ME 354, MECHANICS OF MATERIALS LABORATORY

TIME-DEPENDENT DEFORMATION: CREEP

February 2004 / PEL

PURPOSE

The purposes of this exercise are to study the effect of loading on the time-dependent deformation (i.e., creep) and to characterize the room-temperature creep behaviour of a soft alloy under various forces. Specifically, short-term creep tests will be used to identify constants in the $\dot{\varepsilon}_{\min} = B\sigma^{n}$ relation where $\dot{\varepsilon}_{\min}$ is the minimum creep strain rate, σ is the engineering normal stress, B is the coefficient, and n is the creep stress exponent. Predictions using these constants are compared to results measured from long-term creep tests of this same alloy.

EQUIPMENT

- Constant gage section diameter sections of a ~50% tin- ~50% lead alloy (solder).
- Extension-gage (dial indicator) for total elongation.
- "Dead-weight," lever arm creep test machine.
- Various "dead-weight" masses of 0.5, 1.0, 2.0 and 5.0 kg.
- Timing device.

PROCEDURE

- Measure out and cut to length (~150 mm) constant gage length test specimens.

- Measure the diameter, d, of the gage section each test specimen to 0.02 mm.

- Install the top end of each test specimen in the top grip of a creep test machine.

- Install the bottom end of the test specimen in the lower grip of the creep test machine and measure the initial gripped length, L_o, of the test specimen in mm.

- Apply "dead weight" masses of m_a=3.0, 4.0, 5.0, and 6.0 kg to the pan of the creep test machine for a total of four tests for four different untested test specimens, noting the mechanical advantage of the lever arm system of the creep test machine. (The actual force applied to the test specimen is two times the dead load). Record both the applied mass, m_a, and the mass, m_p, of the pan in kg.

- Record elongation readings (change in length=ΔL) in mm at time, t=10, 20, 30, 60, 90, 120, 180, 240, 360, 480, 600, 720 s, etc. (every 120 s) until 5% engineering strain is achieved.

* REFERENCES
Annual Book or ASTM Standards, American Society for Testing and Materials, Vol. 3.01
E139 Standard Test Method for Conducting Creep, Creep-Rupture, and Stress-Rupture Tests of Metallic Materials

BACKGROUND AND ANALYSIS OF RESULTS

Creep in materials can be defined as time dependent deformation. Often in engineering materials creep becomes of concern at homologous temperatures equal to or greater than 0.3 to 0.6 (rule of thumb is 0.5) . Homologous temperature is defined as:

$$\frac{T(absolute)}{T_{mp}(absolute)} \tag{1}$$

where T is the absolute temperature of the application and T_{mp} is the absolute temperature of the melting point of the material. For example, steels might be expected to creep at T≈600°C which is a homologous temperature of (600°C+273)K/(1500°C+273)K=0.49. Similarly, a lead-tin solder might be expected to creep at room because the homologous temperatures is (20°C+273)K/(200°C+273)K=0.62. Finally, polycrystalline hydrogen oxide (solid H_2O=ice) creeps at –40°C because the homologous temperatures is (-40°C+273)K/(0°C+273)K=0.82.

Thus, creep is not necessarily dependent on high temperature from a human perspective, but is dependent on high temperature from a material's "perspective."

From an engineering mechanics point of view strain measured during the time-dependent deformation of creep can be thought of as the macroscopic manifestation of the cumulative damage process under the action of temperature and stress. Therefore, predictive models of the creep deformation often include strain, strain rate, applied stress, the use temperature as well as various material-related constants such as activation energy for creep and a stress exponent.

In this laboratory exercise, on a single graph, total engineering creep strain ($\varepsilon=\Delta L/L_o$) is plotted versus time, t, (s) for the four short- term creep tests. The minimum creep strain rate, ($\dot{\varepsilon}_{\min}=d\varepsilon/dt$) ($s^{-1}$) can be determined for each short-term creep test by using a linear regression over the linear portion of each creep curve.

Next a linear plot of log $\dot{\varepsilon}_{\min}$ versus log engineering stress, σ, ($\sigma=P/A_o$ where $P=2^*(m_a+m_p)^*$ ($g=9.816\ m/s^2$) and $A_o = \pi d^2/4$) for the short-term creep tests can be constructed. The coefficient, B, and the creep stress exponent, n, can be determined for the relation:

$$\dot{\varepsilon}_{\min} = B\sigma^n \tag{1}$$

from a least squares linear regression of the linear plot of **<u>only the short term creep test results (i.e., log $\dot{\varepsilon}_{\min}$ versus log σ).</u>**

Next, a plot of total engineering creep strain ($\varepsilon=\Delta L/L_o$) versus time, t, (s) can be constructed for long-term creep tests (see Table 1 for test data). Note that the long-term creep test results are given in instantaneous length, L_i, versus time such that the change in length ΔL is $\Delta L=(L_i-L_o)$ where L_o is the initial instantaneous length at t=0.

Using similar methods as for the short terms tests, $\dot{\varepsilon}_{\min}$ (s^{-1}) can be determined for each long-term creep test by using a linear regression over the linear portion of each creep curve

On the same linear plot of log $\dot{\varepsilon}_{\min}$ versus log σ, results of the long-term creep tests can be plotted as identified points. Note that the masses, m_a, for the long-term creep tests were directly applied to the test specimens with no pan or lever arm advantage such that σ=P/A_o where P=(m_a)* (g=9.816 m/s^2 and $A_o = \pi d^{2/4}$. (Do not use these points in the curve fit of the short-term test results)

The relative error of measured creep strain rates for the long-term tests can be compared to creep strain rates calculated using B and n determined from the short-term creep tests. Do not curve fit the long term tests and try to compare B and n values determined from long and short tests.

Note that a rule of thumb is that the time for collecting material test data for creep should be on the order of 10% of the time required for the design.

Table 1 - Long-term tensile creep results for a lead-tin alloy (solder).

Mass on Test Specimen, ma = 1.07 kg		Mass on Test Specimen, ma = 1.47 kg	
Time, t (day)	Length, Li (mm)	Time, t (day)	Length, Li (mm)
0	504	0	502
2	513	1	514
3	513	2	529
6	528	3	542
7	531	4	555
9	541	5	571
10	542	6	586
11	544	7	604
14	557	8	620
15	562	9	640
16	568	10	680
17	571	12	712
18	574	13	753
19	586	15	893
20	592		
21	593		
22	609		

Initial diameters, d = 3.18 mm, Initial lengths, Lo at t=0

Mass directly applied (no pan or lever arm advantage creep test machine)

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DATA SHEET

NAME______________________________________DATE_____________

LABORATORY PARTNER NAMES____
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EQUIPMENT IDENTIFICATION______________________________________
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Note: Be sure to note units of each quantity.

Added Mass, ma (kg)		Added Mass, ma (kg)		Added Mass, ma (kg)		Added Mass, ma (kg)	
Mass of Pan , mp(kg)		Mass of Pan , mp(kg)		Mass of Pan , mp(kg)		Mass of Pan , mp(kg)	
Initial Dia., d (mm)		Initial Dia., d (mm)		Initial Dia., d (mm)		Initial Dia., d (mm)	
Final Dia., df (mm)		Final Dia., d_f (mm)		Final Dia., d_f (mm)		Final Dia., d_f (mm)	
Initial Length, L_o (mm)		Initial Length, L_o (mm)		Initial Length, L_o (mm)		Initial Length, L_o (mm)	
Time, t(s)	ΔL, Length Change (mm)	Time, t(s)	ΔL, Length Change (mm)	Time, t(s)	ΔL, Length Change (mm)	Time, t(s)	ΔL, Length Change (mm)

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WORKSHEET

NAME______________________________________**DATE**_____________

1) Determine the values of total creep strain vs time from the experimental data

<u>Short term tests</u> (from Data Sheet of measured elongation vs time). Note that for each case, applied stress is $\sigma=P/A_o$ where $P=2*(m_a+m_p)*$ ($g=9.816$ m/s^2) and $A_o = \pi d^2/4$ and the creep strain is $\varepsilon=\Delta L/L_o$ where m is kg and d, ΔL and L_o are mm.

Applied Stress, σ = MPa	
Time, t(s)	Creep Strain, ε (mm/mm)

Applied Stress, σ = MPa	
Time, t(s)	Creep Strain, ε (mm/mm)

Applied Stress, σ = MPa	
Time, t(s)	Creep Strain, ε (mm/mm)

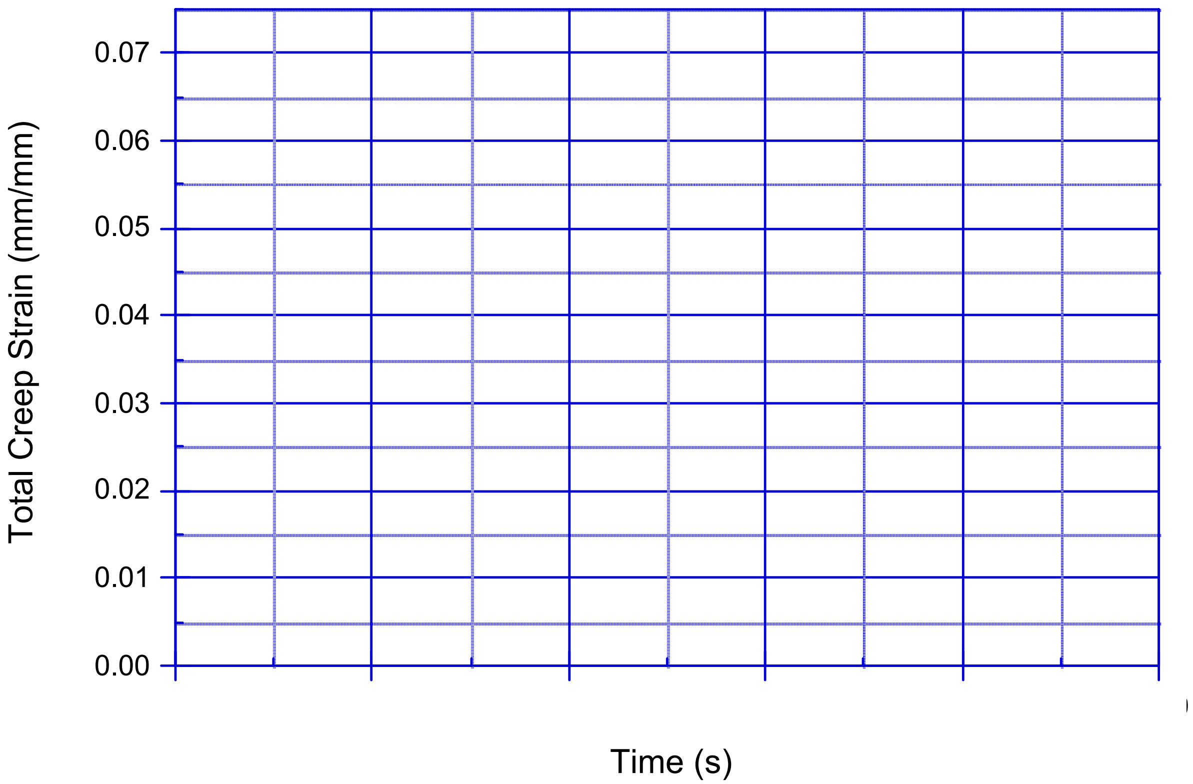
Applied Stress, σ = MPa	
Time, t(s)	Creep Strain, ε (mm/mm)

<u>Long term tests</u> (from Table 1 of measured elongation vs time). Note that for each case, applied stress is σ=P/A_o where P=(m_a) x (g=9.816 m/s^2) and A_o = $\pi d^2/4$ and the creep strain is $\varepsilon=\Delta L/L_o$ where m is kg and d, ΔL and L_o are mm. Note also that t (s)= t (days) x 24 (h/day)x(60 min/h)x(60 s/min).

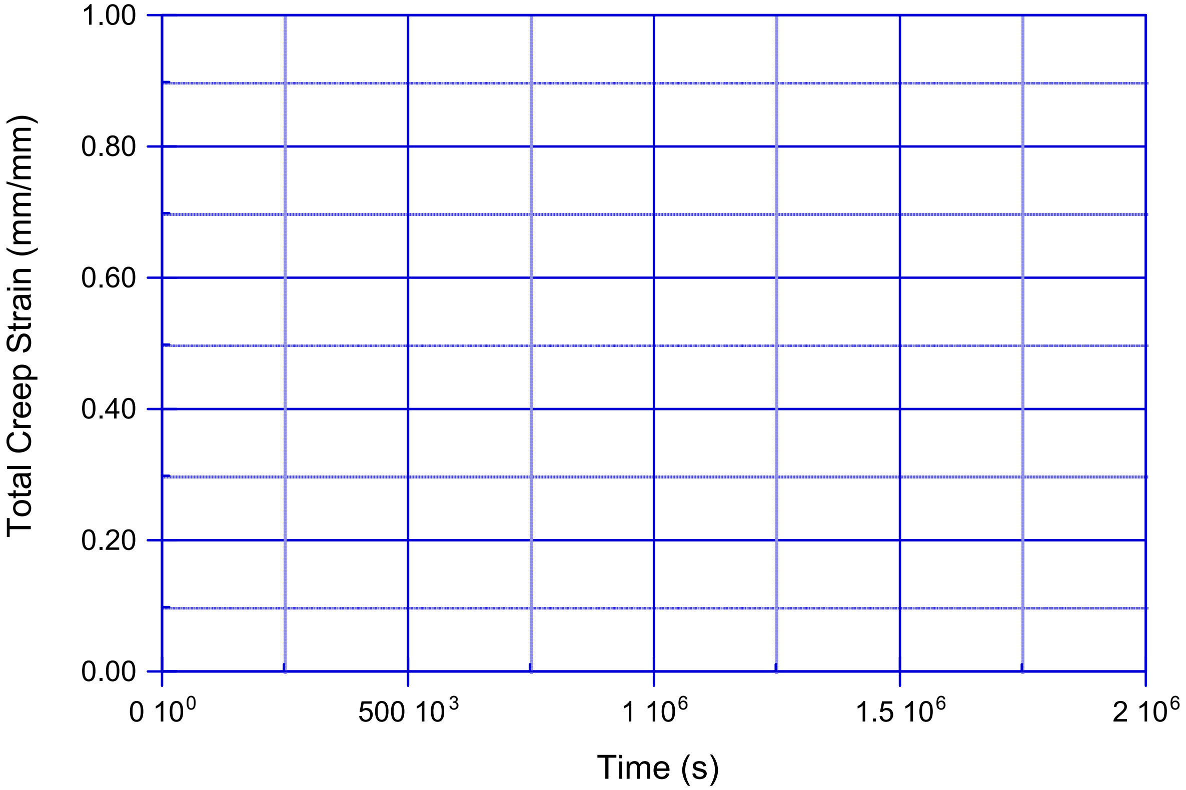
Applied Stress, σ = MPa		Applied Stress, σ = MPa	
Time, t(s)	Creep Strain, ε (mm/mm)	Time, t(s)	Creep Strain, ε (mm/mm)

2) Plot strain vs time to show the creep curves

Short term tests



Long term tests

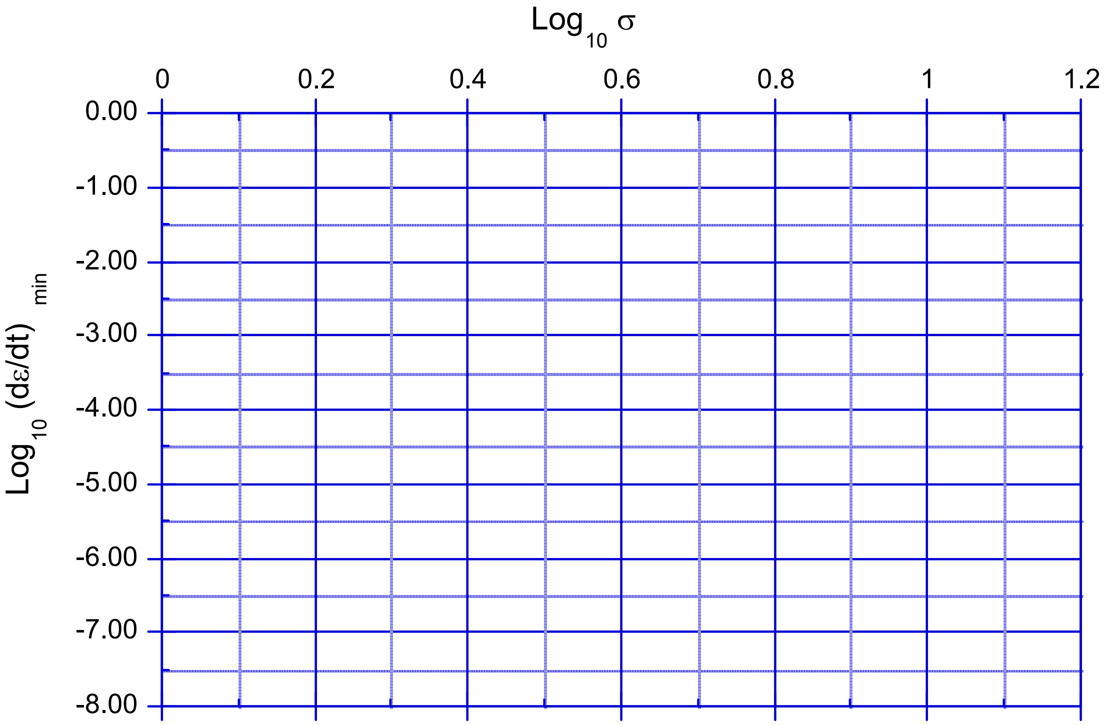


3) Determine the slopes of the linear (secondary) portions of the plots of creep strain vs time. Insert the results in the table and determine the logarithms of each value.

Short-term test	σ (MPa)	$\dot{\varepsilon}_{\min}$ (s^{-1})	Log$_{10}$ σ	Log$_{10}$ $\dot{\varepsilon}_{\min}$
Force #1				
Force #2				
Force #3				
Force #4				

Long-term test	σ (MPa)	$\dot{\varepsilon}_{\min}$ (s^{-1})	Log$_{10}$ σ	Log$_{10}$ $\dot{\varepsilon}_{\min}$
Force #1				
Force #2				

4) Plot Log$_{10}\dot{\varepsilon}_{\min}$ vs Log$_{10}$ σ



5) Determine the slope, m, and intercept, b, of the linear curve fit of the results of the **SHORT TERM** tests **ONLY**. Draw the line on the plot and label the short and long term results. The slope is the stress exponent, n, such that m=n. The intercept, b, is the Log$_{10}$ of the pre-exponential constant B such that B=10^b.

Short-term test results	Linear curve fit parameters of log-log plot
Slope of log-log curve fit, m	
Intercept of log-log curve fit, b	
	Parameters for $\dot{\varepsilon}_{\min} = B\sigma^n$
n=m	
B (MPa^{-n} /s)=10^b	

6) Summarize the results and calculate the prediction of minimum strain rates for the long-term stresses using B and n determined from the short term results. Calculate the differences between the predicted long term strain rates and the measured long terms strains.

Short-term test	$\dot{\varepsilon}_{\min}$ (s^{-1})
Force #1, σ = MPa	
Force #2, σ = MPa	
Force #3, σ = MPa	
Force #4, σ = MPa	

Short-term test results	Parameters for $\dot{\varepsilon}_{\min} = B\sigma^n$
B (MPa^{-n} /s)	
n	

Long term tests	$\dot{\varepsilon}_{\min}$ (s^{-1})
σ = MPa, $\dot{\varepsilon}_{\min}$ measured	
σ = MPa, $\dot{\varepsilon}_{\min} = B\sigma^n$	
% difference	
σ = MPa, $\dot{\varepsilon}_{\min}$ measured	
σ = MPa, $\dot{\varepsilon}_{\min} = B\sigma^n$	
% difference	

7) If possible, compare the n and B values to book values for this solder alloy at room temperature. Discuss any differences. Discuss differences between measured and predicted minimum creep strain rates for the long-term tests discussions about limitations about predicting long-term creep behaviour from short term test results. Schematically sketch curves of creep strain vs. time and show how strain rate calculated at short times (i.e. short term tests) could be different from the strain rate determined at long times (i.e. long term tests).