DEVELOPMENT OF SINGLE SPECIMEN CREEP TESTING MACHINE

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ABSTRACT

The work intends to provide single specimen creep testing machine for laboratory use. This will enhance selection of appropriate materials for national building/advancement. The method employed involves selection of material, design of components of machine, production of components and assembling of the components. The machine comprises of a lever arm, supported with pivot pin and rest pin on the columns. The effort portion of the lever arm is fixed with load hanger while the load (test) portion is fixed with dial gauge, the ends of specimen were fixed in fixture devices on lever arm and base table at a distance of 90 mm. Development of the machine was based on the application of bending moment (simple supported beam) and equilibrium theory to calculate the forces acting on the specimen and components of the machine which is obtained as F=(1.596 + 5.99m)g Newton. Using solder as specimen, tests were carried out with the machine at room temperature under different loads, concept of strain were obtained. Three stages of creep were achieve, creep constants of solder (m and B) were obtained experimentally as 6.25×10^{-3} and 4.0×10^{-4} respectively. The experiment indicates that at a constant stress 31.13 MPa, the creep rate was obtained as 2.1×10^{-3} /min while at 38.60 Mpa, the creep rate was obtained as 6.2×10^{-3} /min. The results indicate that the creep rate increases at higher stress, the creep working hypothesis were confirmed.

Keywords: Creep Testing, deformation, temperature, melting scale

1.0 INTRODUCTION

Single specimen creep testing machine is use to predict the strength and dimensional changes of materials which occur as a result of constant applied load and temperature over a period of time. Creep is defined as time dependent deformation of material under constant load and temperature. In design of a product, allowances for creep are made based on the reliable experimental data in estimating the service life of the material. It is equally important to be able to extrapolate creep data into regions where creep data are not available. Creep problems are prevalent and need optimum consideration in design of products. In as much as it not easy to eliminate the problem of creep entirely, it is necessary that creep data be made available for any material through scientific research, before such material can be employed in engineering services. Creep can occur at any temperature higher than approximately half the absolute melting point in Kelvin scale. Solder has a melting point of 183 ^{0}C (456 K), so room temperature at 25 ^{0}C (298 K) is more than half the melting point.Therefore creep is expected to occur at room temperature in solder when subject to a sufficient stress,

The objectives of this research includes: To develop a single specimen creep testing machine using locally sourced materials; To demonstrate creep as a phenomenon in metals using solder as specimen; To obtain creep rate of solder and constants using experimental data.

Ishikawa et al, (1997) Studied creep behaviour of high purity aluminum at room temperature, it was found that steady state creep could be observed at room temperature, with the creep rate depending upon the applied stress. Ritu and Rajeev (2014), Performed creep tests on five pieces of 2 mm diameter solder of the same gauge length at different temperature, under constant load (1.5 kg). The results shows that, fastest strain rate occur at the higher temperature (65^0C) while the slowest strain rate occur at room temperature (30^0C). Bunnell, (2007) carried out creep tests at room temperature on five pieces of 3.1 mm inches diameter solder suspended with various weight at lower end of the specimens except one specimen with no added weight on it, the upper end of specimens were hang on a rigid body. The results reveal the following:

i. Solder creeps at room temperature.
ii. Strain at failure and time to failure is strongly influenced by applied stress.

2,0 MATERIALS AND METHODS

2.1 Materials

The materials used in this project are:

i. Mild steel (AISI 1013) for columns, lever arm, table base, pins and fixture devices
ii. Stainless steel (AISI 302) for load hanger and set of weight
iii. Solder (sn 30%, Pb 70%) for specimen.
iv. Other accessories used includes
    iv. Thermometer - for measuring room temperature.
    v. Dial gauge - for measuring extension.
    vi. Vernier callipper - for measuring diameter of specimen.
    vii. Stop watch - for time reading.
    viii. Pair of scissor - for cutting of specimen.
    ix. Ruler - for measuring the length of specimen.

2.1 Systematic Drawing of the Creep Testing Mechanism

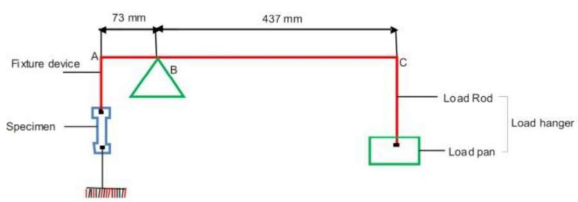

Figure 1: Systematic drawing of the creep testing mechanism

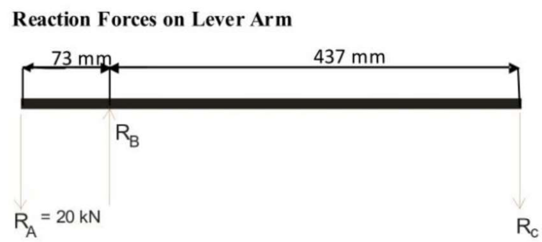

Figure 2: Free body diagram of reaction forces

2.2 Equilibrium conditions

(1) $\Sigma fy=0$ (1)

$-R_A + (-R_C) + R_B = 0$ (2)

$-R_A - R_C + R_B = 0$ (3)

$-(R_A+R_C) = -R_B$ (4)

$20kN + R_C = R_B$ (5)

(2) $\Sigma MB = 0$ (6)

$Rc \times 437 = 20\times10^3 \times 73$ (7)

$$R_C = \frac{1460000}{374}$$

$R_C = 3.341kN$

$R_C = 3.341kN$:- Maximum reaction on the load hanger

The load at R_C includes the weight of load pan and rod.

Therefore to calculate the reaction at B, equation (5) was applied.

$20 x 10^3 + 3.341kN = 23.341kN$, maximum reaction on the column B (R_B).

2.3 Calculation of Forces Acting on Lever Arm and Specimen

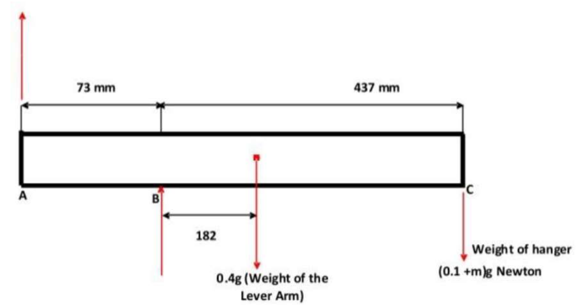

Figure 3: Forces acting on lever arm and specimen.

Applying the theory of equilibrium

$$F_R \times 0.073 = (0.1 + m)0.437g + 0.4g \times 0.182 \quad (8)$$

$$F_R = \frac{g}{0.073}\left((0.1 + m)0.437 + 0.4 \times 0.182\right) \quad (9)$$

$$F_R = \frac{g}{0.073}(0.0437 + 0.437m + 0.0728) \quad (10)$$

$$F_R = \frac{g}{0.073}(0.1165 + 0.437m) \quad (11)$$

$$F_R = (1.596 + 5.99m)g \text{ (Newton)} \quad (12)$$

m = total mass of the hanger (kg)

F_R=Resistant force acting on the lever arm at point A

g = Gravitational pull = (9.8 m/s^2)

$F = F_R$

Where F = tensile force acting on the specimen.

2.4 The Developed Single Specimen Creep Testing Machine

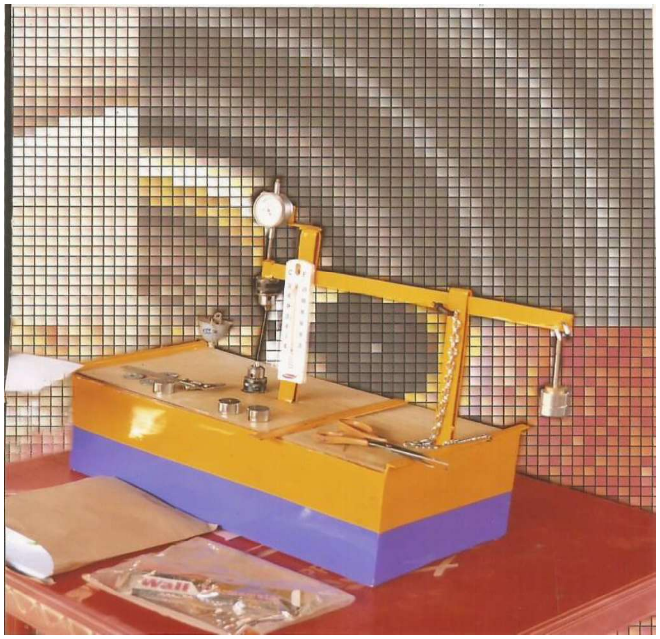

Figure 1: Creep Testing Machine

2.5 Experimental Procedure

i. Cut four lengths of solder to 120mm each and straighten the specimen with finger strength to remove bends.
ii. Measure the diameter (do) of the gauge length of specimen.
iii. Rise the lever arm up and insert the rest pin in the column.
iv. Install the top and bottom end of the specimen in upper and lower fixture device and tighten both ends with finger strength.
v. Hang a known mass on the load pin.
vi. Measure the gauge length (Lo) of the specimen.
vii. Adjust the dial gauge to zero and set stop watch to zero too.
viii. Read and record the room temperature with thermometer.
ix. To start the experiment, gently remove the rest pin and immediately, set the stop watch on.
x. Record the extension at one minute intervals.
xi. Calculate the strain and plot the graph of strain versus time

3.0 Experimental Results

Table 1 Value of time, change in gauge length and strain for 0.25 kg

T (min)	ΔL(mm) Change in length	Strain
0	3.556	0.0395
1	4.318	0.0479
2	6.477	0.0719
3	7.874	0.0875
4	9.915	0.1022
5	10.211	0.1135
6	11.049	0.1227
7	11.811	0.1312
8	12.446	0.1383
9	13.132	0.1459
10	13.716	0.1468
11	14.351	0.1595
12	14.935	0.1659
13	15.443	0.1716
14	15.951	0.1772
15	16.459	0.1829
16	16.967	0.1885
17	17.449	0.1939
18	17.907	0.1989
19	18.364	0.2040
20	18.872	0.2097
21	19.355	0.2151
22	21.082	0.2340
23	22.838	0.2532
24	24.562	0.2729

Load = 0.25 kg
Temperature = 33 ^{0}C
L_0 = 90mm
d_0 =1mm
Instantaneous strain ε= 0.0395
σ = 38.60 Mpa
Tensile force (F) = 30.32 N

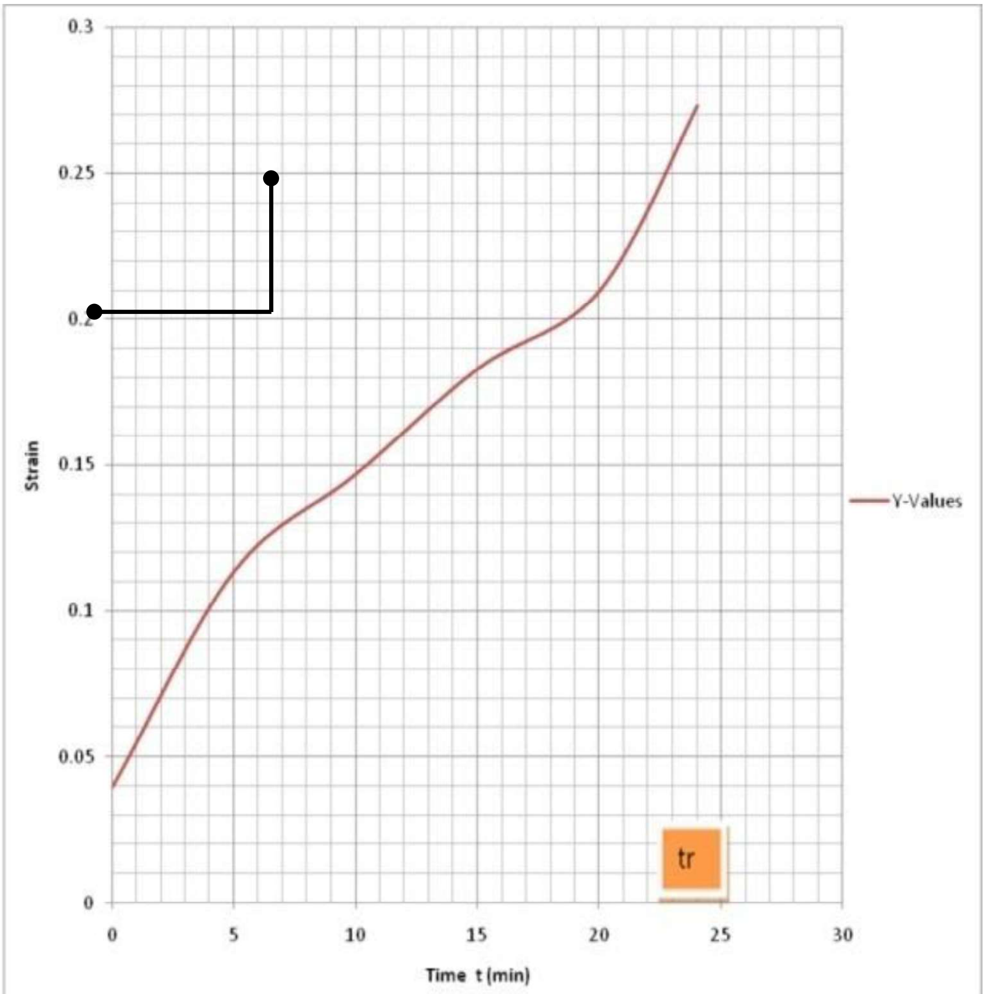

Figure 4 Strain versus time for 0.25 kg mass attached to specimen

$$\bar{E} = \frac{d\varepsilon}{dt} = \frac{0.19 - 0.11}{18 - 5} = \frac{0.08}{13} = 6.2 \text{ x } 10^{-3} \text{ /min}$$

Table : 2 value of time, change in gauge length and strain for 0.20 kg

T (min)	ΔL (mm) Change in length	Strain
0	2.286	0.0254
1	3.048	0.0339
2	3.911	0.0434
3	4.521	0.0502
4	5.105	0.0567
5	5.537	0.0615
6	5.892	0.0655
8	6.752	0.0751
10	7.442	0.0826
12	8.001	0.0889
14	8.559	0.0951
16	9.017	0.1002
18	9.449	0.1050
20	9.906	0.1100
22	10.287	0.1143
24	10.668	0.1185
26	11.049	0.1228
28	11.379	0.1262
30	11.811	0.1312
32	12.192	0.1355
34	12.573	0.1397
36	12.954	0.1439
38	13.335	0.1482
40	13.919	0.1547

Load = 0.20kg

Temperature 31 ^{0}C

L_0 = 90mm

d_0 = 1mm

Instantaneous strain = 0.0254

σ = 34.86 Mpa

Tensile force (F) = 27.38 N

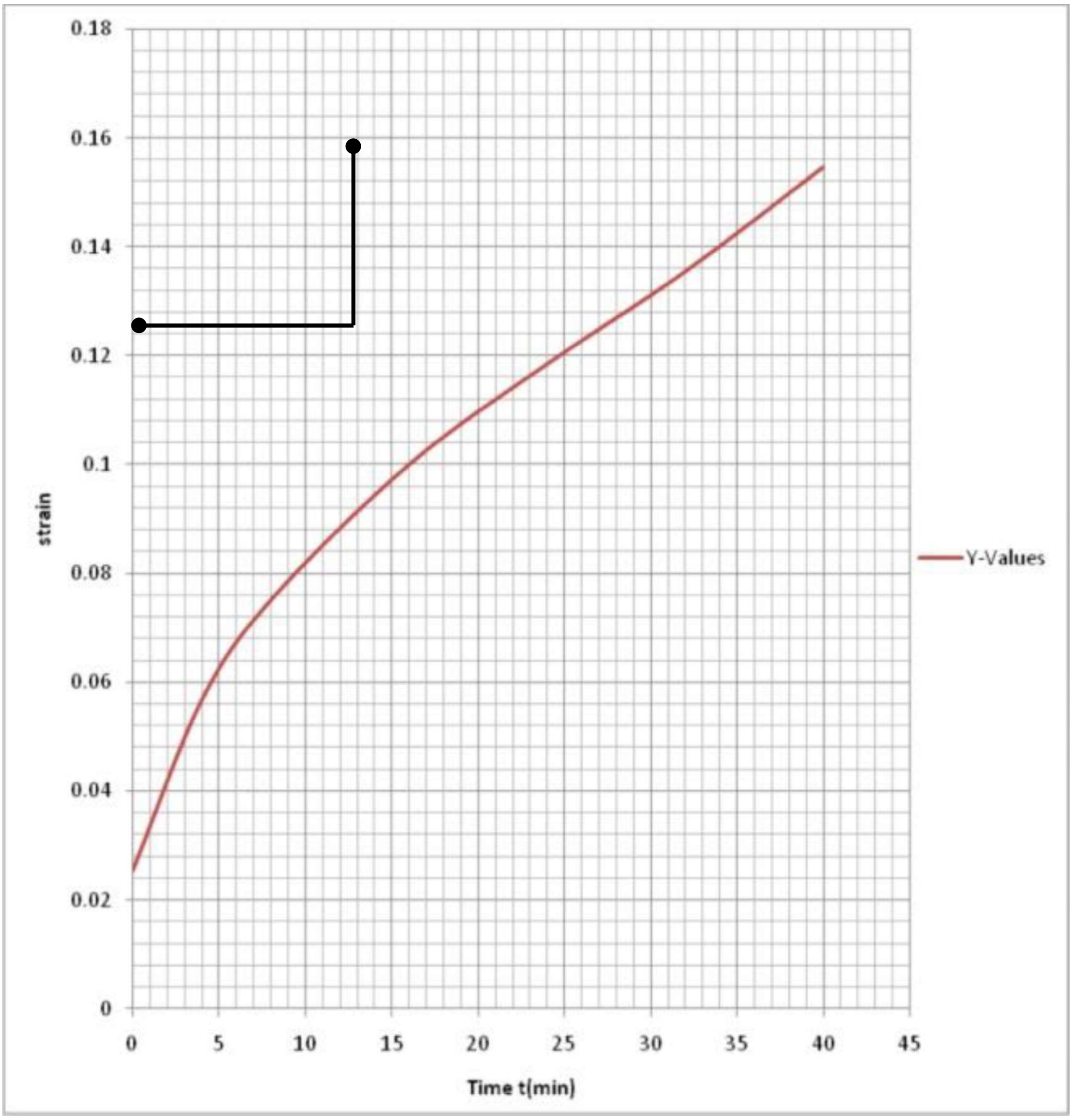

Figure .5: **S**train versus time for 0.20 kg mass attached to specimen

$$\bar{E} = \frac{d\varepsilon}{dt} = \frac{0.137 - 0.072}{31 - 7} = \frac{0.065}{24} = 2.7 \text{ x } 10^{-3} \text{ /min}$$

Table: 3 Value of time, change in gauge length and strain for 0.15 kg

T (min)	ΔL (mm) Change in length	Strain
0	0.635	0.0071
1	0.889	0.0099
2	1.397	0.0155
3	1.905	0.0212
4	2.362	0.0262
5	2.743	0.035
6	3.022	0.0338
7	3.302	0.0367
8	3.581	0.0373
10	4.064	0.0451
12	4.495	0.0499
14	4.928	0.0548
16	5.283	0.0587
18	5.588	0.0621
20	5.893	0.0655
22	6.147	0.0683
24	6.426	0.0714
26	6.655	0.0739
28	6.934	0.0770
30	7.188	0.0799
32	7.442	0.0822
34	7.722	0.0858
36	8.010	0.0890
38	8.163	0.0907

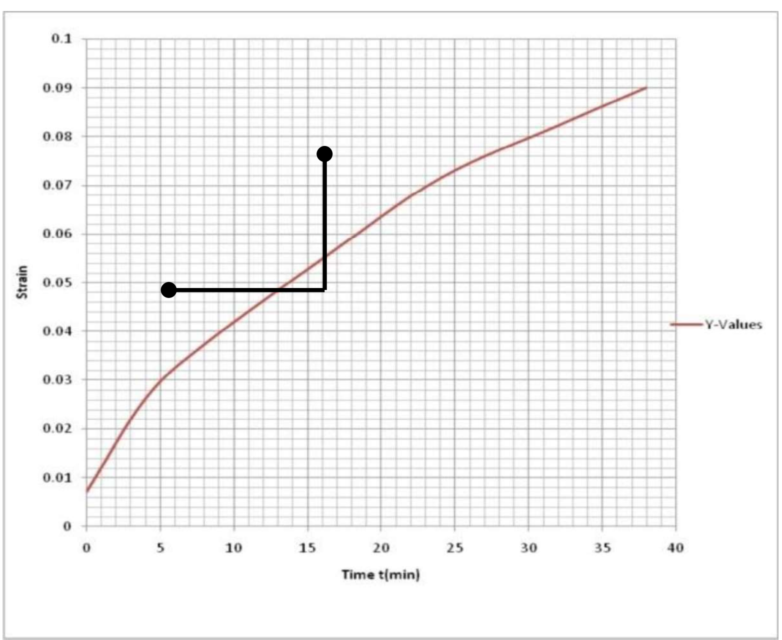

Figure 6: Strain versus time for 0.15kg mass attached to specimen

$$\overline{E} = \frac{d\varepsilon}{dt} = \frac{0.072 - 0.04}{24 - 9} = \frac{0.032}{15} = 2.1 \times 10^{-3}\ /\text{min}$$

Table: 4 Value of time, change in gauge length and strain for 0.10 kg

T (min)	ΔL (mm) Change in length	Strain
0	0.254	0.0028
1	0.381	0.0042
2	0.508	0.0056
3	0.635	0.0071
4	0.711	0.0079
5	0.812	0.0090
6	0.889	0.0099
8	1.016	0.0113
10	1.168	0.0129
12	1.295	0.0144
14	1.448	0.0161
16	1.549	0.0172
18	1.651	0.0183
20	1.778	0.0198
22	1.879	0.0209
24	1.981	0.0220
26	2.083	0.0331
28	2.184	0.0243
30	2.286	0.0254
32	2.388	0.0265
34	2.489	0.0277
36	2.590	0.0288
38	2.692	0.0299
40	2.790	0.0310

Load = 0.10 kg
Temperature= 31^0C
L_0 = 90mm
d_0 = 1mm
Instantaneous strain ε = 0.00282
σ = 27.39 Mpa
Tensile force (F) = 21.5 N

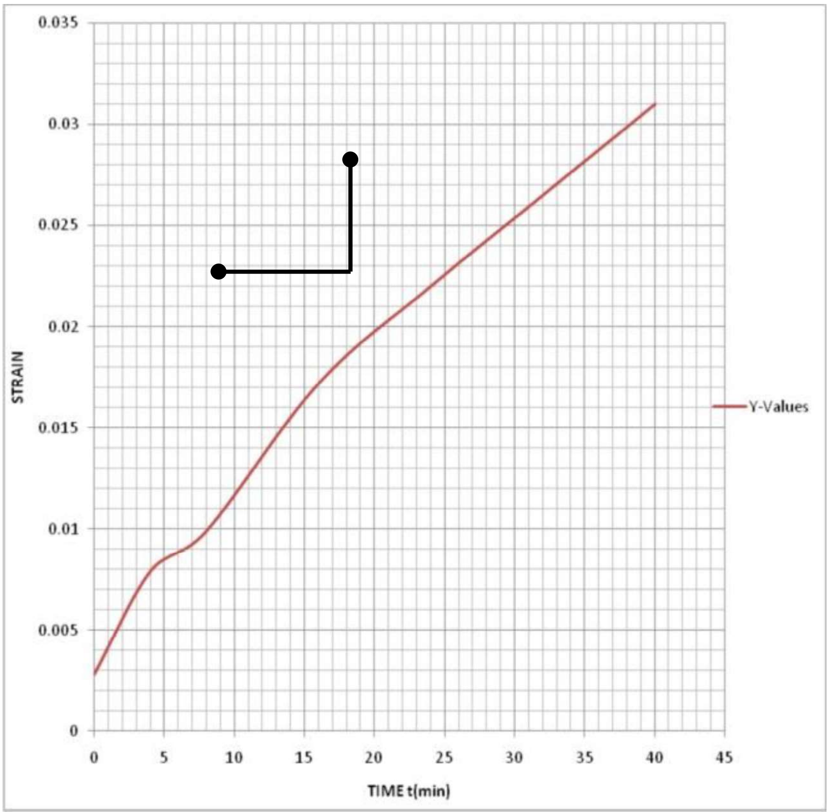

Figure 7: Strain versus time for 0.10 kg mass attached to specimen

$$\bar{E} = \frac{d\varepsilon}{dt} = \frac{0.025 - 0.017}{29 - 16} = \frac{0.008}{13} = 6.2 \text{ x } 10^{-4} \text{ /min}$$

Table: 5 Logarithms of creep rate and applied stress

Mass kg	Applied stress (Mpa)	Log applied stress	Creep rateE /(min)	Log E
0.10	27.39	1.44	0.00062	- 3.21
0.15	31.13	1.49	0.0021	- 2.68
0.20	34.86	1.54	0.0027	- 2.57
0.25	38.60	1.59	0.0062	- 2.21

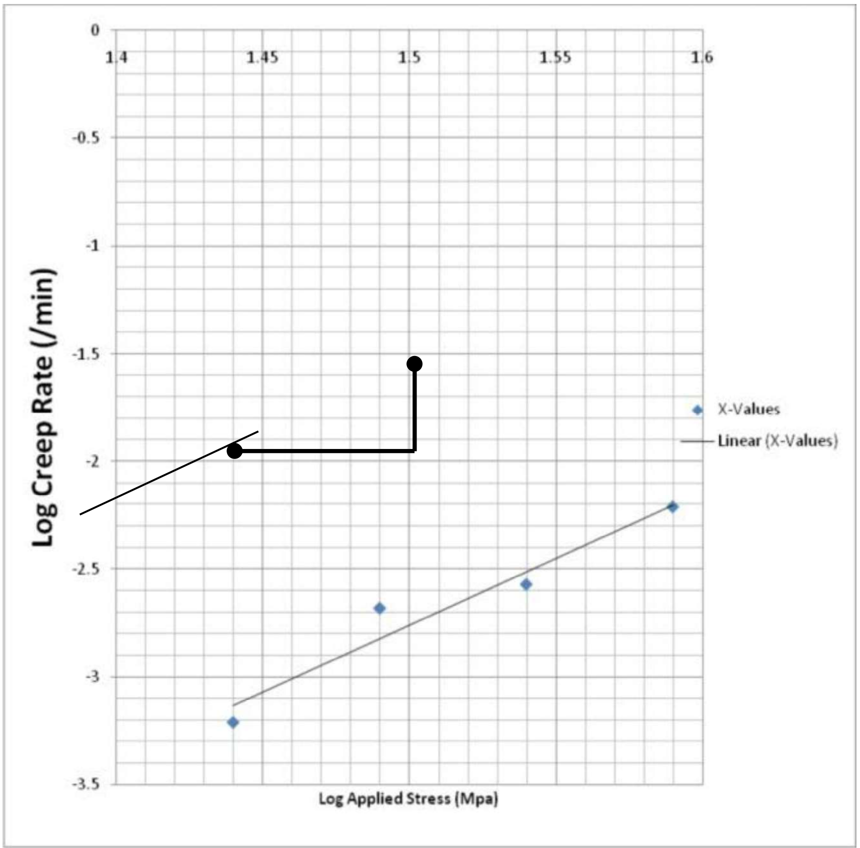

Figure 8: Log creep rate versus log applied stress

Intercept= log (B) = -3.4 ∴ B = $10^{(-3.4)}$ = 4.0 X 10^{-4}

Slope (m) = $\frac{-2.3 - -2.8}{1.57 - 1.49} = \frac{0.50}{0.08} = 6.25$

Discussions

From the results, figure 4 reflected a typical creep curve where the three stages of creep curve can be clearly identified. Primary stage takes 3 minutes, secondary stage takes 17 minutes and tertiary stage takes 4 minutes. Creep rupture occurred at 24 minutes, under a constant load of 0.25 kg and room temperature of 33^0C with creep rate 6.2 x 10^{-3}/min.

In figure 5, primary stage takes 4.5 minutes and secondary stage takes 35.5 minutes. At 40 minutes, the gauge length increased to 104.2mm, tertiary stage did not take place and creep rupture did not occur under a constant load of 0.20 kg and room temperature of 31^0C with creep rate of 2.7 x 10^{-3}/min. In figure 6, primary stage takes 6 minutes and secondary stage takes 32 minutes. At 38 minutes, the gauge length extends to 98.3mm, tertiary stage did not take place and creep rupture did not occur under a constant load 0.15 kg and room temperature of 31 ^{0}C with creep rate of 2.1 x 10^{-3}/min.

In figure 7, the primary stage takes 8 minutes and secondary stage takes 32 minutes. At 40 minutes, the gauge length of specimen extends to 92.8 mm, tertiary stage did not take place and creep rupture did not occur under a constant load of 0.10 kg and room temperature of 31 ^{0}C with creep rate of 6.2 x 10^{-4}/min. Figure 8 is a linear graph, shows the relationship between logE and Logδ in creep power law equation $\left(log\bar{E} = logB + mlog\,\delta - \frac{E}{RT}\right)$ (13) (m) and (B) can only be determined experimentally from the slope and intercept of the graph respectively, which is agreed with Hearn (1985).

4.0 Conclusions

A single specimen creep testing machine was developed; four experiments were carried out with the machine under different loads and room temperature. The results of the creep rate obtained indicate that the higher stress applied to the specimen, the faster the creep rate, also the result agreed with Bunnell, (2007), Ritu and Rajeev, (2014).

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