Creep Deformation in Solder Wire

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Abstract:

The aim of our experiment was to study the effect of uniaxial loading on creep deformation of a solder wire at room temperature. The Proving Ring Apparatus was used to perform the experiment by rolling the solder wire over the top and the bottom nail. Then, appropriate weights were kept on the weighing pan which was hung over the bottom nail. The change in length between two points separated by a distance of 15 cm on the wire was noted down and the strain v/s time graph was plotted for the same. Using the graph, the 3 regions of creep deformation was studied with more emphasis on the secondary region and the average stress exponent was obtained.

Introduction:

Creep is the tendency of a solid material to move slowly or deform permanently under the influence of mechanical stresses. Plastic deformation can occur even when the applied stress is less than the yield stress. Such deformation is called creep, where the plastic strain is dependent not only on the stress but also on time.

Solder is a metallic alloy which is used extensively in the electronics industry to make electrically conducting connections between wires and components. It is an alloy of lead and tin and has a very low melting temperature, therefore solder wire shows creep deformation at room temperature.

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. This is why we wish to understand the creep behavior of solder.

Creep deformation consists of three stages: primary, secondary and tertiary creep.

The central steady-state part is prolonged and the most important in practice, because it determines how long the material can be used safely. In the steady-state regime, the rate at which strain occurs is given by $\dot{\epsilon} = C\sigma^n$, where σ is the stress, C is a proportionality constant and n is known as the stress-exponent. Hence, we wanted to validate this result and correspondingly find out the stress-exponent.

Materials required:

Proving ring apparatus, 500 gram weighing pan, 2 weights of 100 grams each, 60-40 Lead-Tin solder wire, nails, meter scale, permanent marker, stopwatch, tape

Experimental Methodology:

1. Firstly, we thought of performing the creep on Universal Testing Machine but since the jaws of the UTM were too large to hold the small diameter solder wire, we had to find alternate methods. Also, UTM could not provide the feature of a constant load which was the essential part of the experiment.
2. Next option to perform the experiment was by using the Proving Ring Apparatus. We thought of using strain gauges to measure strain but due to budget constraints, weren't able to go ahead with it. Owing to the large change in the dimension of the wire during the trial experiment, we decided to measure the strain by using a meter scale. Also, this setup provided the required constant load.
3. We fixed the solder wire by rolling it over the end nails and using tape. The weight pan is to be held before starting the experiment so as not to load the solder wire.
4. Holding the weight pan, two points, 15cm apart are marked on the wire using permanent marker since we measure strain using these two points.
5. The weight of the weight pan is measured using a weighing machine which comes out to be 500gms. The meter scale is hung on the top nail.
6. The wire is loaded by adding 100gm weight on the pan which makes the total load 600gms. Note that creep occurs at a stress below the yield strength. So, the weight on the pan must be chosen accordingly.
7. Start the stopwatch immediately once you leave the pan freely. Note down the distance of the two points from the top end of the setup at intervals of 30 seconds initially and 1 minute after 10 minutes. This is to precisely examine the primary region.

8. After a long time (about 30-35 minutes), the solder wire will break after scanning through the tertiary region.
9. The distance between the two points divided by the initial length gives the engineering strain which is plotted against time

Quantities measured and calculated:

- **Strain:** Strain was calculated using the change in length between two marked points divided by the original length. The distances were measured using a meter scale
- **Time:** Time is measured right from the start of loading until the solder wire fractures. The length readings are noted after regular intervals of time measured by a stopwatch.
- **Strain Rate:** Strain rate is calculated from the slope of the secondary region.
- **Stress Exponent:** In the secondary region, the strain rate is directly proportional to stress to the power of n. This n is called stress exponent.

Results and Discussion:

- Here, the phenomenon of creep deformation at room temperature in lead-tin solder wire is investigated by uniaxial tension.
- In the secondary region, the rate of creep is constant and this is analyzed through our experiment.
- The phenomena of tertiary and primary regions are also briefly touched upon.

Graphs:

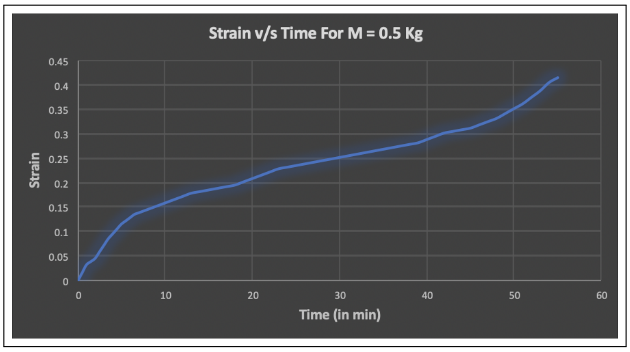

Fig 1: Strain v/s Time for M = 0.5 Kg

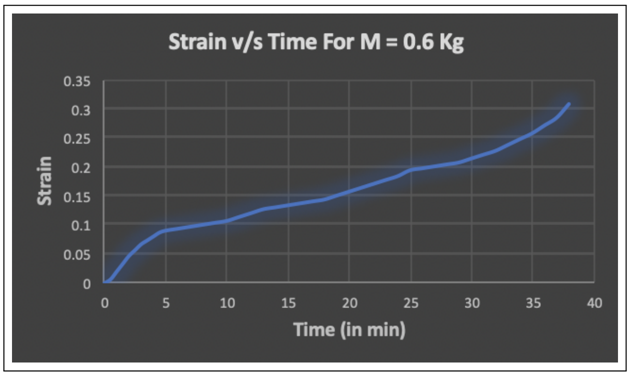

Fig 2: Strain v/s Time for M = 0.6 Kg

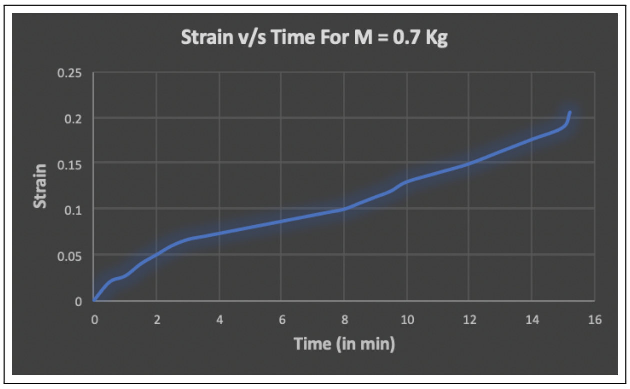

Fig 3: Strain v/s Time for M = 0.7 Kg

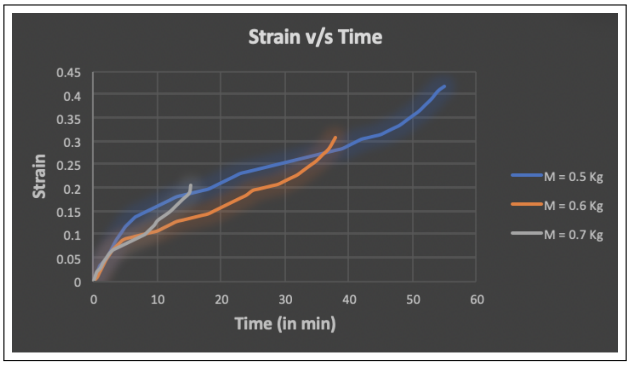

Fig 4: Strain v/s Time for all the 3 cases

Calculations:

The strain rate is determined by the slope of the strain vs time graph in the secondary region.
Area of the cross-section of wire = $\frac{\pi D^2}{4}$ = 0.78 * 10^{-6} m^2

Sr. No.	Weight (in grams)	Stress in solder wire (MPa)	Strain rate
1	500	6.28	0.000086
2	600	7.54	0.000136
3	700	8.79	0.000243

- Considering m = 0.5 kg and 0.6 kg

$$\text{Stress exponent} = \frac{log(\frac{strain-rate1}{strain-rate2})}{log(\frac{stress1}{stress2})} = \frac{log(\frac{0.000086}{0.000136})}{log(\frac{6.28}{7.54})} = 2.50643$$

- Considering m = 0.5 kg and 0.7 kg

$$\text{Stress exponent} = \frac{log(\frac{strain-rate1}{strain-rate3})}{log(\frac{stress1}{stress3})} = \frac{log(\frac{0.000086}{0.000243})}{log(\frac{6.28}{8.79})} = 3.08916$$

- Considering m = 0.7 kg and 0.6 kg

$$\text{Stress exponent} = \frac{log(\frac{strain-rate3}{strain-rate2})}{log(\frac{stress3}{stress2})} = \frac{log(\frac{0.000243}{0.000136})}{log(\frac{8.79}{7.54})} = 3.78379$$

Average stress exponent = $\frac{2.50643+3.08916+3.78379}{3}$ = 3.12646

Conclusions:

- In this experiment, we successfully studied the creep deformation in a solder wire at room temperature.
- All three regions primary, secondary and tertiary appear during the whole process. In the primary region, strain increases gradually and then increases at an almost constant rate after entering the secondary region. While in the tertiary region higher strain rate is observed before fracture.
- The average stress exponent comes out to be around 3.1265 for the second region of creep in solder wire.
- As the stress increases by increasing load, the strain rate increases as we can see from the slope in secondary regions of combined graph.

Sources of error:

- Instrumentation error in the weighing machine.
- The lead-tin solder wire may not be perfectly isotropic and homogeneous due to manufacturing defects.
- Human error while measuring time and noting distances from meter scale.
- Error due to movement of the weight pan due to the fan in the room.
- Parallax error while measuring the length between two points

Precautions:

- The wire should not be loaded impulsively.
- The wire should be tightly wound around the nail to avoid slipping.
- The setup should not be disturbed at all during the course of the experiment.
- One should maintain a safe distance from the weight pan since this falls once the wire fractures.

Recommendations:

- Provision of extra strain gauges in the lab can increase the accuracy with which strain is measured and reduce the error.

References:

1. ME221 - Structural Materials, Course Instructor - Amol A. Gokhale, Department of Mechanical Engineering, IIT Bombay
2. ME202 - Strength of Materials, Course Instructor - Amit Singh, Department of Mechanical Engineering, IIT Bombay
3. S.H. Crandell, M.C. Dahl and S.J. Lardner. An Introduction to the Mechanics of Solids, McGraw Hill Education (India) Private Limited, Third Edition, 2012.
4. James M Gere; Barry J Goodno. Mechanics of materials, Cl-Engineering, 9th edition, 2017