Mechanical Laboratory 2

Lab #7: Fatigue

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MMAE-419-L01

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ABSTRACT:

In process of determining if structure is sustainable for service fatigue testing plays major role. The purpose of fatigue testing is to determine lifespan of material that can be expected by repeatedly applying load to the specimen until it fractures. It is also used to determine the maximal load that can hold for specified number of cycles. Students tested structural steel and aluminum by ASTM E606 standard, also called Strain-Controlled High and Low Fatigue Testing. It is testing where uniaxial forces are applied to hourglass shaped specimen. Understanding of mechanical properties of material is crucial for engineering because choosing right material for design will decide if design will give optimal results and minimize failure of systems and machines.

INTRODUCTION:

Main goal of this lab is better understanding of mechanical properties of structural metals by finding fatigue endurance limit and lifespan of metal. Test is conducted to fit requirements such as particular stress and adequate factor of safety. Two materials were tested, structural steel 1045CR and aluminum 7075-T6. Standard test method for strain-controlled fatigue testing (ASTM E606 standard) was performed. As it is represented in Figure 1a. $\boldsymbol{\sigma_m}$ is average of maximum and minimum values that are given, and it is called *Mean Stress.* In experiment performed in lab $\boldsymbol{\sigma_m}$ was equal to zero, it is called completely reversed stressing and cycles looks same as it is shown in Figure 1b. Maximum and minimum stress levels $\boldsymbol{\sigma_{max}}$ and $\boldsymbol{\sigma_{min}}$ can be find using **(1)** and **(2).** *Stress ratio* (**R**) is found using equation **(3)**, and since $\boldsymbol{\sigma_m}$=0, R is -1.

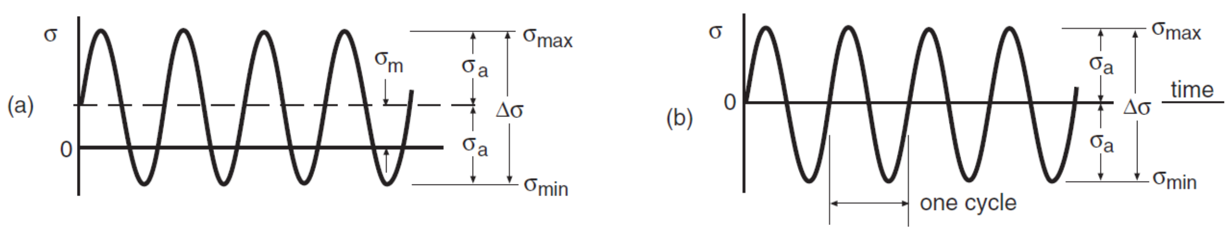

Figure 1. a) Nonzero mean stress σ_m, **b)** Completely reversed stressing, σ_m = 0

$$\boldsymbol{\sigma_{max} = \sigma_m + \sigma_a} \qquad \textbf{(1)}$$

$$\boldsymbol{\sigma_{min} = \sigma_m - \sigma_a} \qquad \textbf{(2)}$$

Stress ratio (**R**) is found using equation **(3)**, and since $\boldsymbol{\sigma_m}$=0, R= will be -1.

$$R = \frac{\sigma_{min}}{\sigma_{max}} = -1 \qquad (3)$$

Equation of fitted line in log-log plot can be found by using **(4)**, **(5**), from where **A** and **B** is found using **(6)** and **(7),** for both structural steel 1045CR and aluminum 7075-T6:

$$\sigma_A = S_f = AN_f^B \qquad (4)$$

$$logN_f = \frac{1}{B} \cdot logS_f - \frac{1}{B} logA \qquad (5)$$

Which is equation of straight line on a log–log plot in form: $y = mx + c$

$$(logN_f = y, \quad \frac{1}{B} = m, \quad log\ S_f = x, \quad -\frac{1}{B} logA = c)$$

From there we have values for A and B:

$$B = \frac{1}{m} \qquad (6)$$

$$A = 10^{-cB} \qquad (7)$$

Values for **C** and **D** are found by fitting curve trough stress vs. (log)cycles plot and C is constant and D is slope of that fitted linear S-N curve:

$$\sigma_A = S_f = C + D * logN_f \qquad (8)$$

The stress value below which the material will withstand many load cycles, which is similar to fatigue limit by ASTM is called ***Endurance limit*** it is used only for steel. Endurance limit (**El**) is found two ways, by fitting log-log curve using **(4)** and by fitting log-linear curve using **(5)**, and values are:

El = 391 [MPa] (log-linear) and 398.8 [MPa] (log-log)

For structural steel 1045CR and for aluminum 7075-T6, standard deviation is found by using **(9)**, results are presented in **Tables 1 and 2**

$$\textbf{standard deviation} = S_x = \sqrt{\frac{\sum_i^n (X_i - X_{ave})^2}{(n-1)}} \quad \textbf{(9)}$$

PROCEDURE:

Experiment started by polishing specimens that were machined in hourglass shape prior to experiment. Students than polished specimen by putting it to lathes machine and spinning it while fine sandpaper polished central part of specimen. Example of polished specimen is shown in **Figure 2.** Than specimen smallest diameter is measured. When part is polished (**figure 4**) it was placed in servo-hydraulic axial fatigue machine (**figure 5**) and testing started. To have better understanding how fatigue machine works one other, more primitive machine is shown in **figure 3,** and even if it is not hydraulic it helps to describe mechanics of fatigue testing. Important detail to notice is that load is uniaxially applied to specimen. Testing of this kind is described in ASTM E606 standard procedure. When testing started software tracked number of cycles and stress amplitude until specimen breaks. Student could do only one ore maybe two tests during class since fatigue can last much longer but gut provided with data that was collected from previous sessions. One fractured specimen is shown in **Figure 6.**

Figure 2. Specimen shape before testing

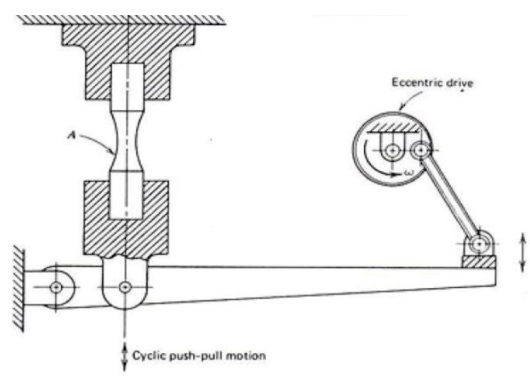

Figure 3. Mechanics of uniaxial load fatigue testing (non-hydraulic)

Figure 4. Specimen polishing

Figure 5. Specimen during testing

Figure 6. Fractured specimen after testing

RESULTS:

Only stresses amplitude of 70 [ksi] or 483[MPa] is considered for analysis of 1045CR steel while 50 [ksi] or 344[MPa] is considered for 7075-T6 aluminum alloy analysis. Results for standard deviation are presented in **Tables 1. and 2.**

Table 1. Standard deviation, average # of cycles, lower and upper limits for 1045CR Steel

Standard Deviation (σ)	20307.9
2 · Standard Deviations (2·σ)	40615.8
Average # of Cycles (Na)	48220.11
Lower Cycles Limit [Na - 2·σ]	7604.309
Upper Cycles Limit [Na + 2·σ]	88835.91

Table 2. Standard deviation, average # of cycles, lower and upper limits for 7075-T6 Aluminum

Standard Deviation (σ)	5514.17
2 · Standard Deviations (2·σ)	11028.34
Average # of Cycles (Na)	18601.04
Lower Cycles Limit [Na - 2·σ]	7572.7
Upper Cycles Limit [Na + 2·σ]	29629.38

By using equations (4) - (8) coefficients A, B, C and D are determined and presented in **Tables 3 and 4**, but equations are shown in **Figures 8 and 9** where those are plotted.

Table 3. 1045CR Steel parameters.

A	B	C	D
963.45	-0.0639	822.97	-71.99

Table 4. 7075-T6 Aluminum parameters

A	B	C	D
2124.68	-0.1855	871.48	-123.11

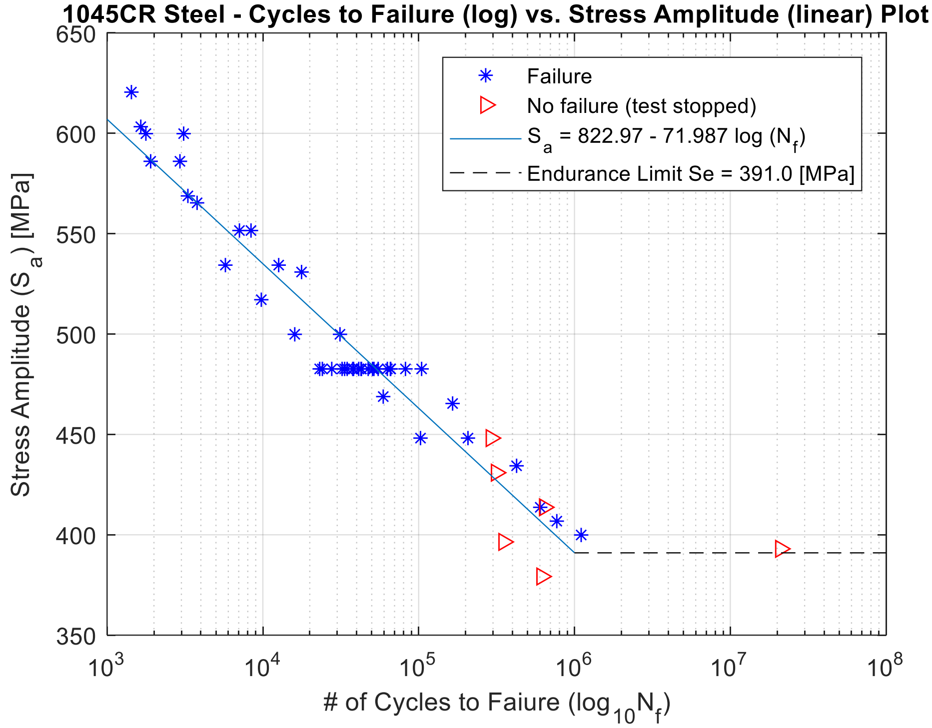

Figure 7. 1045CR Steel Log-Linear S-N Curve

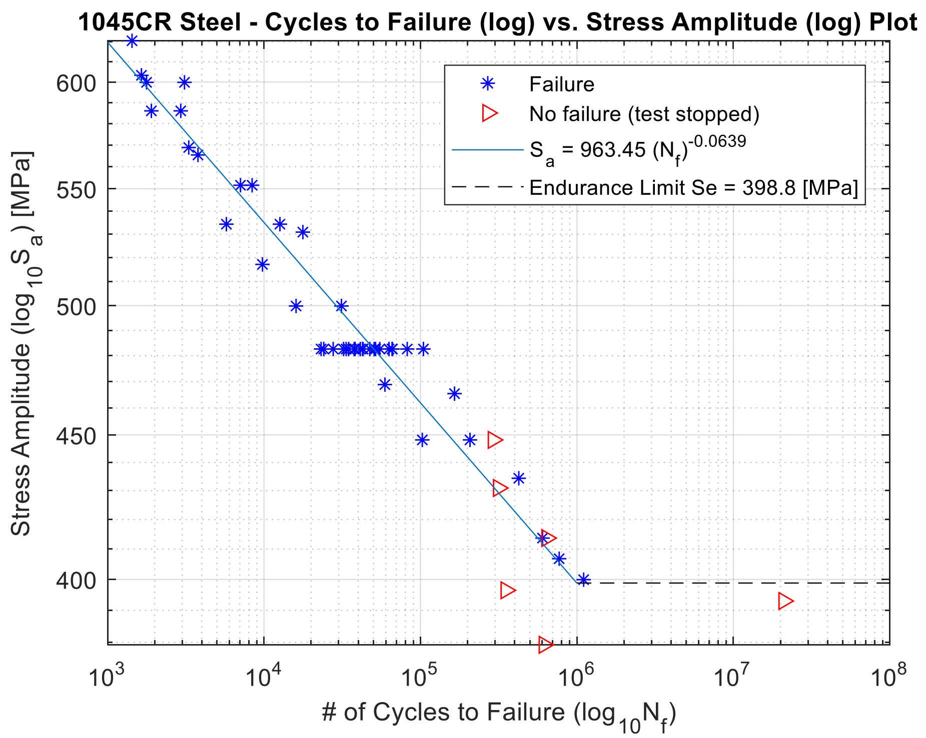

Figure 8. 1045CR Steel Log-Log S-N Curve

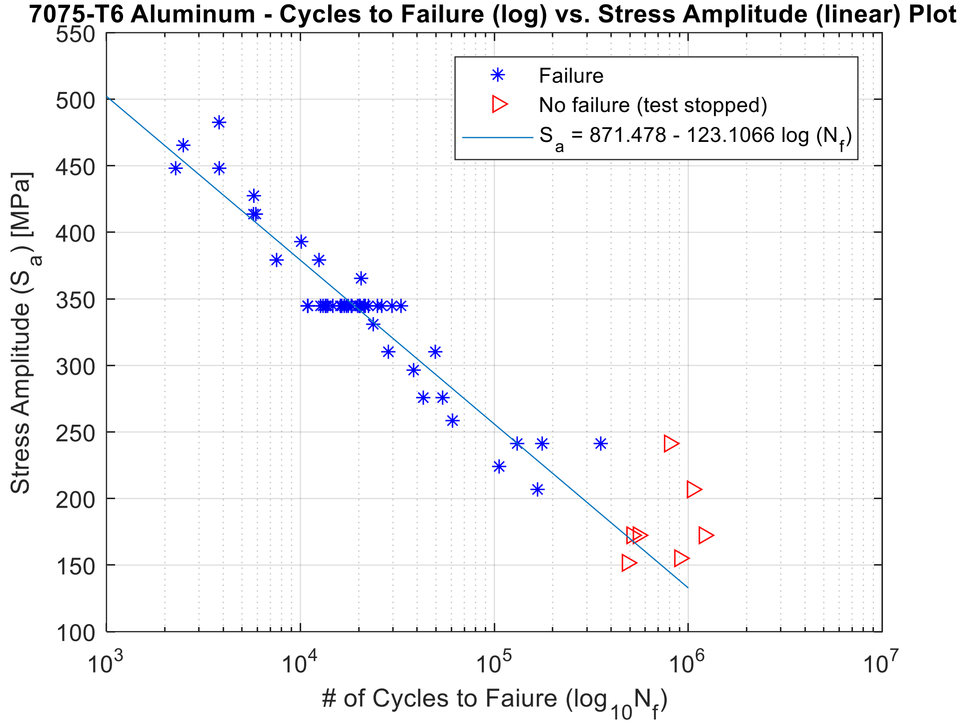

Figure 9. 7075-T6 Aluminum Log-Linear S-N Curve

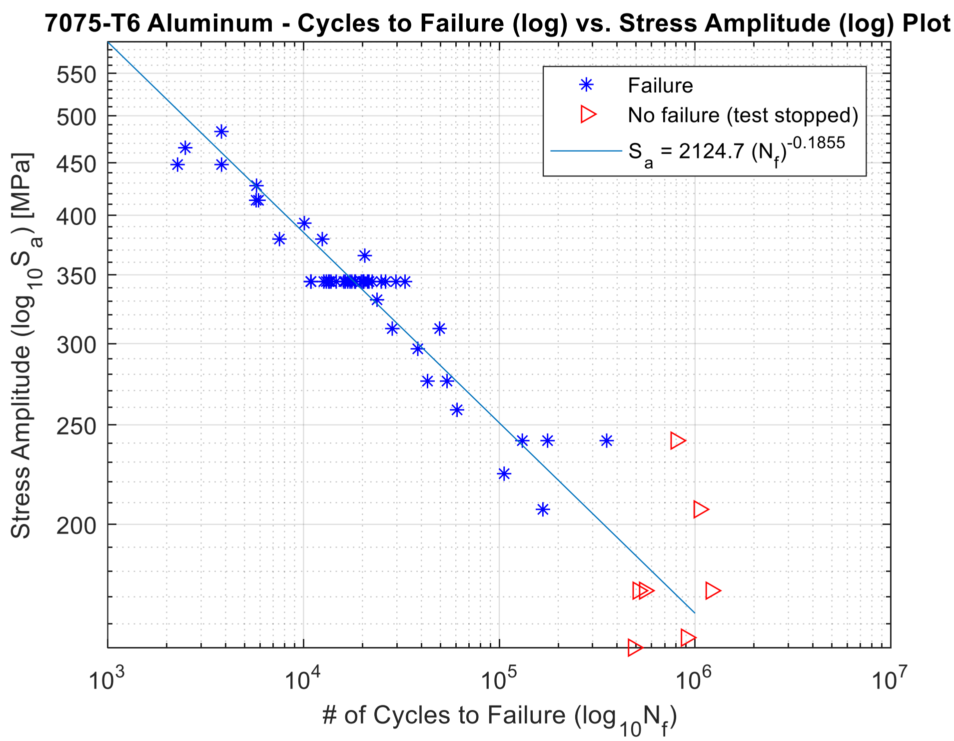

Figure 10. 7075-T6 Aluminum Log-Log S-N Curve

Table 5. 1045CR Steel raw data

Specimen ID	Max Stress (ksi)	Cycles	comment
1	90	1433	0
2	85	2936	
3	80	7073	
4	75	9773	
5	70	27680	
6	70	24090	
7	70	34760	
8	70	62953	
9	70	42641	
10	70	51634	
11	70	38217	
12	70	33490	
13	70	41251	
14	60	640979	failed in grip
15	57.5	351676	failed in grip
16	87.5	1646	
17	65	207222	
18	62.5	314667	failed in grip
19	70	50559	
20	70	82267	
21	70	37727	
22	70	65818	
23	70	54963	
24	70	42942	
25	70	66165	
26	67.5	165109	
27	82.5	3302	
28	77.5	12637	
29	72.5	31251	
30	70	47403.0	
31	80	8392.0	
32	87	3102.0	
33	77	17714.0	
34	70	104444.0	
35	55	616535.0	failed in grip
36	65	291434.0	failed in grip
37	85	1905	
38	65	102751	
39	82	3783	
40	77.5	5747	
41	72.5	16024	
42	70	32238	
43	68	59237	
44	63	425000	failed in the grip
45	57	21000000	exp stopped due to hydraulic leakage
46	60	602912	
47	58	1104055	
48	59	770180	
49	87	1775	
50	70	23160	

Table 6. 7075-T6 Aluminum raw data

Specimen ID	Max Stress (ksi)	Cycles	comment
1	70	3809	
2	60	5892	
3	50	18426	
4	40	43005	
5	30	167045	
6	25	511083	failed in grip
7	50	17286	
8	50	21600	
9	22	484153	failed in grip
10	50	17644	
11	50	12697	
12	50	16074	
13	50	20117	
14	50	20327	
15	50	10895	
16	35	353777	
17	65	3815	
18	67.5	2490	
19	55	7538	
20	50	13817	
21	50	16826	
22	45	28406	
23	32.5	105887	
24	37.5	60877	
25	50	13085	
26	50	18291	
27	50	16345	
28	50	10929	
29	50	14691	
30	35	176492	
31	22.5	902156	failed in grip
32	50	13553	
33	50	24950	
34	50	19742	
35	43	38350	
36	62	5754	
37	25	1206736	failed in grip
38	35	798994	failed in grip
39	55	12473	
40	60	5728	
41	50	20262	
42	50	21245	
43	30	1047963	failed in grip
44	50	33013	
45	53	20562	
46	48	23743	
47	50	26259	
48	35	131156	
49	57	10099	
50	45	49602	
51	40	54099	
52	50	29662	
53	65	2274	
54	50	22439	
55	50	13452	
56	25	551401	failed in grip

DISCUSSION:

It is noticed that when lower load is applied, on both materials 1045CR Steel and 7075-T6 Aluminum, test had tendency to do much more cycles but also specimen tend to break in grip and not on neck area. Endurance limit for steel was around 400[MPa] using both plots, log-log and log-linear, which is just approximation. Error that could occur could be due to surface that is not smooth enough. Standard deviation calculated for both materials and it can be concluded that for steel:

95% of fractures would happen in range of: 7604 cycles > Nf > 88835 for steel

95% of fractures would happen in range of: 7572 cycles > Nf > 29629 for aluminum

(Average #of cycles (Na) –2*Standard deviation)>**Nf**>(Average # of cycles (Na) –2*Standard deviation)

Errors could occur because not all specimens are polished same way.

CONCLUSION:

Even if some samples failed in grip they did fall under same curve fit. This lab gives students some inside on how materials have limitations, and how does aluminum and steel acting under different circumstances, meaning different load and different endurance.

REFERENCES:

Mechanical Behavior of Materials 4th Ed. by Norman E. Dowling (Pearson, 2013 ISBN 0-13-139506-8)

Dr. Murat Vural, MMAE 419 Fatigue Testing Handout, IIT, Chicago