ME 354, MECHANICS OF MATERIALS LAB

CREEP

February 2010 NJS

PURPOSE

Creep is an important factor in the time-dependent mechanical failure of engineering components. The aims of this exercise are to study the effect of uniaxial loading on creep deformation by characterizing the steady-state creep behavior of a solder wire at room temperature. Specifically, creep tests[1] for different applied loads will be used to measure the values of B and m in the power law stress-creep strain rate relationship $\dot{\varepsilon} = B\sigma^m$ during the secondary creep response. You will then compare your estimations of creep strain to the measured data to determine the accuracy of the creep values B and m.

EQUIPMENT

1) Solder wire: The wire has a constant diameter and is composed of 50% tin, 50% lead alloy. The wire is spooled so you will need to cut it with scissors. Straighten the wire as best you can before testing.
2) Timer: Most cell phones have this feature.
3) Standard creep test machine: This is a dead-weight loading setup with top and bottom grips and a balanced lever arm for the applied load. The specimen is loaded in axial tension. A dial extension gage is mounted upside-down (because that's the direction gravity works). You will use the gage to measure the extension in the specimen (ΔL).
4) Metric ruler or caliper: You will use this to measure the diameter and length of the specimen
5) Load pan (m_p = 103 g)
6) Calibrated masses: You will use dead-weights (0.5, 1.0, 2.0, or 5.0 kg) to apply constant load to the specimen during testing.
7) Electronic Thermocouple
8) *Items to bring*:
    a) Paper to record data
    b) Calculator.
9) *Suggested items*:
    a) Dowling's book
    b) ASTM Standards, Vol. 3.01 E139
    c) Camera to document the test
    d) Laptop for data analysis – check if tests need to be rerun

[1] ASTM Standards, Vol. 3.01 E139

PROCEDURE

Since you will be handling LEAD (Pb) material, you MUST wash your hands with soap and water immediately after the lab.

1) Cut four lengths of solder wire to a length of 140-150 mm with scissors.
2) Straighten the solder wire as best as you can to remove the bends and kinks. Rolling it between the benchtop and flat surface will work, but do not provide excessive force.
3) Measure the initial diameter d_i of the gage section for each test specimen
4) Install the top end of the specimen in the top grip of the creep test and lightly tighten the wing-nut.
5) Install the bottom end of the specimen in the lower grip and lightly tighten the wing-nut. You will need to adjust the position of the lever arm so that it is in contact with the dial extension gage.
6) Once the specimen is properly seated in the creep test, tighten down both top and bottom wing-nuts with as much finger strength you have so that the specimen will not slip during testing.
7) Measure the initial gage length of the test specimen.
8) Zero the reading on the dial extension gage.
9) Apply the weight of the load pan (m_p) plus dead-weight mass (m_a). Gently lower the hook of the load pan onto the lever arm of the creep testing apparatus and immediately start the timer.
10) Record the elongation until 5% strain is reached. The more weight that is applied to the specimen will make the test go faster. Record the reading from the dial extension gage at 10 second intervals for the first minute and if necessary, every 30 seconds until 5 minutes and then every minute thereafter.
11) Record the room temperature using the thermocouple. Creep is a temperature-dependent process.

BACKGROUND AND ANALYSIS OF RESULTS

Solder is a eutectic alloy used to make electrical conducting connections between wires on printed circuit boards and microelectronic components such as integrated circuits, resistors, transistors, capacitors, inductors, MEMS components[2], etc. These components can be easily damaged by excessive heat so solder must have a low melting temperature in order to form the electrical connections. However, the low eutectic point (~ 200ºC) also makes creep behavior a problem for these devices. Most solder joint failure fall under three major categories: 1) tensile fracture due to stress overloading greater than the ultimate strength; 2) creep failure due to long-term applied load; and 3) fatigue failure due to applied cyclic loads. For this lab, we will study the creep behavior of solder. In the real-world, creep may come from a printed circuit board that is bent and stressed when mounted, for example, in a computer's chassis or by thermal expansion of the wires. Long-term conditions of the board in a stressed position will cause the mounted microelectronic devices to be under constant mechanical loading and thus can lead to creep failure.

[2] MEMS = Micro-Electro-Mechanical Systems (e.g., accelerometers, pressure sensors, micromirrors, etc.)

Creep can be defined as a time-dependent deformation that becomes more severe with temperature. In a material, creep occurs at temperatures below its melting temperature. A more specific description is that creep occurs at a *homologous temperature* equal to or greater than 0.3 to 0.6, where *homologous temperature* is defined as the ratio of the material's current temperature to its melting temperature on a Kelvin scale (T/T_m). For our tests with solder, the homologous temperature is 295 K / 473 K = 0.6, so creep is clearly a design concern. Steel melts at 1500ºC, so creep might be expected to creep at around 600ºC (T/T_m = 873 K / 1773 K = 0.49). The "take-away message" is that creep is not necessarily dependent on *absolute* high temperatures, but is depended on *relatively* high temperatures that depend on the crystalline behavior of the material and its melting temperature.

Creep tests are carried out by loading a sample and observe the development of strain as a function of time, for a given temperature and stress. Often the creep testing machine is placed inside a furnace with a thermocouple attached to study the creep behavior at elevated temperatures. The measured strain vs. time data will have three distinct portions: the primary creep region (transient), the secondary creep region (steady-state), and the tertiary creep region (unstable, accelerated). An example of creep strain-time behavior is shown in Figure 1. The secondary region takes the longest amount of time: the primary is transient due to the applied load at the beginning of the test and the tertiary quickly accelerates to stress rupture. Thus, the linear, steady-state behavior in the secondary region is the most important in practice to characterize and can be used to determine how long a material can be used safely or effectively. In the secondary region, the rate at which strain occurs, i.e. the creep strain rate, which is the slope of the strain-time curve, is given by

$$\dot{\varepsilon} = B\sigma^m \tag{1}$$

where σ is the stress, B is the proportionality constant, and m is the stress-exponent.

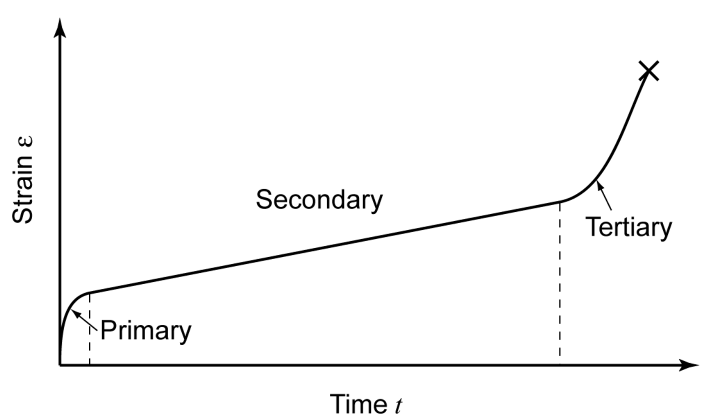

Figure 1. Creep deformation curve illustrating strain-time behavior until stress rupture (×).

THINGS TO INCLUDE IN YOUR REPORT

In this lab, we aim to measure the steady-state creep and evaluate the match of Eq. 1 to the data. For each applied load, you will use a least-squares regression fit through the linear portion of the strain-time curve to find the strain rate ($\dot{\varepsilon}$). You will then plot the values of strain rate versus applied stress on a log-log plot. From this approach, you will be able to obtain values for the constants in Eq. 1 using another least-squares fit.

1) Calculate the values of creep strain from the experimental data.
2) Create a plot of creep strain vs. time for each applied load on the same graph.
3) Find the creep strain rate $\dot{\varepsilon}$ for the secondary creep response for each test.
4) Create a table of the applied stress, creep strain rate, the logarithm (base 10) of the applied stress, and creep strain rate.
5) Create a log-log plot of creep strain rate vs. applied stress.
6) Determine the values of m and B from the slope and intercept from a linear fit.
7) Make a plot of creep strain vs. time with measured and predicted behavior for comparison. Determine the appropriateness of the values of m and B by percent error.

CREEP WORKSHEET

Temperature:

Mass m_a =	**3 kg**
Pan m_p =	kg
Diam. d_i =	*mm*
Length L_i =	mm
Time (s)	**ΔL (mm)**
0	
10	
20	
30	
40	
50	
60	
90	
120	
150	
180	
210	
240	
270	
300	
360	
420	
480	
540	
600	
660	
720	
780	
840	
900	
960	
1020	
1080	
1140	

Mass m_a =	**4 kg**
Pan m_p =	kg
Diam. d_i =	*mm*
Length L_i =	mm
Time (s)	**ΔL (mm)**
0	
10	
20	
30	
40	
50	
60	
90	
120	
150	
180	
210	
240	
270	
300	
360	
420	
480	
540	
600	
660	
720	
780	
840	
900	
960	
1020	
1080	
1140	

Mass m_a =	**5 kg**
Pan m_p =	kg
Diam. d_i =	*mm*
Length L_i =	mm
Time (s)	**ΔL (mm)**
0	
10	
20	
30	
40	
50	
60	
90	
120	
150	
180	
210	
240	
270	
300	
360	
420	
480	
540	
600	
660	
720	
780	
840	
900	
960	
1020	
1080	
1140	

Mass m_a =	**6 kg**
Pan m_p =	kg
Diam. d_i =	*mm*
Length L_i =	mm
Time (s)	**ΔL (mm)**
0	
10	
20	
30	
40	
50	
60	
90	
120	
150	
180	
210	
240	
270	
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