ME 354, MECHANICS OF MATERIALS LABORATORY

TIME-DEPENDENT FAILURE: FATIGUE

February 2004 / PEL

PURPOSE

The purposes of this exercise are to determine the effect of cyclic forces on the long-term behaviour of structures and to determine the fatigue lives (N_f) as functions of uniaxial tensile stress for an aluminum alloy. Axial fatigue tests are used to obtain the fatigue strength of materials where the strains are predominately elastic both upon initial loading and throughout the test.

EQUIPMENT

- Reduced gage section tensile test specimens of 6061-T6 aluminum
- Tensile test machine with grips, controller, and data acquisition system

PROCEDURE

- Measure the diameter, d, of the gage section of the test specimen to 0.02 mm.
- Calculate the maximum, P_{max}, and minimum, P_{min}, loads for the test based on the desired maximum and minimum stresses (Note: $P = \sigma^*A = \sigma * (\pi d^2/4)$. Since, these tests are being conducted in tension only, the stress ratio, R, is chosen to be close to but not exactly zero such that R=0.1. Thus, $\sigma_{min}=R^* \sigma_{max}$ where σ_{max} is the desired maximum stress.
- Calculate the mean load as $P_m=(P_{max}+P_{min})/2$.
- Calculate the load amplitude as $P_a=(P_{max}-P_{min})/2$.
- Zero the load output (balance).
- Set the maximum load limit at ~5 kN during the test specimen installation. Activate the limit detect for actuator off.
- Do not set the minimum load limit during specimen installation
- Activate load protect (~0.05 kN) on the test machine to prevent overloading the test specimen during installation.
- Install the top end of the tensile specimen in the top grip of the test machine while the test machine is in displacement control.
- Install the bottom end of the tensile specimen in the lower grip of the test machine.
- Set the maximum load limit at ~0.5 kN greater than P_{max} and activate the limit detect for actuator off.
- Set the minimum load limit at -0.2 kN and activate the limit detect for actuator off.
- Deactivate load protect.
- Activate load control by going to this control mode immediately,
- On the test machine, zero the cycle counter for the total count.
- In load control adjust the setpoint in increments of not greater than 1 kN to achieve the mean load, P_m.
- Select the waveform as sine wave and input an initial frequency of 1 Hz
- Input the load amplitude, P_a.
- Activate amplitude control to ensure that the loading envelope maintains its integrity during the course of the test.
- Initiate the data acquisition and control program (if desired).
- Enter the correct file name and test specimen information as required.
- Initiate the test sequence via the computer program otherwise activate the test via the front control panel.
- After the test has been running for 30-60 s, increase the frequency in 1 Hz increments up to a maximum of 15 to 25 Hz.
- Activate event detector 1 for break detect but no action.
- Continue the test until test specimen fracture (or the break detect).
- Record the number of cycles on the cycle counter at the end of the test.

* REFERENCES

Annual Book or ASTM Standards, American Society for Testing and Materials, Vol. 3.01
E466 Standard Practice for Conducting Constant Amplitude Axial Fatigue Tests of Metallic Specimens
E468 Standard Practice for Presentation of Constant Amplitude Fatigue Test Results for Metallic Specimens

RESULTS

Fatigue test results may be significantly influenced by the properties and history of the parent material, the operations performed during the preparation of the fatigue specimens, and the testing machine and test procedures used during the generation of the data. The presentation of the fatigue test results should include citation of the basic information on the material, the specimens, and testing to increase the utility of the results and to reduce to a minimum the possibility of misinterpretation or improper application of the results.

Enter your results in Table 1, comparing your results to the control data generated for this same aluminum under uniaxial tensile fatigue conditions.

Plot your test results as maximum stress, σ_{max}, versus log of cycles to failure, N_f in Figure 1. Note that a log scale is used for N_f so there is no need to compute log N_f.

Answer the following questions on the Worksheet, turning this in as the In-class Laboratory report.

ME 354, MECHANICS OF MATERIALS LABORATORY

TIME-DEPENDENT FAILURE: FATIGUE

01 January 2000 / mgj

WORK SHEET

NAME______________________________________DATE_____________

EQUIPMENT IDENTIFICATION_______________________________________

1) Tabulate the following mechanical properties from your tensile test results.

6061-T6 Aluminum
Selected Mechanical Properties (R.T.)

E (GPa)	
σ_o (MPa)	
S_{UTS} (MPa)	
% elongation	

2) For the maximum stress assigned to your laboratory section determine the required test forces from the measured diameter of the test specimen.

Test specimen diameter, d (mm)	
Gage section area, $A=\pi d^2/4$ (mm^2)	
Stress ratio, R	0.1
Maximum stress, σ_{max} (MPa)	
Minimum stress, $\sigma_{min} = R * \sigma_{max}$ (MPa)	
Mean stress, $\sigma_m = (\sigma_{max} + \sigma_{min})/2$ (MPa)	
Stress amplitude, $\sigma_a = (\sigma_{max} - \sigma_{min})/2$ (MPa)	
Stress Range = $\Delta\sigma = \sigma_{max} - \sigma_{min}$ (MPa)	
Maximum load, $P_{max} = \sigma_{max} * A$ (N)	
Minimum load, $P_{min} = \sigma_{min} * A$ (N)	
Mean load, $P_m = \sigma_m * A$ (N)	
Load amplitude, $P_a = \sigma_a * A$ (N)	

3) Tabulate your test results and compare them to the control data for this material.

Table 1 Fatigue Test Results for 6061-T6 Aluminum at R.T.

R	σ_{max} (MPa)	σ_{min} (MPa)	σ_m (MPa)	σ_a (MPa)	**N_f**
0	S_{uts}=	N/A	N/A	N/A	<1
-1	345	-345	0	345	10^2
-1	276	-276	0	276	10^3
-1	248	-248	0	248	10^4
-1	200	-200	0	200	10^5
-1	166	-166	0	166	10^6
-1	117	-117	0	117	10^7
-1	100	-100	0	100	10^8
0.1	322	32	177	145	2
0.1	304	30	167	138	1.923
0.1	295	29	162	133	11,324
0.1 (replicate)	285	28	156	128	34,900
0.1 (replicate)	285	28	156	128	49,671
0.1 (replicate)	285	28	156	128	91,711
0.1 (replicate)	285	28	156	128	35,964
0.1 (replicate)	285	28	156	128	51,700
0.1	270	27	148	122	108,243
0.1	250	25	138	115	294,849
0.1	215	21	118	93	338,943
0.1	178	17	98	82	1,169,307
Test Result	**for this**	**Laboratory**	**Exercise**		
0.1					

4) Plot the all the test results for R=0.1 on the S-N curve shown in Figure 1. For this material, is there evidence of a well-defined fatigue (endurance) limit, σ_e? Is this what you expected?

5) Do your test results agree with the control (or previous test) results? If so, why? if not, why not? Would you expect fatigue failures to have little or much scatter? Does it seem reasonable to try to fit a single curve through the data?

6) Examine the fracture surface of the test specimen. Given that the maximum force in the fatigue test was less than the yield force for material (as determined from the monotonic tensile test), discuss how fatigue can occur given that the loading was in the elastic range. Where do the fatigue cracks initiate from? Is surface condition important? How would you design components to minimize fatigue failures?

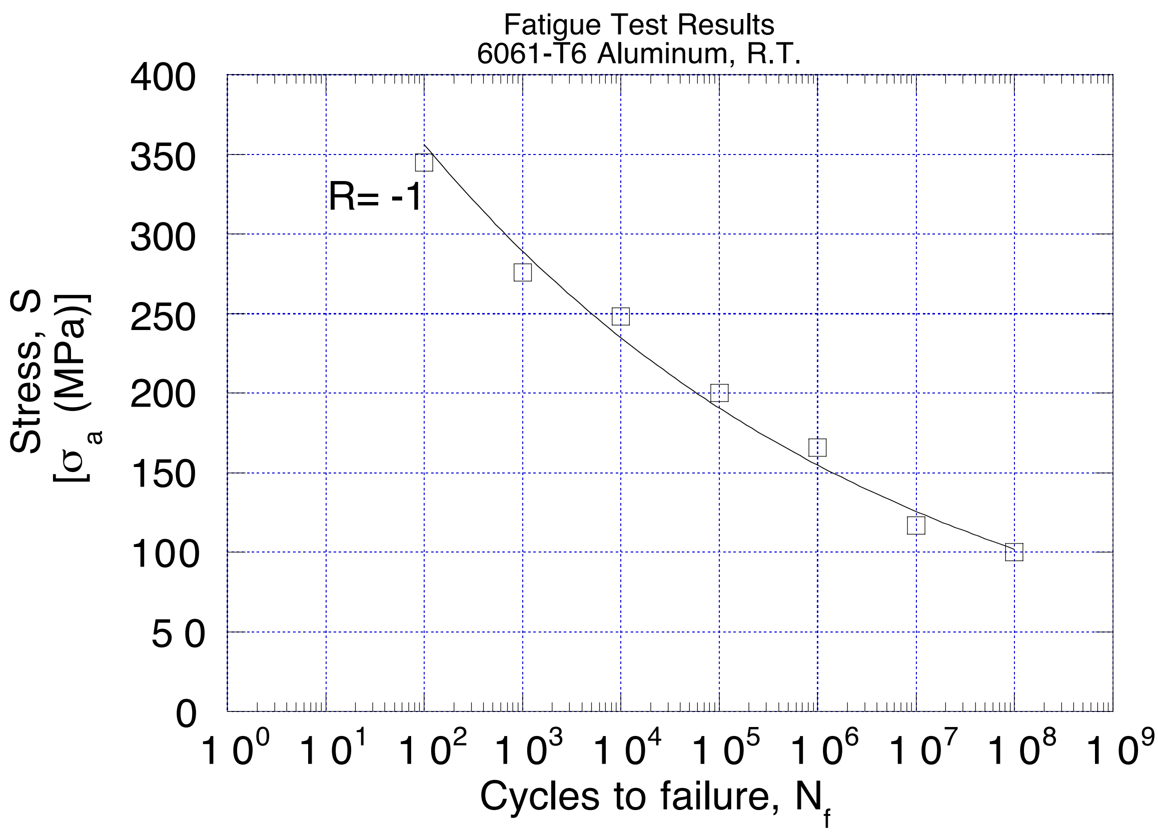

Figure 1 S-N curve for 6061-T6 aluminum at room temperature

6) (cont'd)

7) Fatigue can be analyzed from a fracture mechanics standpoint. If the stress intensity factor solution for this case can be approximated as $K_I = 1.75\sigma\sqrt{\pi a}$, determine the critical crack length at fracture such that $a_f = \frac{1}{\pi}\left(\frac{K_{Ic}}{1.75\sigma_{max}}\right)^2$ for your result (Note K_{Ic}=35 MPa√m). Compare calculated a_f to the actual a_f measured on the fracture surface. Are they similar? Why or why not? Finally, assuming a_i=0.1 mm and $da/dN = C(\Delta K)^m$ (Note: a has units of metres, σ_{max} and $\Delta\sigma$ have units of MPa, F=1.75, m=3.59 and C=1.6 X 10^{-11} with units to give da/dN in m/cycle), calculate the cycles to failure from tensile crack initiation to final fracture using the relation: $N_f = \frac{a_f^{(1-(m/2))} - a_i^{(1-(m/2))}}{C\left[F(\Delta\sigma)\sqrt{\pi}\right]^m\left[1-(m/2)\right]}$. Compare the N_f for crack propagation to the total N_f for the test. Is crack propagation a significant (i.e., large) part of the total fatigue life?