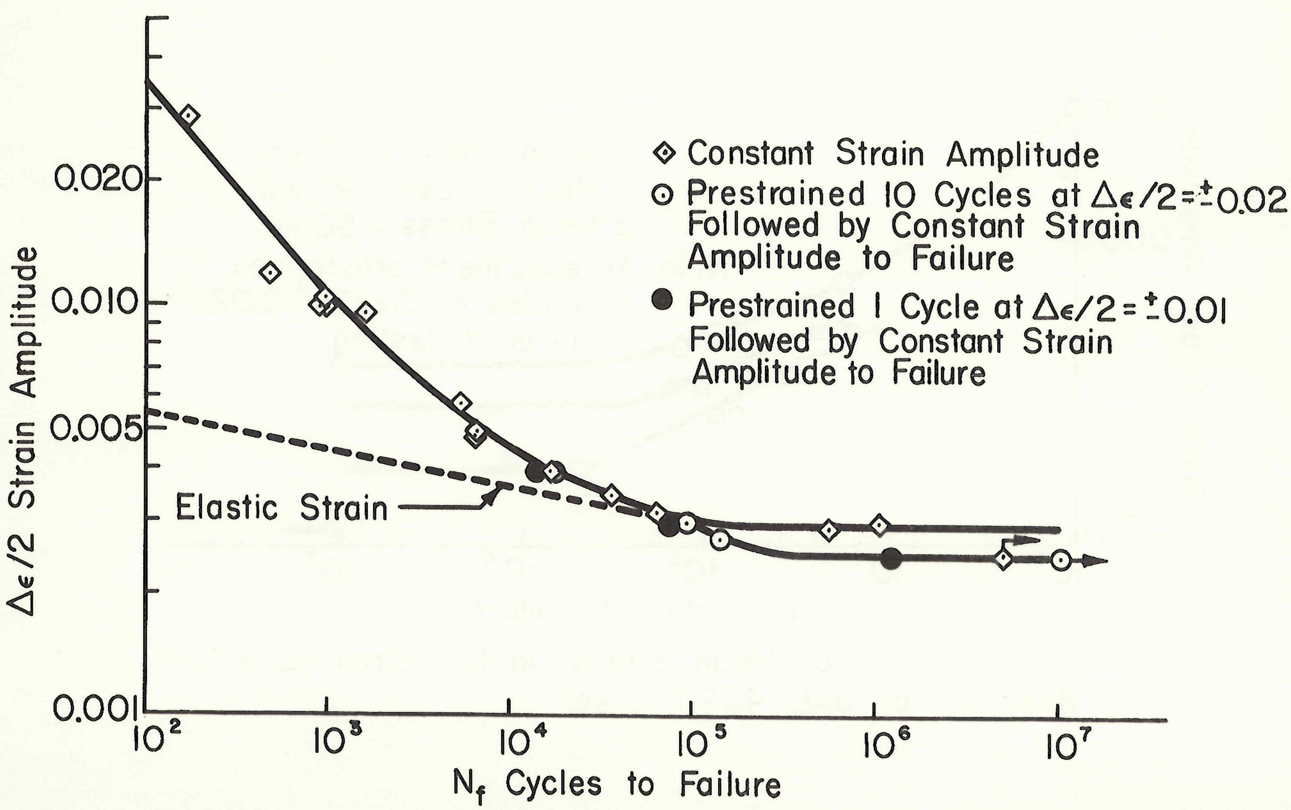

Fig. 2 Effect of a Prestrain on the Strain-Life Behavior of SAE 4340 Steel

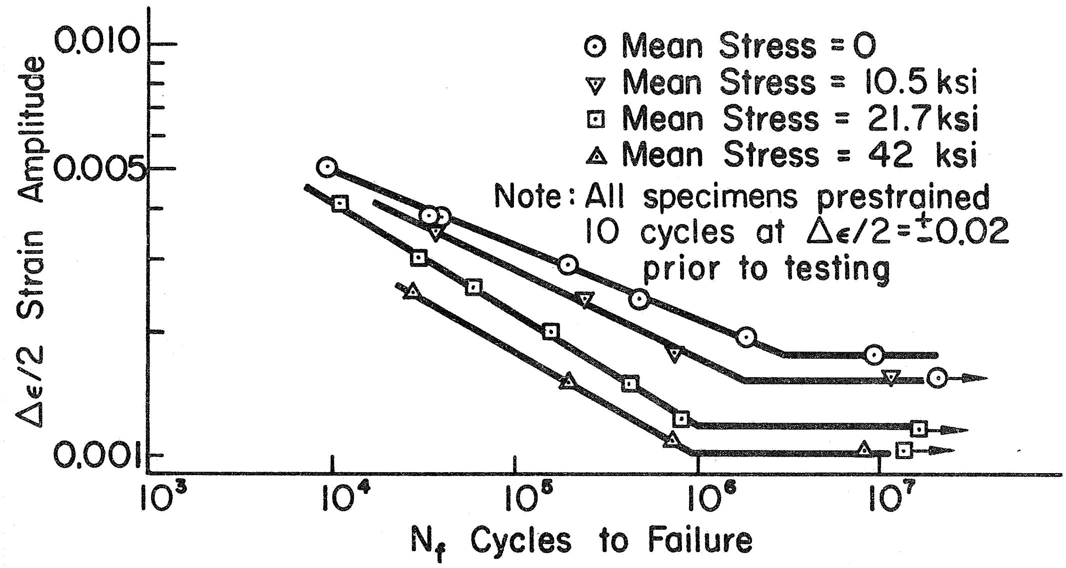

Fig. 3 Effect of Mean Stress on the Strain-Life Behavior of 2024-T4 Aluminum

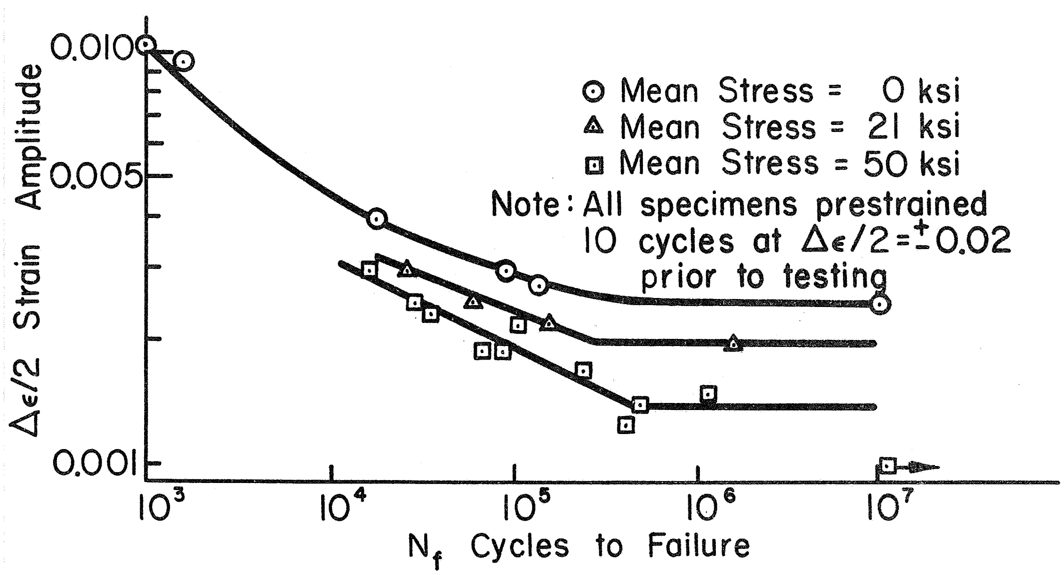

Fig. 4 Effect of Mean Stress on the Strain-Life Behavior of SAE 4340 Steel

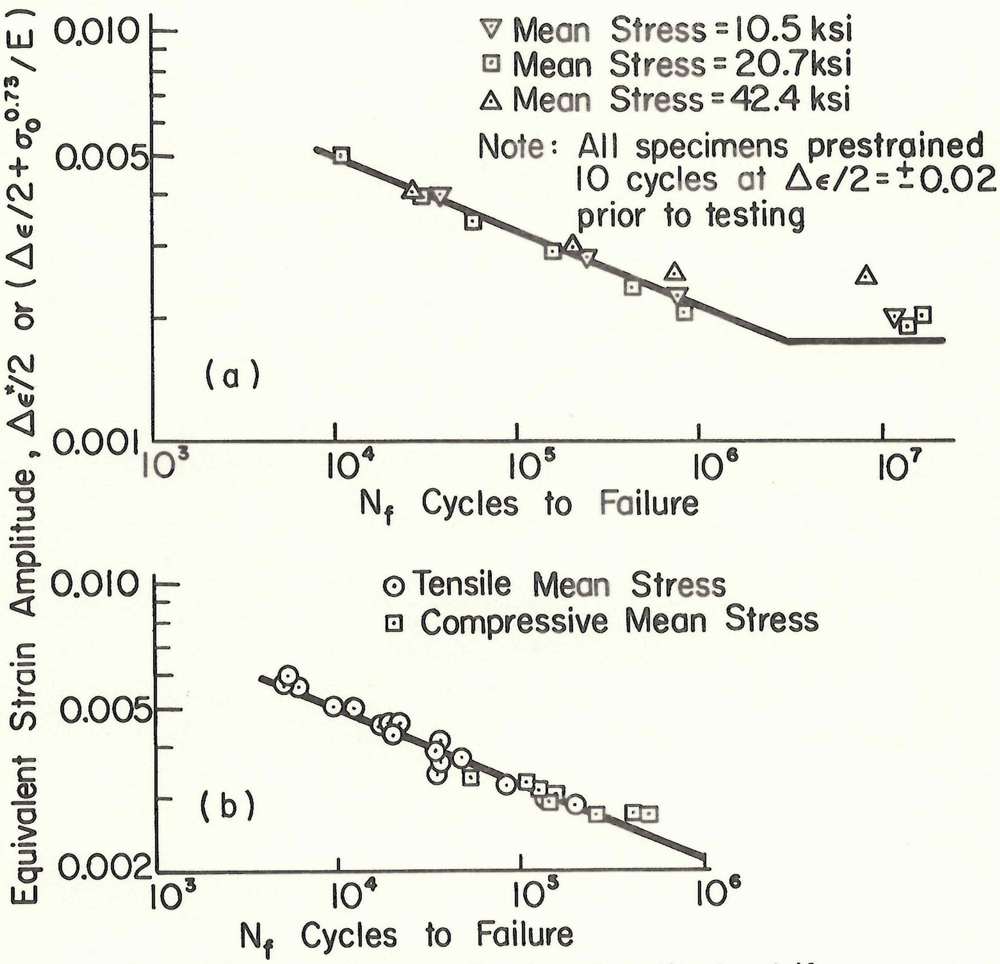

Fig. 5 Equivalent Strain Amplitude - Life Comparison for 2024-T4 Aluminum Alloy

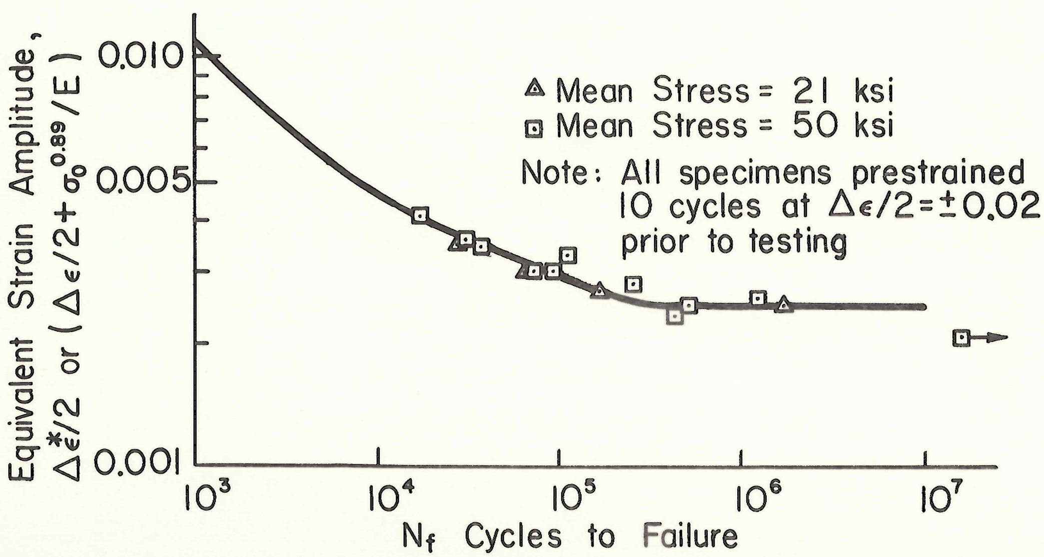

Fig. 6 Equivalent Strain Amplitude - Life Comparison for SAE 4340 Steel