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Design and Fabrication of a Creep Testing Machine & Analysis of Creep Behavior of Soldering Wire

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Abstract-This experiment uses common lead-tin solder as a model material to demonstrate creep in metals at different temperature. By using four 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. 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. The aims of this experiment 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 test 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. Then compare estimations of creep strain to the measured data to determine the accuracy of the creep values B and m[1].
Key words: Creep, solder wire, stress, strain,Type of Module: Laboratory Experiment.
Objectives of research: To demonstrate creep as a phenomenon in metals, without using expensive furnaces or equipment, to reinforce the concepts of stress and strain. To drive creep constant from the experimental data. To study the principal of creep testing and practice the testing procedure.

1. INTRODUCTION

The lower grip is fixed in heating chamber, upper grip is attached to a pulley system, and the loading arrangement is attached to pulley mechanism, which also has a load pan to allow masses. On load pan, a load is applied, and a digital display unit records elongation of the wire. The process is repeats for different temperatures of 300c, 500c, 550c, 600c, and 650c. The fastest strain rate with the 650c at 4.56*10-5(mm/mm)/(sec). The room temperature is the slowest at 9.548*10-6 (mm/mm)/(sec). After calculating the applied stress and the strain rate, two constants B and m are determined to create a power-law equation, which could predict strain values as a function of time. The values of m and B are 0.0846 and 8.334*10-6 respectively at room temperature .However; the power-law equation only functioned in the secondary region of the creep strain curve. The secondary region is the region, which can accurately model. Using the power-law equation, the room temperature is the predicted strain rate has an error of 2.81% when compared to the experimental data. The 500c the predicted strain rate is close at 0.10%. At 550c the percent error begins to decrease more drastically, becoming 0.01%. Finally, the 600c has the less percent error between its predicted and experimental strain rates at 0.37%.

2. CREEP TEST PROCEDURE.

First, fine pieces of solder wire are cut to a length of approximately 100 – 140 mm. Then the wire is straightened to remove bends and kinks. Excessive force is avoided before testing the specimens; the initial diameter of the gauge section of each test specimen is measured. Next, the top end of a specimen is loaded into the lower and upper grips of the creep test mechanism and the wing-nut tightened so the solder could not move up and down, or not side-to-side. After that, the initial gauge length of the specimen measured. The initial strain is set to zero, then calibrated mass is gently lowered onto the load pan. At the same instant as the load placed on the load pan, a digital display unit started. The elongation recorded at time when the change in length. The process repeated for different temperature added to the load pan including 1.5kg mass. After the trials conducted, the temperature of the ambient air in the room recorded. Figure 1 shows the experiment setup, including the solder rod and the creep machine.

3. TEST PROCEDURE FOR THE TESTING MACHINE

(i) Any load from the hanger is to be removed
(ii) Cross sectional area 'A' of the specimen is to Measure and write down
(iii) The wire length (L) is to be Mark out
(iv) The specimen is to be placed between the lower and upper grips in the heating chamber
(v) The wire of ultra sonic distance sensor is to be attached with digital display unit
(vi) The heating element is switched on to heat the chamber for desired temperature
(vii) Apply load gradually and adjust the PCB with PC for measure the change in length.

4. DESIGN OF CREEP TESTING MACHINE AND ITS FEATURES

Figure1: Set up Developed for Creep Testing

5. RESULTS AND DISCUSSIONS

From the data is collected during the experiments on the specimens, at the various temperatures 30°c, 50°c, 55°c, 60°c, and 65°c, the change in length versus time is recorded in table 1-5 for 1.5kg weight. In addition, the strain values that correspond to each change in length listed a column beside the change in the length in the table. The majority of the experiments are in secondary creep. Secondary creep is the part where the creep strain rate is constant. When the percent error between the power-law equations are greater than 10%, which only occurs during the primary creep.Once secondary creep has set in, the highest percent error for any point during any trial is 12.18%.

From what can observe in this experiment, when the percent error between the secondary creep model and the experimental data has reached or less, the material can said to be experiencing secondary creep. However, the percent errors are as high as 100% for the primary creep this means that the model is very inaccurate in that region of time and creep. As for the working hypothesis, it is true that the maximum temperature that applied to the solder, the faster the creep rate will be. For example, the fastest strain rate with the 650c at 4.56*10-6(mm/mm)/(sec).At room temperature is the slowest at 9.817*10-6(mm/mm)/sec.

There is a clear correlation between increasing the load on the load pan and increasing the strain rate.Also, the more load that is applied, the sooner the primary creep gives way to secondary creep. For at room temperature, it took 15000sec. For the 650c, it took only 2760sec. That is a difference of 12240sec. To speed up strain testing, a maximum temperature should be applied. Creep is dependent on stress (load) so if the load of the specimens is increase, increasing the creep strains rate. With 5 people inside the room and equipment running, the temperature in the room was difficult to control. Creep is dependent on temperature, so if the temperature of the specimens is not uniform, then the log10 solution for the power relationship will have errors in it. Although there were sources of error for the experiment, overall, the data confirms what the models suggest, which is shown by the large errors over the primary creep region with small percent errors over the secondary region.

The values gathered from the experiment for the 1.5 kg mass test are listed in table 1 at different temperature, including the change in length of the solder wire and the corresponding time. The third column of strain is calculated by dividing the change in length by the original length, which for the 1.5 kg mass test was 103 mm, 105mm, 104mm, 105mm, and 103mm at different temperature.

TABLE 1

Value of time, Change in length, and Corresponding Strain for 1.5 kg mass test at room temperature

Time (min.)	Change in length (mm)	Strain (mm/mm)
0	0	0
25	1	0.009
50	2	0.019
70	3	0.029
90	4	0.038
110	5	0.049
130	6	0.058
150	7	0.068
165	8	0.078
180	9	0.088
198	10	0.098
210	11	0.107
220	12	0.117
230	13	0.127
240	14	0.137
250	15	0.147

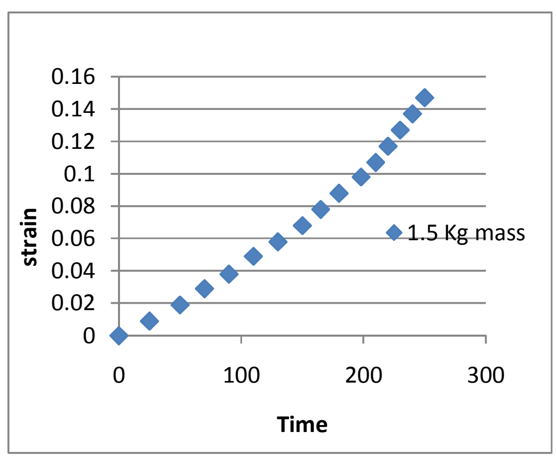

Figure 2: Plot of strain vs. time for a 1.5 kg mass attached to solder specimen at room temperature

Table 2
Value of time, Change in length, and Corresponding Strain for 1.5 kg mass test at 500c

Time (min.)	Change in length (mm)	Strain (mm/mm)
0	0	0
10	1	0.009
20	2	0.019
30	3	0.028
40	4	0.038
50	5	0.047
60	6	0.057
68	7	0.066
75	8	0.076
80	9	0.085
85	10	0.095
90	11	0.104
95	12	0.114
100	13	0.123
105	14	0.133
110	15	0.142
115	16	0.152
120	17	0.161
125	18	0.171
130	19	0.18

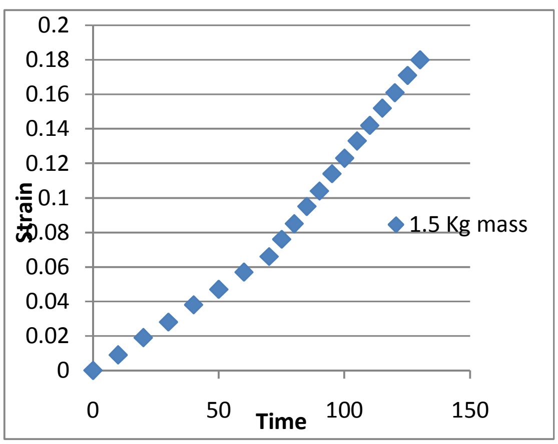

Figure 3: Plot of strain vs. time for a 1.5 kg mass attached to solder specimen at 50°c

Table 3
Value of time, Change in length, and Corresponding Strain for 1.5 kg mass test at 55°c

Time (min.)	Change in length (mm)	Strain (mm/mm)
0	0	0
8	1	0.009
16	2	0.019
24	3	0.028
32	4	0.038
40	5	0.048
52	6	0.057
58	7	0.067
64	8	0.076
70	9	0.086
75	10	0.096
80	11	0.105
85	12	0.115
90	13	0.125
94	14	0.134
100	15	0.144
115	16	0.153
120	17	0.163

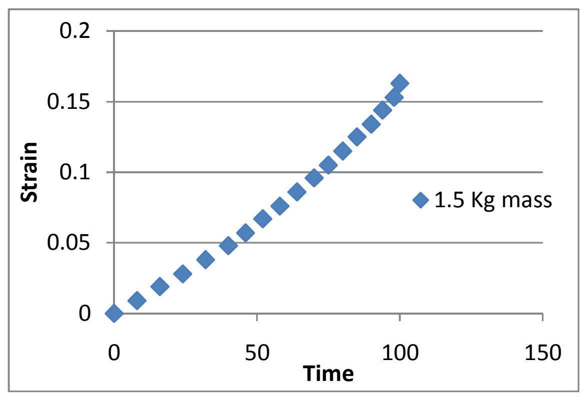

Figure 4: Plot of strain vs. time for a 1.5 kg mass attached to solder specimen at 55°c

Table 4
Value of time, Change in length, and Corresponding Strain for 1.5 kg mass test at 60°c

Time (min.)	Change in length (mm)	Strain (mm/mm)
0	0	0
6	1	0.0098
12	2	0.0196
18	3	0.0294
24	4	0.0392
30	5	0.049
36	6	0.0588
42	7	0.0686
48	8	0.0784
54	9	0.0882
60	10	0.098
66	11	0.1078
72	12	0.1176
78	13	0.1274
84	14	0.1372
90	15	0.147

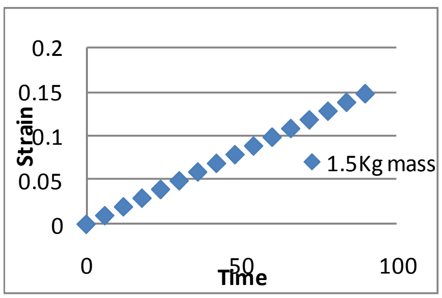

Figure 5: Plot of strain vs. time for a 1.5 kg mass attached to solder specimen at 60°c

Table 5
Value of time, Change in length, and Corresponding Strain for 1.5 kg mass test at 65°c

Time (min.)	Change in length (mm)	Strain (mm/mm)
0	0	0
5	1	0.009
10	2	0.019
15	3	0.029
20	4	0.038
24	5	0.048
27	6	0.058
30	7	0.067
33	8	0.077
36	9	0.087
39	10	0.097
42	11	0.106
44	12	0.116
46	13	0.126

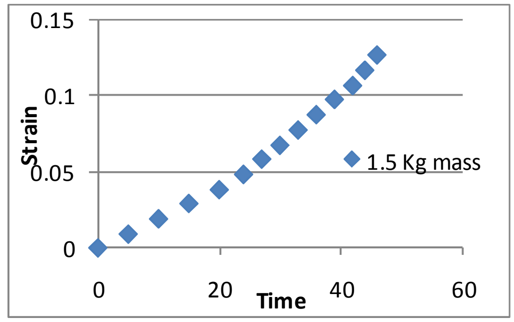

Figure 6: Plot of strain vs. time for a 1.5 kg mass attached to solder specimen at 65°c

6. CREEP STRAIN RATES CALCULATIONS

Creep strain has three regions to it: the primary, secondary, and tertiary regions. The primary and tertiary regions are the most unpredictable because the strain rates are not constant in those regions. However, the majority of a components life will spent in the secondary region, which is why the secondary region is being study in this experiment. An example of the creep strain curve is Figure 7.

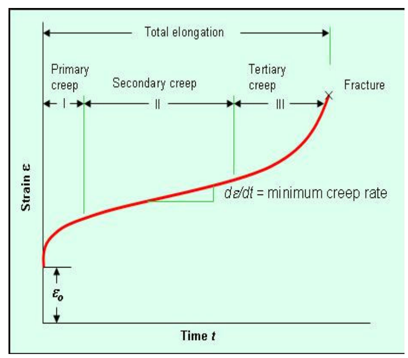

Figure 7: Plot of creep strain showing the strain-time relationship until stress fracture (X) [3]

Using the strain and time data from Tables 1 - 5, the creep strain rates can generated by finding the slope in the secondary region. The resulting creep strain rates for the secondary creep response listed in Table 6.

Table 6
Creep Stra in Rates for Different Trials' Masses and temperatures

Temperatures	Creep Strain Rate(mm/mm)/sec.
30○c	9.817*10-6
50○c	2.30*10-5
55○c	2.75*10-5
60○c	2.722*10-5
65○c	4.56*10-5

7. Applied Stress Calculations

It is important to remember that the mass attached not only include the calibrated masses, but also the load pan, which in this experiment has a mass of 100 grams. As a result, each total calibrated mass to include the load pan. To find the applied stress, the applied force is divided by the cross-sectional areas of the rod of solder. The equation for area is given in Equation [1].

$$A = \frac{\pi}{4} \text{*Diameter}^2 \qquad \text{Eq. [1]}$$

The diameters of the solder wires for the 1.5, 2, 3, and 4kg calibrated mass trials are 2mm. Table 7 shows the masses attached to the load pan during each trial, the resulting applied force on the solder, the cross-sectional area of the solder, and the applied stress.

Table7

The Applied Stress on Each Solder Rod with Log10 Applied stress

Mass kg	Total mass kg	Applied Force on solder N	Area mm^2	Applied stress MPa	Log10 Applied stress
1.5	1.6	15.68	3.14	4.9936	0.6984

8. Applied Stress vs. Creep Strain Rate on Logarithmic Plot

To predict the behavior in the secondary region, Equation [2] can used to find the predicted strain rate.

$$\dot{\varepsilon} = B\,\sigma^{m} \qquad \text{Eq. [2]}$$

Where B (proportionality constant) and m (stress-exponent) are material constants To find B and m, the applied stress values and the corresponding strain rates must use. Using the values calculated in tables 6 and 7 table generated with creep strain rates, applied stress.

The function "$\log_{10}$" allows B and m to found, since the constant m in Equation [2] is in an exponential function. To find the proportionality constant (B) and stress-exponent (m) for a strain-rate model, several calculations had to be done. First, the creep strain rate in the secondary region had to found, then the applied stress acting on the solder wires had to found, which involves finding the force acting on the solder wire and dividing by the cross-sectional area of the wire. The calculations for the applied stress and the creep strain rates known for the at different temperatures. m and B determined to be .0846 and 10^ (-5.079) = $8.334e^{-6}$ at room temperature.

9. Comparing Predicted Strain to Experimental Strain

Table 8

Predicted creep strain rates for different temperatures

Mass kg	Creep strain Rate sec 30°c	Creep Strain Rate sec. 50°c	Creep Strain Rate sec. 55°c	Creep Strain Rate sec. 60°c	Creep Strain Rate sec. 65°c
1.5	$9.548 *10^{-6}$	$2.330 *10^{-5}$	$2.754 *10^{-5}$	$4.378 *10^{-5}$	$4.560 *10^{-5}$

To provide predicted creep strains at any time, Equation [3] can be utilized [4].

$$\square(t) = \square_0 + \square\square\text{predicted}* (t - t_0) \qquad \text{Eq. [3]}$$

Where $\square_0$ is the strain of the specimen when the secondary region begins, and t0 is the time at which the secondary region begins. Tables 9 -13 Show the experimental strain and the predicted strain.

Table 9

Values of time, and experimental and predicted strain for 1.5 kg mass test at 30°c

Time (min)	**Experimental strain (mm/mm)**	**Predicted strain (mm/mm**	**Percent Error (%)**
0	0	0	0
25	0.009	0.014322	37.17394
50	0.019	0.028644	33.69713
70	0.029	0.040102	27.72379
90	0.038	0.051559	26.34987
110	0.049	0.063017	22.30597
130	0.058	0.074474	22.19536
150	0.068	0.085932	20.95359
165	0.078	0.094525	17.57685
180	0.088	0.103118	14.76432
198	0.098	0.11343	13.71672
210	0.107	0.120305	11.17955
220	0.117	0.126034	7.293646
230	0.127	0.131762	3.746147
240	0.137	0.137491	0.49475
250	0.147	0.14322	-2.49608

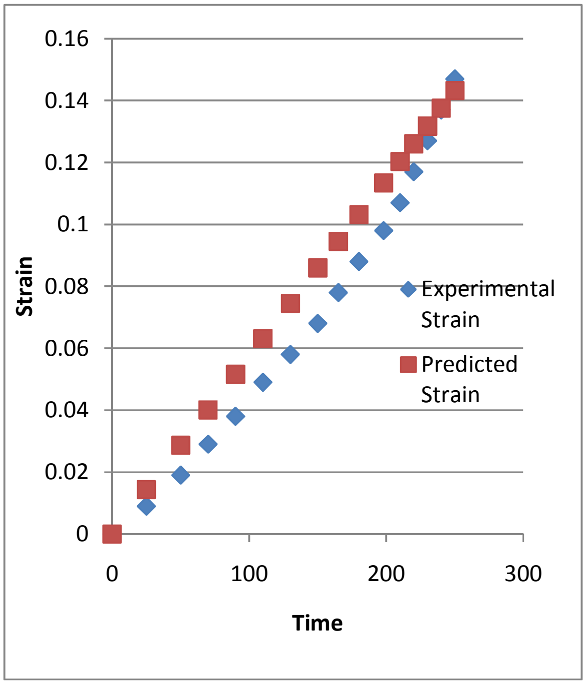

Figure 8: Plot of experimental and predicted strain vs. time for 1.5kg mass at 30°c

Table 10
Values of time, and experimental and predicted strain for 1.5 kg mass test at 50°c

Time (min)	Experimental strain (mm/mm)	Predicted strain (mm/mm	Percent Error (%)
0	0	0	0
10	0.009	0.01398	35.6363
20	0.019	0.02796	32.07374
30	0.028	0.04194	33.2799
40	0.038	0.05592	32.1017
50	0.047	0.0699	32.83099
58	0.057	0.081084	29.78361
66	0.066	0.092268	28.56151
73	0.076	0.102054	25.63168
78	0.085	0.109044	22.15886
85	0.095	0.11883	20.17269
90	0.104	0.12582	17.46805
95	0.114	0.13281	14.2959
100	0.123	0.1398	12.15697
105	0.133	0.14679	9.541163
110	0.142	0.15378	7.814074
115	0.152	0.160778	5.615768
120	0.161	0.16776	4.197326
125	0.171	0.17475	2.320673
130	0.18	0.18174	1.139152

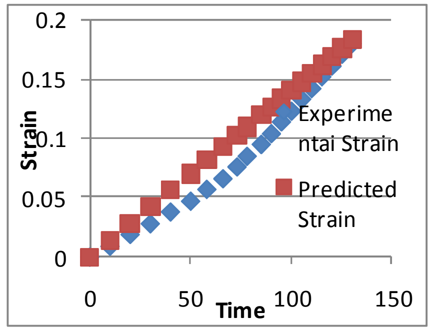

Figure 9: Plot of experimental and predicted strain vs. time for 1.5kg mass at 50°c

Table 11
Values of time, and experimental and predicted strain for 1.5 kg mass test at 55°c

Time (min)	Experimental strain (mm/mm)	Predicted strain (mm/mm	Percent Error (%)
0	0	0	0
8	0.009	0.013219	31.9294
16	0.019	0.026438	28.16018
24	0.028	0.039658	29.436
32	0.038	0.052877	28.18798
40	0.048	0.066096	27.44445
46	0.057	0.07601	25.08588
52	0.067	0.085925	22.11095
58	0.076	0.095839	20.79618
64	0.086	0.105754	18.78495
70	0.096	0.115668	17.11951
75	0.105	0.12393	15.39868
80	0.115	0.132192	13.13752
85	0.125	0.140454	11.14334
90	0.134	0.148716	10.04409
94	0.144	0.155326	7.447087
98	0.153	0.161935	5.679581
100	0.163	0.16524	1.520844

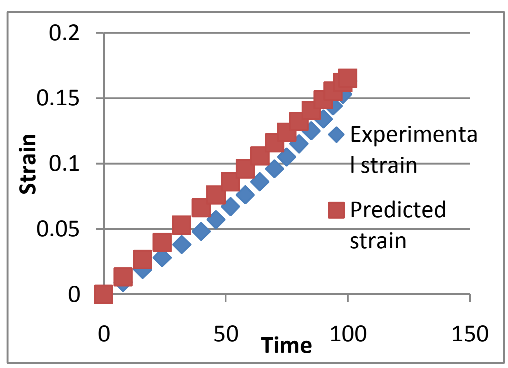

Figure 10: Plot of experimental and predicted strain vs. time for 1.5kg mass at 55°c

Table 12
Values of time, and experimental and predicted strain for 1.5 kg mass test at 60°c

Time (min)	Experimental strain (mm/mm)	Predicted strain (mm/mm	Percent Error (%)
0	0	0	0
6	0.0098	0.009839	0.406221
12	0.0196	0.019678	0.41606
18	0.0294	0.029516	0.422523
24	0.0392	0.039355	0.433206
30	0.049	0.049194	0.443551
36	0.0588	0.059033	0.453727
42	0.0686	0.068872	0.463808
48	0.0784	0.07871	0.472561
54	0.0882	0.088549	0.482681
60	0.098	0.098388	0.492745
66	0.1078	0.108227	0.502768
72	0.1176	0.118066	0.51276
78	0.1274	0.127904	0.52195
84	0.1372	0.137743	0.531955
90	0.147	0.147582	0.541939

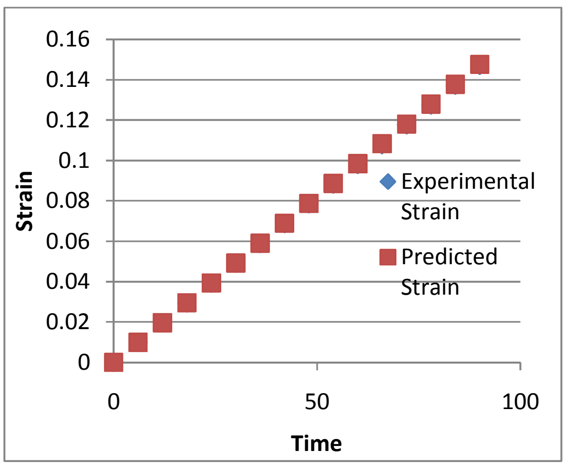

Figure 11: Plot of experimental and predicted strain vs. time for 1.5kg mass at 60°c

Table 13
Values of time, and experimental and predicted strain for 1.5 kg mass test at 65°c

Time (min)	Experimental strain (mm/mm)	Predicted strain (mm/mm	Percent Error (%)
0	0	0	0
4	0.009	0.010507	14.35333
8	0.019	0.021014	9.605101
12	0.029	0.031522	8.032283
16	0.038	0.042029	9.628267
20	0.048	0.052536	8.686615
24	0.058	0.063043	8.062345
28	0.067	0.07355	8.979056
32	0.077	0.084058	8.480641
35	0.087	0.091938	5.462949
38	0.097	0.099818	1.685244
41	0.106	0.107699	1.685244
44	0.116	0.115579	-0.24867
46	0.126	0.120833	-4.15532

B. Future course of action

(I). Potential future experimentation includes testing different materials, including different compositions of solder wire.

(II). Testing the solder at different loadsfor different diameter. Recommendations for future research involve keeping the load varying but constant the temperature, testing different materials like steel and aluminium, copper for their m and B constants and comparing them to solder's, and controlling more of the factors which could have given rise to some of errors like temperature

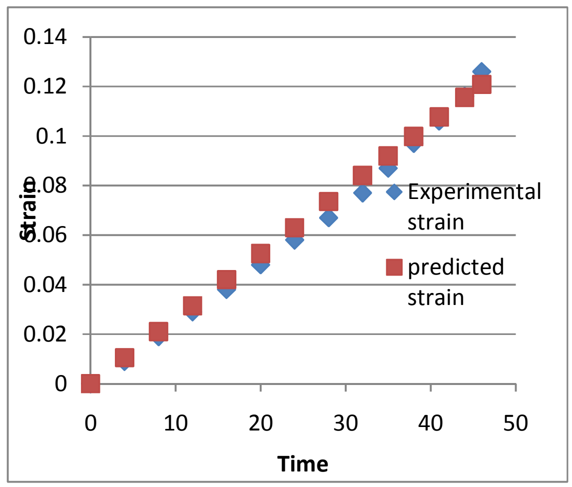

Figure 12: Plot of experimental and predicted strain vs. time for 1.5kg mass at 65°c

10. CONCLUSION & FUTURE COURSE OF ACTION

A. CONCLUSION

1.The power-law equation accurately models the secondary region, but only the secondary region. Therefore, solder should used in environments with as little applied stress as possible. To summarize, the power-law equation is only effective in the secondary creep region. The primary region is too unpredictable. In addition, the more loads that applied to a material, faster the creep will occur in the material, which means the working hypothesis was correct.

2. An increase in the temperature on a solder wire of material increases the strain rate at which creep occurs.

3. At the constant load, increasing the temperature on a wire of material increases the rate at which creep occurs.

(III). In this, take test on different piece of metals like industrial rope, steel rod, and copper rod via creep testing machine. Apply load on creep testing machine and measure the rupture of those material. It should not damage, in case the wires breaks suddenly or slip out of the grips in course of time. The load will be released and act instantaneously and transfer of load will be performed smoothly and without much.

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