A Low-Temperature Creep Experiment Using Common Solder

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Abstract: This experiment uses common lead-tin solder as a model material to demonstrate creep in metals at room temperature. By using two specimens loaded with the same stress but with different gauge lengths and under the same stress, the concept of the strain is well illustrated. The data are plotted in a simple manner, but analysis easily shows the effect of increased stress due the reduction in specimen cross-section as strain increases.

Objectives: To demonstrate creep as a phenomenon in metals, without using expensive furnaces or equipment, to reinforce the concepts of stress and strain.

Student learning objectives: Students see creep actually happening, and by developing a graphical plot, realize the role of stress in determining the creep rate in a metal alloy.

MatEd Core Competencies covered:

0.A	Demonstrate good communication skills
0.B	Prepare tests and analyze data
1.A	Carry out measurements of dimensions and physical properties
7.G	Define stress and strength
7.H	Define strain and deformation
16.B	Describe the effects of defects on material properties

Key words: Creep, solder, stress, strain

Type of Module: Laboratory Experiment

Time Required: Approximately 1 week, with experiment conducted at the front of the classroom; observation requires only a few minutes per class period, so the experiment and run concurrently with other instruction.

Pre-requisite knowledge: Introduction to concepts of stress and strain in mechanical testing would be helpful.

Target Grade Levels: 11^{th}-12^{th} grade and introductory college courses.

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Equipment and Supplies Required:

Solid-core lead-tin solder (no built-in flux):

The test material used in this lab was 60/40 tin/lead solder. Be sure that it is solid core solder with no built-in flux. You can also try (or compare) other solder compositions. Solder diameter used in this experiment was 1/8 inch; larger diameters will need heavier weights.

Also:

Brass weights, meter stick, graph paper.

Curriculum overview and notes for the instructor

This experiment is a modified version, for a high school audience, of an experiment originally developed by Prof. Robert Stang and the University of Washington. His approach, however, used a tensile testing machine and mathematical analysis of the data that is beyond most introductory technology or high school classes and students. The intent of this work is to adapt that experiment for use as an introduction without the mathematical finesse. In this experiment, the mechanical testing machine is replaced by dead weights, and the gauge length of the specimens is measured when convenient, using a common meter stick.

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 the melting 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 if possible, 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.

Module Procedure:

1. Sample preparation: 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 around a piece of ¾" hardwood dowel about 1" long, with a ¼" hole drilled lengthwise through it (see Figure 1). Once the solder wire is looped around this end grip, it is wrapped

around itself at least 6 times to preclude slippage, and about ½ in. of solder is left projecting perpendicular to the wire to be stressed (to be used as a guide in measuring the sample length during the experiment). This should all be done by hand, to avoid nicking the solder using tools. Premature failure may occur at any nicks. The distance between the two ends is measured as a function of time, and is regarded as a gauge length. A total of 5 of these specimens is suggested, four of them with a gauge length of about 6" and one with a gauge length of about 18". The longer specimen is used to show that the strain calculation eliminates the effect of gauge length.

2. Sample testing: The creep specimens are stressed in the following manner: Specimen #1 has no added weight on it, and is intended as a control, to show that creep requires a minimum stress level to occur. Specimen #2 supports a weight of 1000 grams, producing a stress level (force/area) of about 200 pounds per square inch. Specimen 3 also supports a weight of 1 kg, with specimen 3 about 3 X as long as specimen 2. Specimen 4 supports 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 supports 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 once you are above half the melting temperature. In order to stress the specimens, the appropriate weights are suspended from their lower ends, while the upper ends were suspended from supports at the front of the classroom.
3. Measurement and observation: After the creep experiment is started, measurements should be taken twice per day, once in the morning and once just before leaving. Each specimen eventually will fail at some tiny defect such as a nick where stress was higher, and the effect of this local overload is seen as "necking", which eventually leads to local overstressing and failure.
4. Data Recording: For convenience, the data may be recorded in an Excel spreadsheet, and this spreadsheet projected at the start of each class for students to review or copy. Strain should be calculated for each data point. The formula for strain is:

   Strain = (gauge length at any time-original gauge length)/original gauge length

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

   Strain versus time for this example is plotted in Fig. 3. Students should be 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 (#1) 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. Also, note that Specimens 2 and 3 plot almost identically even though differing greatly in length, because the strain calculation automatically adjusts for sample length. The creep rate of the specimen 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 2 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 Southridge High School, and is a good way to show this metal failure mechanism at minimum trouble and expense. One possible change could be to add one more specimen, stressed by 500 grams of weight. 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. For comparison, other solder compositions could be tried, as could be other materials such as nylon fishing line. Conclusions from this experiment:

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.

Supporting Materials: see attached

Reference:

Solid core solder may be available at your local hardware store. Other options include

1. Cline Glass Co., http://www.clineglasscompany.com/products/product_index.shtml
2. Discount Tools, http://www.discount-tools.com/catalogs/gen/420.pdf

Acknowledgement:

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Evaluation Packet:

Student evaluation questions (discussion or quiz):

1. Why is solder used for this experiment instead of some other metal or alloy?
2. Why do we use strain as the measure of creep?
3. Does the length of the specimen determine creep behavior?
4. What would happen if we doubled the diameter of the specimen with other variable remaining the same?

Instructor evaluation questions:

1. At what grade level was this module used?
2. Was the level and rigor of the module what you expected? If not, how can it be improved?

3. Did the lab work as presented? Did they add to student learning? Please note any problems or suggestions.
4. Was the background material sufficient for your background? Sufficient for your discussion with the students? Comments?
5. Did the lab generate interest among the students? Explain.
6. Please provide your input on how this module can be improved, including comments or suggestions concerning the approach, focus and effectiveness of this activity in your context.

Course evaluation questions (for the students)

1. Was the lab clear and understandable?
2. Was the instructor's explanation comprehensive and thorough?
3. Was the instructor interested in your questions?
4. Was the instructor able to answer your questions?
5. Was the importance of materials testing made clear?
6. What was the most interesting thing that you learned?

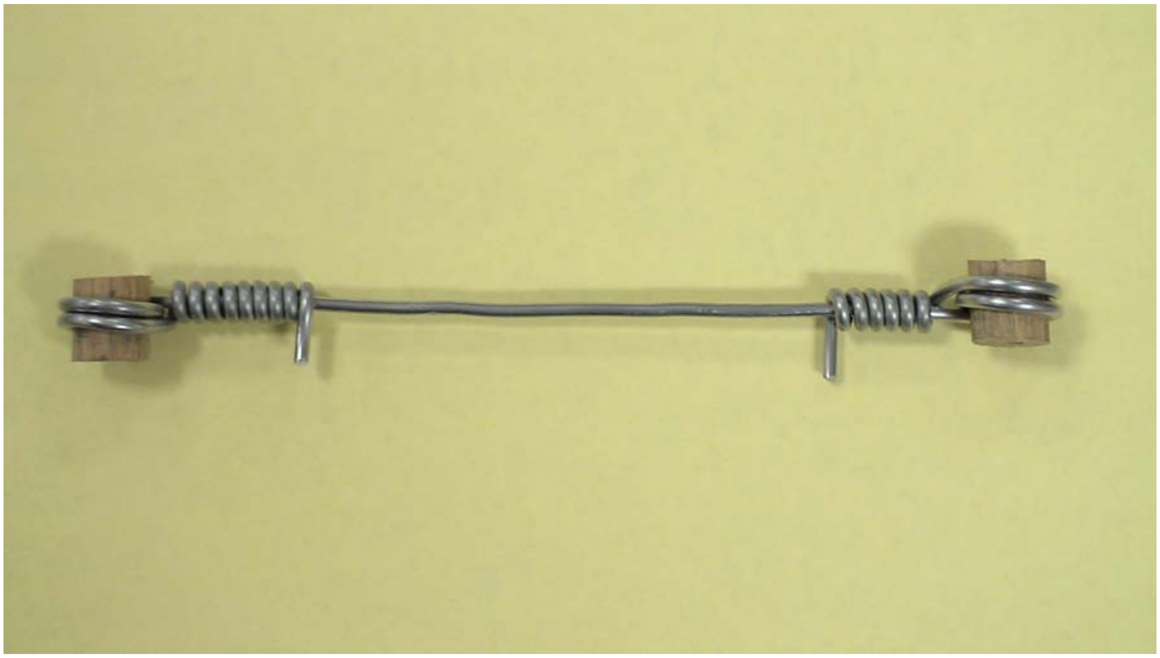

Figure 1. Solder Creep Specimen Ready for Use.

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

	W=0	W=1000g	W=1000g	W=1500g	W=700g
	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5
t=0 h	6.5 cm(0)	6.1 cm	30.9 cm	5.2 cm	4.9 cm
t=7 h	6.5 cm(0)	6.5, 6.6	32.0, 3.6	6.2, 19	4.9, 0
t=23 h	6.5 cm(0)	7.7, 26	34.3, 11.0	10.3, 98	5.0, 2
t=30 h	6.5 cm(0)	8.2, 34	35.6, 15	12.1, 133	5.1, 4
t=47 h	6.5 cm(0)	9.1, 49	38.9, 26	17.9, 244	5.8, 18
t=54 h	6.5 cm(0)	9.7, 59	40.5, 31	21.7, 317	5.6, 14
t=71 h	6.5 cm(0)	10.8, 77	44.9, 45	40.7, 683	5.9, 20
t=72 h				Broke	
t=78 h	6.5 cm(0)	11.5, 89	46.7, 51		5.9, 20
t=106 h	6.5 cm(0)	14.7, 141	56.0, 83		6.5, 33
t=121 h	6.5 cm(0)	16.8, 175	62.3, 107		6.8, 39
t=143 h	6.5 cm(0)	20.9, 243	73.9, 146		7.3, 49
t=150 h	6.5 cm(0)	22.9, 275	79.9, 164		7.3, 49
t=174 h	6.5 cm(0)	29.4, 382	98.5, 227		7.8, 59
			Broke, 177 h		
t=182 h	6.5 cm(0)	34.8, 471			8.0, 63

Table 1. Typical Data Set. At each time after test start, each entry contains the gauge length at the time of measurement, then the calculated strain at that time.

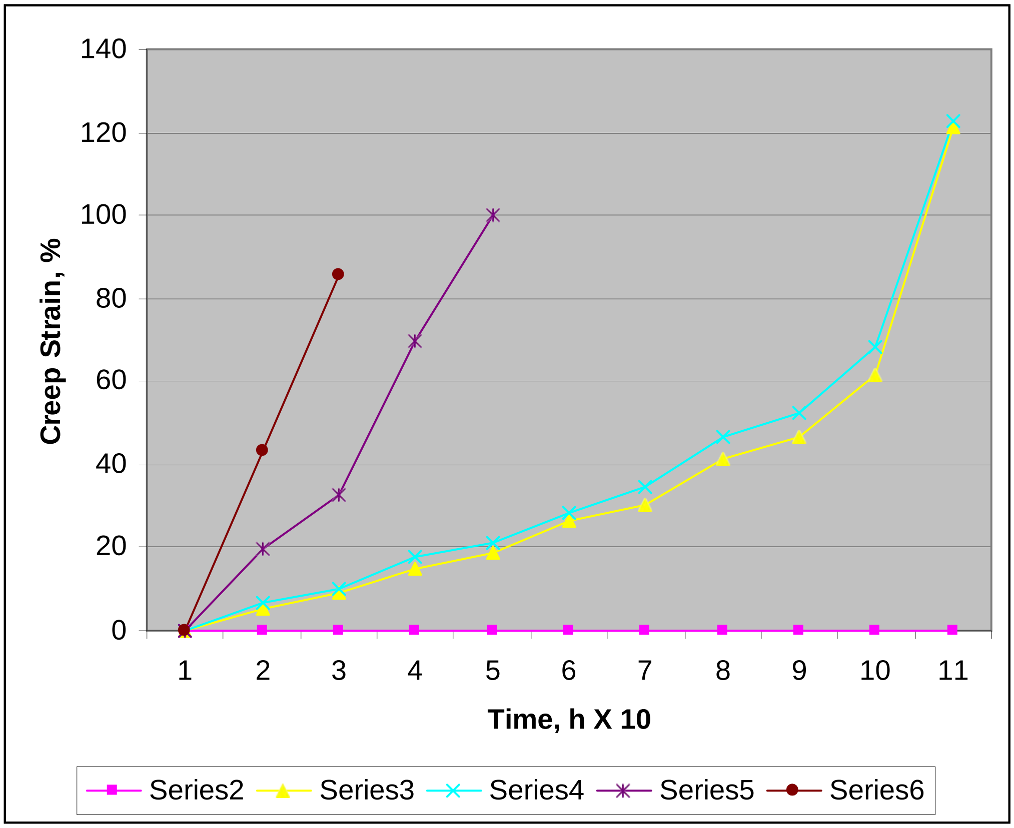

Fig. 3. Creep Strain in Lead-Tin Solder as a Function of Stress and Time. Series 2 is Specimen 1, while Series 3 and 4 are Specimens 2 and 3. Series 5 is Specimen 4, and Series 6 is Specimen 5.