

15.

Creep of Lead-Tin Solder at Room Temperature

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NOTE: THE EXPERIMENT BELOW IS A MODIFIED VERSION, FOR A HIGH SCHOOL AUDIENCE, OF AN EXPERIMENT PRESENTED BY R. G. STANG OF THE UNIVERSITY OF WASHINGTON AT A PREVIOUS NATIONAL EDUCATORS' WORKSHOP

BACKGROUND:

Creep is a slow extension of a material in response to a comparatively low stress. Under a constant load, extension of the material results in a reduction in cross-section area, so stress increases under constant load. The higher the stress, the higher the creep rate until failure finally occurs. In metals, creep can occur at any temperature higher than approximately half the absolute melting point (Celsius melting point + 273). Thus creep is not a problem for common metals used at ordinary temperatures. By choosing the right alloy, however, creep can be demonstrated at room temperature, and the creep of common lead + tin solder is the subject of this experiment.

Lead-tin solder has a melting point of 183 C (456 K), so room temperature at 298K is more than half this temperature. Thus we would expect creep to occur at room temperature in solder if it is put under sufficient stress. This is also why a soldered electrical connection should always include a mechanical connection, so that stresses on the soldered joint are minimized.

Creep is also a relevant failure mechanism for high-temperature engines, such as jet turbines. The need for greater efficiency and power output drives temperatures ever higher, and this makes creep an ever-more-present failure mechanism despite our best efforts to prevent it. As an example of creep-prevention methods, consider the fact that creep is enhanced by fine-grained metals. Turbine blades in the hottest sections of today's engines are now frequently composed of a single grain, a triumph of materials processing.

EXPERIMENTAL AND DATA ANALYSIS:

The test material used in this lab was 60/40 tin/lead solder with a solid core (no built-in flux) purchased from Cline Glass Co. in Portland, OR. This material had an outside diameter of 0.121 inches. The first task was to fabricate specimens that would not fail due to end effects. One practical method is to first allow approximately 8 inches of extra wire at each end of a specimen, and to loop the wire twice a piece of $\frac{3}{4}$ " hardwood dowel about 1" long, with a $\frac{1}{4}$ " hole drilled lengthwise through it. Once the solder wire is looped around this end grip, it is wrapped around itself at least 6 times to preclude slippage, and about $\frac{1}{2}$ in. of material is left projecting perpendicular to the wire to be stressed. This should all be done by hand, to avoid nicking the solder using tools. The distance between the two ends is measured as a function of time, and is regarded as a

gauge length. A photograph of a finished specimen is below, see Fig. 1. A total of 5 of these specimens were made, four of them with a gauge length of about 6" and one with a gauge length of about 18". The longer specimen was used to show that the strain calculation eliminates the effect of gauge length.

The creep specimens were stressed in the following manner: Specimen #1 had no added weight on it, and was intended as a control, to show that creep requires a minimum stress level to occur. Specimen #2 supported a weight of 1000 grams, producing a stress level (force/area) of about 200 pounds per square inch. Specimen 3 also supported a weight of 1 kg, with specimen 3 about 3 X as long as specimen 2. Specimen 4 supported a weight of 1.5 kg (stress level about 300 psi), to illustrate the faster failure that occurs when the stress is proportionately higher. Finally, specimen 5 supported a weight of 2000 g (about 400 psi) to be like #4 except more so. Note that all of these stress levels are rather trivial for metals, demonstrating that the stresses do not have to be very high for creep to occur in solder. In order to stress the specimens, the appropriate weights were suspended from their lower ends, while the upper ends were suspended from supports at the front of the classroom. After the creep experiment was started, measurements were taken twice per day, once in the morning and once just before leaving. Each specimen eventually failed at some tiny defect such as a nick where stress was higher, and the effect of this local overload was seen as "necking", which eventually led to local overstressing and failure. For convenience, the data were recorded in an Excel spreadsheet, and this spreadsheet was projected during each class for students to copy. In order to calculate the strains produced in the specimens by creep, the usual formula for strain was used:

$$\text{Strain} = (\text{gauge length at any time} - \text{original gauge length}) / \text{original gauge length}$$

Since the units of length cancel in the formula above, strain was expressed as a percentage. The Excel spreadsheet is shown in Table 1, as calculated strains as a function of time for the five specimens.

Strain versus time for the specimens is plotted in Fig. 2. Students were required to plot the data in this manner, and to explain the shapes and ordering of the curves. Note that, as expected, the specimen with no added weight exhibited no strain during this experiment, and would not be expected to creep because the stress from its own weight is below the critical creep stress at room temperature for solder. The creep rate of the specimens is powerfully affected by stress, with higher stress producing higher creep rates and failure in shorter times. Note also that all the curves have basically the same shape; this is because, as the specimens stretch, the cross-sectional area must decrease, increasing the stress. Consistent with the previous statement, the higher stress produces higher creep rates. The failure time is also very sensitive to the stress level. Figure 3 shows the current high-strain record-holder, a specimen loaded with 700 grams of weight (stress = 110 psi) that has not failed while undergoing almost 600% strain. This strain could undoubtedly be exceeded, with careful enough specimen preparation, an even lower stress level, and enough time.

This experiment has been performed for several years at my high school, and is a good way to show this metal failure mechanism at minimum trouble and expense. The only change that seems reasonable is to add one more specimen, stressed by 500 grams of

weight. Though not included in this write-up, this has been done and strains have exceeded 300%, a dramatic example of creep. At this lower stress level, failure times are often more than a week, depending on ambient temperature. Specimen #5 could also be eliminated, since the idea of higher stress effects is conveyed by specimen #4.

CONCLUSIONS:

1. Common lead-tin solder creeps at room temperature, and is thus a convenient model material to demonstrate creep in metals.
2. Strain at failure and time to failure are strongly influenced by the applied stress.

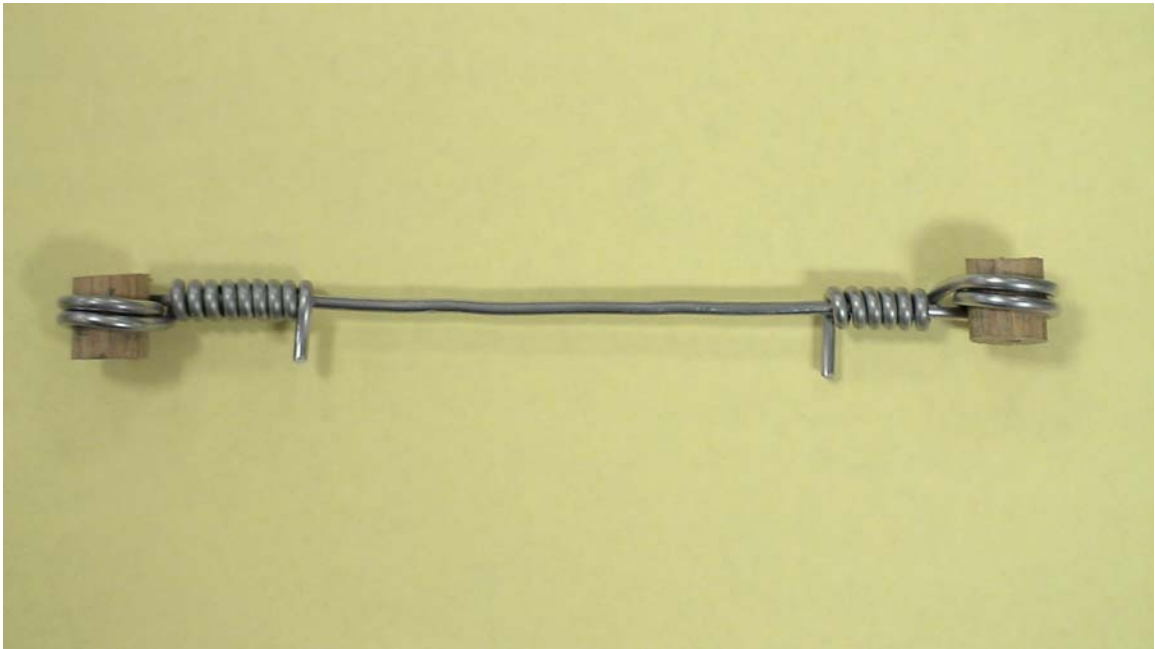


Figure 1. Solder Creep Specimen Ready for Use.



Figure 2. Highest-Strain Specimen Tested to Date; Strain is Almost 600%.

Time, h	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5
0	0	0	0	0	0
15	0	5.3	6.6	19.8	43.2
23	0	9	10.3	32.7	85.6
39	0	15	17.9	69.8	
47	0	18.8	21.3	100	
63	0	26.3	28.5		
71	0	30.1	34.7		
87	0	41.3	46.6		
95	0	46.6	52.4		
111	0	61.6	68.3		

121 0 121 122.6
 Table 1. Creep Strain (%) for the Five Specimens, as a Function of Time

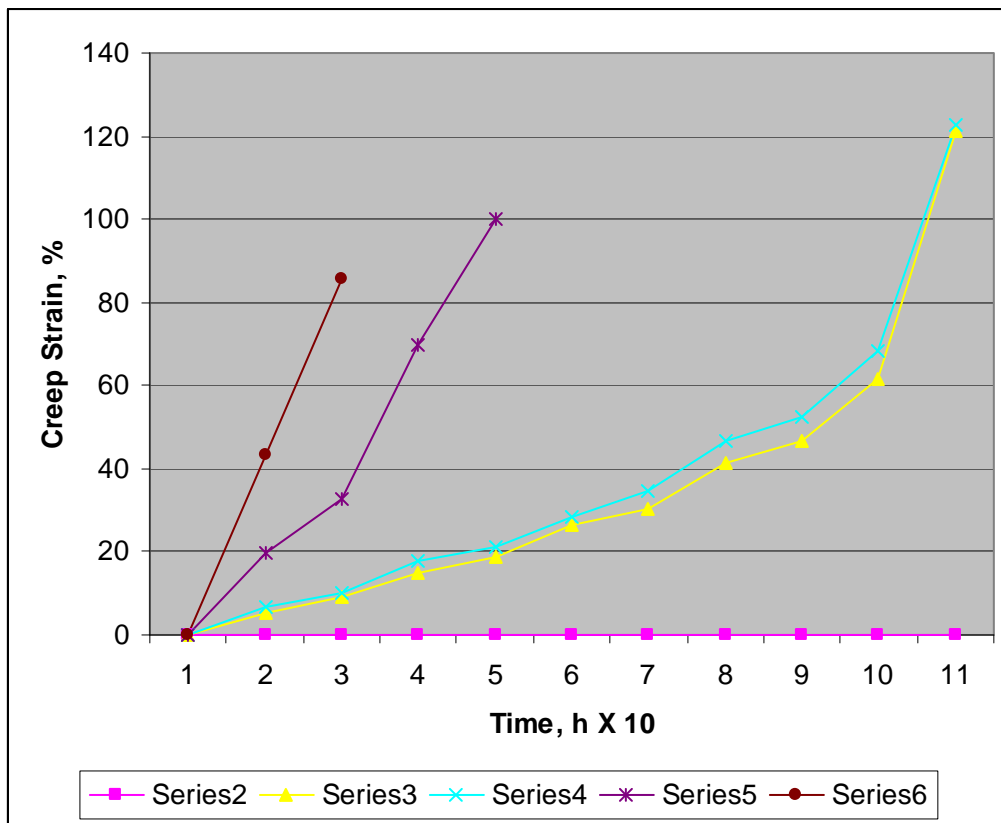


Figure 3. Plotted Solder Creep Data as a Function of Time. “Series 2” is Spec. 1, “Series 3” is Spec. 2, etc.