

## **Author's Instructions for ME354 Formal Laboratory Report**

by

Author's Name

Author's Laboratory Section, Day, Time, Date of this Laboratory Exercise

Author's LaboratoryTA

**Date of Laboratory Report:** (usually the official due date)

**Report submitted to:** Instructor of the course

### **Executive Summary:**

The executive summary should provide a brief description of the objectives, procedure, results and conclusions of the laboratory exercise. Total verbiage should be ~300 to 500 words. Quantitative results (e.g., % of error) should be given to add credibility to conclusions.

## OBJECTIVES

The Objectives section provides an introduction to the laboratory report through a short statement of the goals of the experiment or test. Keep in mind that every experiment has a hypothesis (i.e., what do I expect?). Very few, if any, experiments are "what if" exercises.

The objectives must provide some background (i.e., some lead in thoughts justifying the laboratory exercise) as well as describing the goals of the exercise. For example:

*Mechanics of materials provides basic equations to determine the stress state in a beam in bending. Experimental mechanics provides means to measure the strain state in a beam in bending. Continuum mechanics provides constitutive relations to relate stress and strain.*

*In this laboratory exercise, a strain-gaged beam was subjected to a measured force. The strain state was determined using uniaxial and rosette strain gages. Constitutive relations were used to calculate the experimentally-determined stresses from resulting strain measurements. These stresses were compared to analytically-determined stresses to assess how well analytical methods match the experimental results. Specific objectives included: a) to familiarize the user with strain gages and associated instrumentation, b) to measure deflections and compare these to predicted deflections, and c) to verify certain aspects of stress-strain relations and simple beam theory.*

## TEST DESCRIPTION

The Test Description section must provide such sufficient detail regarding the test setup to allow replication of both the test itself and the test results. Replication is necessary to verify the test and to allow someone else to setup and run a test in the future.

Describe the type of experiment or test, the material tested, and the apparatus used in the experiment or test (include an illustration of the actual experimental set up used). A detailed description of the apparatus (usually contained in an Appendix) should include make, model and serial number (if possible). Description of the test material should include the proper specification for the material. Illustrations should be referred to in the text by figure number with a proper caption for each figure. For example:

*Uniaxial tensile tests of reduced gage section tensile specimens (see Fig. 1) were conducted on four different materials per ASTM E8M "Standard Test Methods of Tension Testing of Metallic Materials [Metric]." Materials tested included a low carbon steel (1018-hot rolled), a structural aluminum alloy (6061-T6), a ductile polymer (polycarbonate), and brittle polymer (polymethylmethacrylate). All tensile specimens were fabricated on a conventional lathe from 7.9 mm diameter rod stock.*

*As shown schematically in Fig. 2, a servo-hydraulic, universal test machine (Instron Model 8511) with a digital controller and computer interface was used to conduct the tests. Force capacity was 20 kN. The stroke range was  $\pm 50$  mm. The clip-on extensometer had a range of  $\pm 40\%$  with a 12.7 mm initial gage length. Manually-operated, wedge grips with V-grooved faces were used to grip the specimens. Digital data (force, stroke and strain displacement) were acquired at a rate of 5 points per second up to 1 minute of test time, and 2.5 points per second after 1 minute of testing. A complete list of equipment is contained in Appendix C.*

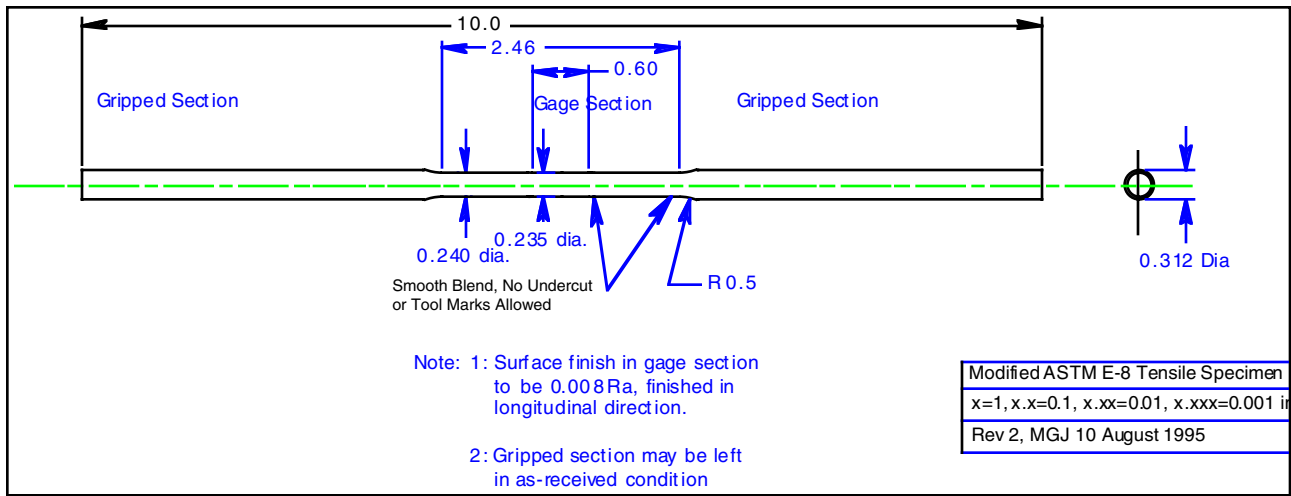


Figure 1 - Reduced-gage section, tensile specimen.

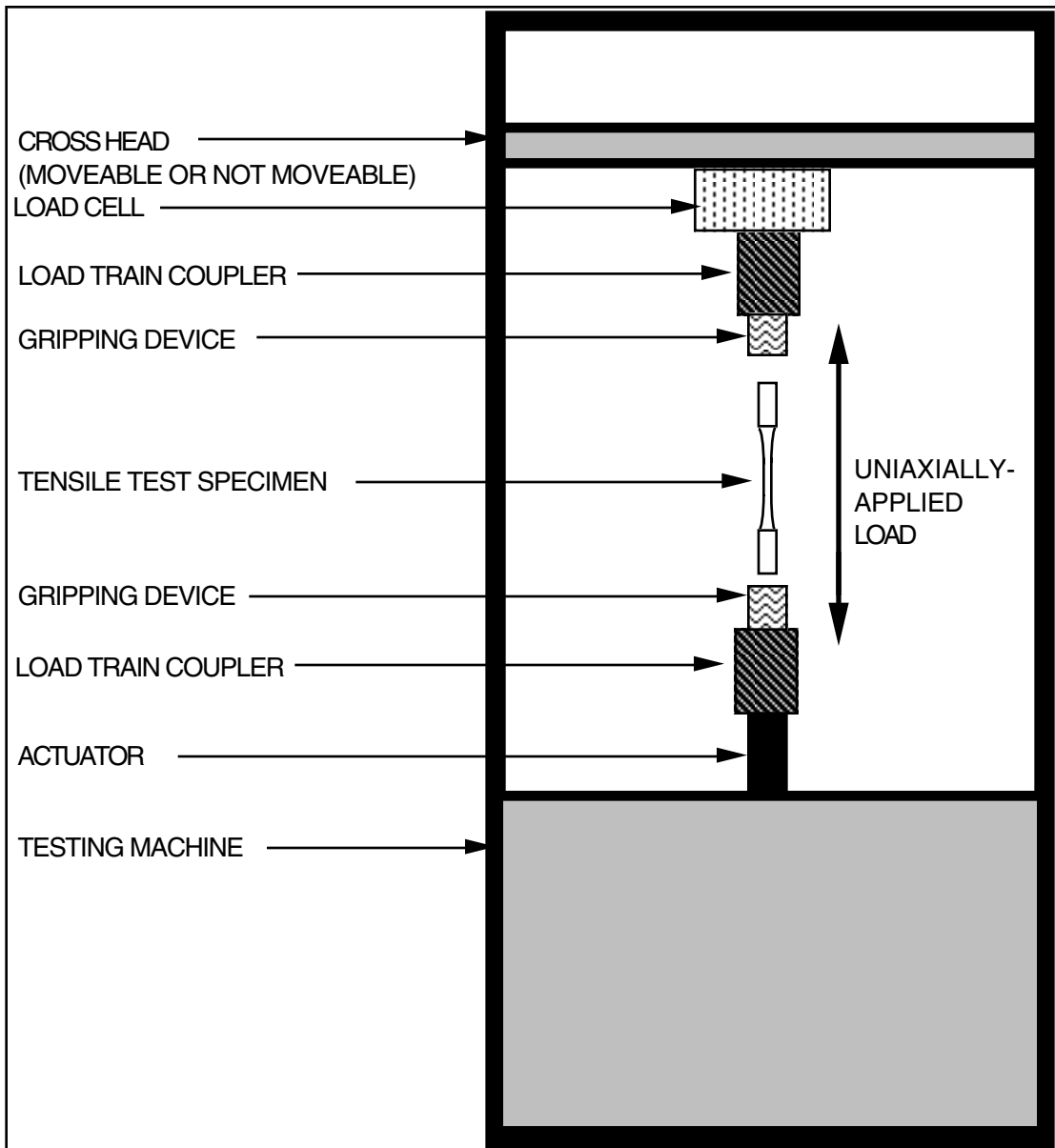


Figure 2 - Schematic illustration of a tensile test setup.

## RESULTS

The Results section contains calculated results, graphs, tables, and final equations in a coherent and understandable manner. Explanations must be given to provide the reader with an understanding of how reduced results were obtained. Each graph, table, etc. must have a figure caption or table heading and must be referred to the text in support of the presented results. Place raw data (such as strip chart plots and data sheets) in an Appendix.

Just showing a large number of graphs and tables without supporting text is not coherent and understandable!! However, the Results section should not contain excessive verbiage since detailed explanations and interpretation are best left to the Discussion section. For example:

*The primary test results from the room-temperature creep tests of the lead-tin solder are in the form of relative displacement versus time data sets (See Appendix A for raw data sets). However, these raw data were reduced to more meaningful engineering results by calculating the engineering strain,  $\epsilon$ , such that:*

$$\epsilon = \frac{\Delta L}{L_0} \quad (1)$$

*where  $\Delta L$  is the relative displacement and  $L_0$  is the initial gage length. (See Appendix B for sample calculations).*

*The resulting strain versus time plots are shown in Fig. 3 for four different pan masses (4, 6, 7, and 8 lb) corresponding to four different stresses ( $\sigma=4.48, 6.64, 7.89$  and  $8.90$  MPa). Note that as expected, as the stress increased, both the levels and shape of the strain-time curves changed.*

*The strain-time results were further reduced by calculating the creep strain rate (i.e., the derivative,  $d\epsilon/dt$ ) as a function of time,  $t$ . The minimum creep strain rate,  $\dot{\epsilon}_{\min}$ , was then found for each applied stress as shown in Table 1. A power law relation between minimum strain rate and applied stress was assumed such that:*

$$\dot{\epsilon}_{\min} = B\sigma^n \quad (2)$$

*where  $B$  is the pre-exponential coefficient and  $n$  is the creep stress exponent. The data was linearized by taking logarithms of both sides of Eq. 2. These results are plotted in Fig. 4. A least squares, linear regression of data was then used to determine  $A$  and  $n$  as shown in Table 1.*

*Finally, long-term test results obtained previously are compared in Fig. 4 to the short-term results determined in this exercise. Note that when  $B$  and  $n$  determined from the short-term tests were substituted into Eq. 2 to predict  $\dot{\epsilon}_{\min}$  from the stresses of the long-term tests, errors of 17 to 80% resulted (See Table 1 and Fig. 4). Graphically, this prediction is shown by the solid line in Fig. 4.*

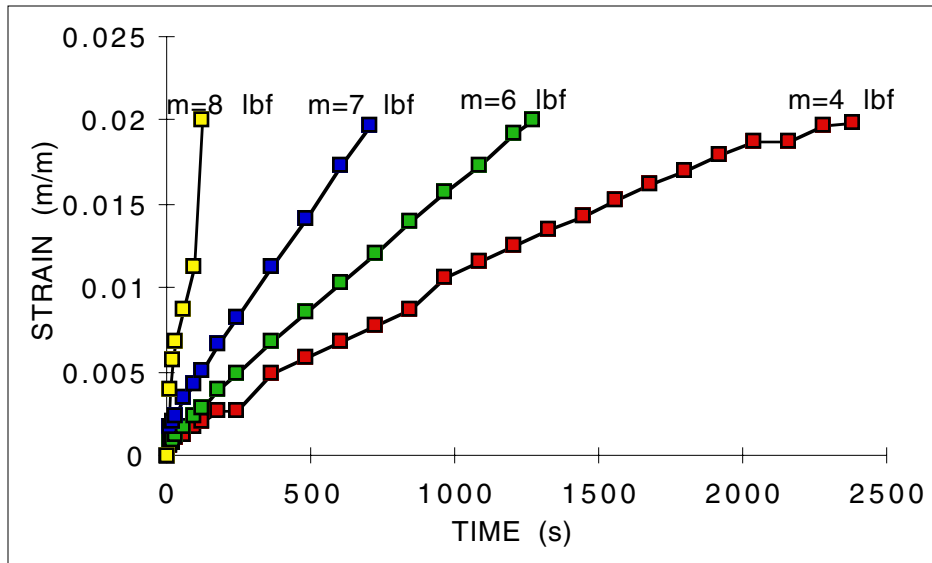


Figure 3 - Creep strain versus time for four different applied masses on a lead-tin solder at room temperature.

Table 1 Creep test results of solder for short and long-term tests

Short-term tests	$\dot{\epsilon}_{\min} \text{ (s}^{-1}\text{)}$
Force #1, $\sigma = 4.48 \text{ MPa}$	$7.8 \times 10^{-6}$
Force #2, $\sigma = 6.64 \text{ MPa}$	$1.5 \times 10^{-5}$
Force #3, $\sigma = 7.89 \text{ MPa}$	$2.5 \times 10^{-5}$
Force #4, $\sigma = 8.90 \text{ MPa}$	$7.6 \times 10^{-6}$
Short-term test results	Parameters for $\dot{\epsilon}_{\min} = B\sigma^n$
$B \text{ (MPa}^{-n} \text{/s)}$	$7.84 \times 10^{-8}$
$n$	2.97
Long term tests	$\dot{\epsilon}_{\min} \text{ (s}^{-1}\text{)}$
$\sigma = 1.32 \text{ MPa}$ , $\dot{\epsilon}_{\min}$ measured	$9.5 \times 10^{-8}$
$\sigma = 1.32 \text{ MPa}$ , $\dot{\epsilon}_{\min} = B\sigma^n$	$1.7 \times 10^{-7}$
% difference	80%
$\sigma = 1.82 \text{ MPa}$ , $\dot{\epsilon}_{\min}$ measured	$3.8 \times 10^{-7}$
$\sigma = 1.82 \text{ MPa}$ , $\dot{\epsilon}_{\min} = B\sigma^n$	$4.4 \times 10^{-7}$
% difference	17%

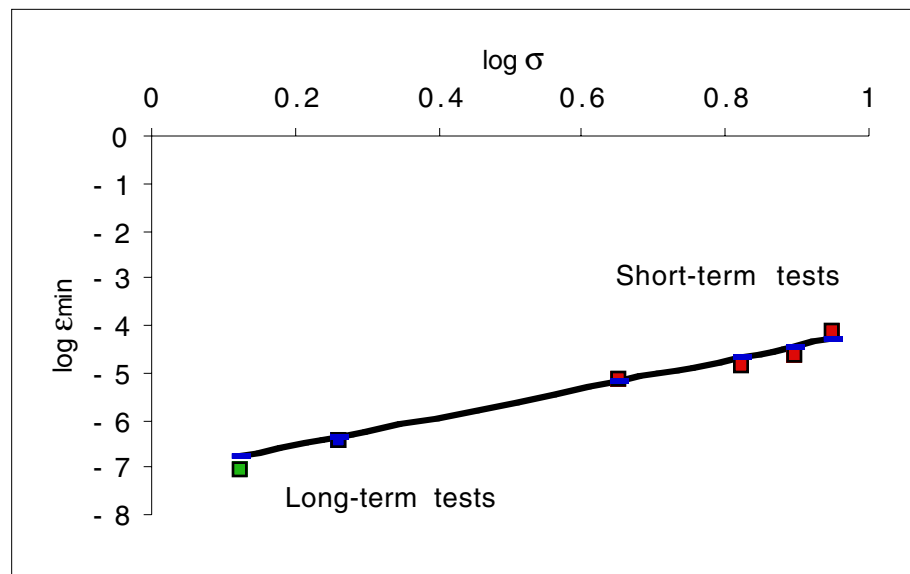


Figure 4 - Log creep strain rate versus log stress for a lead-tin solder at room temperature.

## DISCUSSION / CONCLUSIONS

In the Discussion / Conclusions section, discuss the results of the experiment or test through interpretation of data, error analysis (i.e. include all sources and discuss relative magnitude, probability, how ([quantitative  $\pm$ ] the error would affect the experimental results), etc. (Note: Answer the question - Did I get the results I expected? If not, why not?) If obtaining material properties, compare your experimental results to published data.

In this section, the results which are merely presented in the Results section are discussed in more detail. For example:

*Use of Eq. 2 to fit the creep results was fairly successful. Comparison of the A and n values obtained for the short term tests of this 60-40 lead-tin solder showed the A value to be in reasonable agreement ( $A=7.4 \times 10^{-8}$  for this experiment and  $A=2.6 \times 10^{-7}$  from the text, Mechanical Behavior of Material, N.E. Dowling, 1993, Prentice Hall). Similarly the n value was in reasonable agreement ( $n=2.9$  for this experiment and  $n=2.2$  from Dowling)*

*Although Eq. 2 can be used to obtain fairly good descriptions of the creep test results for the short term tests (see Fig. 4), use of the A and n values obtained from the short term tests to predict the long-term strain rates gave poor agreement (17-80% error). This poor agreement could be attributed to several factors. For example, the alloys from the long and short term tests may not have been the same, or the temperatures between the two tests may not have been the same, or the data was not recorded correctly for the two tests, or there is a change of creep mechanism between low and high stress tests.*

*However, the more plausible explanation is that the rule-of-thumb for predicting long-term creep from short-term test results was violated (i.e., test results should be at least 10% of the required prediction). In this case, the short term results were less than 3 hr whereas the long-term results extended to over 500 h. Thus, it seems reasonable that the so-called "minimum" strain rate for the short-term tests was actually still a transient strain rate rather than a steady-state strain rate (See Fig 5). The errors in predicting the minimum strain rates of the long-term tests are therefore due to the A and n values determined from the short-term tests not being representative of the steady-state strain rate behavior.*

Errors due to a small temperature change can be estimated by assuming an Arrhenius relation such that:

$$\dot{\epsilon}_{\min} = A\sigma^n \exp(-Q/RT) \quad (3)$$

where  $Q$  is the activation energy for creep,  $R$  is the universal gas constant and  $T$  is the absolute temperature. If the short-term tests are assumed to have been conducted at  $23^\circ\text{C}$  rather than  $20^\circ\text{C}$ , and an activation energy of  $100 \text{ kJ/mole K}$  is assumed, then for a universal gas constant of  $8.31 \text{ J/mole K}$ , the error due to a temperature difference of  $3 \text{ K}$  at room temperature can be shown to be on the order of  $\sim 1\%$  which is much less than the observed  $17\text{-}80\%$  error.

The salient conclusive points of this exercise can be enumerated as follows:

- 1) Creep strain and strain rates can be determined for a lead-tin solder alloy for various stresses at room temperature
- 2) The relation  $\dot{\epsilon}_{\min} = A\sigma^n$  can be used to describe the isothermal creep behavior.
- 3) Good agreement was not possible between long term results and predictions of long term behavior from short-term results because steady-state creep behavior had not been achieved in the short-term tests

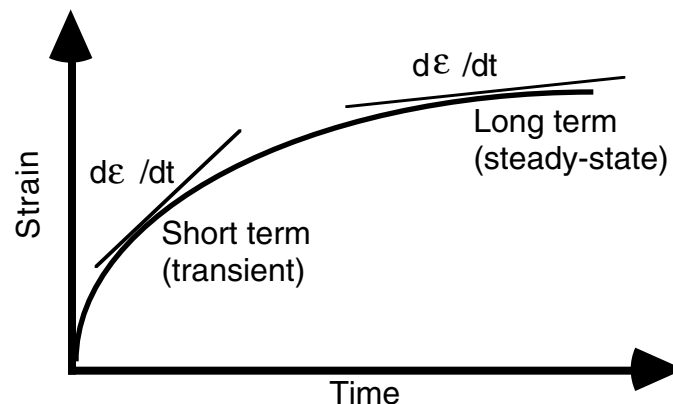


Figure 5 - Schematic illustration of higher strain rate for a short-term test compared to that of a long-term test

## APPENDIX

In the Appendix (or appendices) it is appropriate to include equations, calculations, or work which are secondary to the report including actual (or copies of) actual data sheets, strip chart plots, etc. If there is more than one appendix, it is a good idea to list the appendices in a short table of contents as shown. Each appendix should then be clearly labeled so the reader can refer to it by name.

## **APPENDICES**

- Appendix A** - *Raw Data*
- Appendix B** - *Sample Calculations*
- Appendix C** - *List of Equipment*
- Appendix D** - *References*



## **Appendix A - Raw Data**

*In this appendix, the raw data sheets for the exercise are contained .*