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INVESTIGATION OF CREEP RESPONSES OF SELECTED ENGINEERING MATERIALS

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ABSTRACT

Mechanical Testing, a concept totally ignored previously, is now a major area of concern. Before now, the concept of testing was merely an afterthought of the procurement process. With the advent of science and technology especially of the type seen in our today's world, the concept of testing is now an integral part of research and development, product design and manufacturing. This work investigated the creep responses of selected engineering materials (Lead, Polypropylene, and Aluminum alloy samples). Procedure for creep testing and analysis of creep properties of engineering materials from test data are reviewed. The experimental results reveal that the creep resistance of PP was the least with a creep rate of 1.66x10^{-3} min^{-1} at 33 ^{O}C and 14.22 MPa. Typical values of Creep Strain Rates obtained are 23.5x10^{-3} min^{-1} for Pb (BS 1178) at 33 ^{O}C and 10.34 MPa; and 4.8X10^{-6} hr^{-1} for Wrought Al alloy at 200 ^{o}C and 54.58 MPa;

Keywords: Creep deformation, High temperatures, Constant stress, Metals, Plastics

INTRODUCTION

Various mechanical tests such as the tensile and impact tests offer useful information as per the strength characteristics, responses, and behaviours of engineering materials when subjected to loads over short periods of time.

Creep is the progressive deformation of a material at constant stress and temperature. It is used to describe the slow plastic deformation that occurs under prolonged loading, usually at high temperatures. Creep in its simplest form is the progressive accumulation of plastic strain in a specimen or machine part under stress at elevated temperatures over a period of time (Myer, 2002). Creep failure occurs when the accumulated creep strain results in a deformation of the machine part that exceeds the design limit. Creep rupture is an extension of the creep process to the limiting condition where the stressed member actually separates into two parts. Stress rupture is a term used inter-changeably by many with creep rupture; however, others reserve the term stress rupture for the rupture termination of a creep process in which steady-state creep is never reached, and use the term creep rupture for the rupture termination of a creep process in which a period of steady-state creep has persisted. Figure 1 illustrates these differences. The interaction of creep and stress rupture with cyclic stressing and the fatigue process has not yet been clearly understood but is of great importance in many modern high-performance engineering systems (Wiley and Hetenyi, 1950).

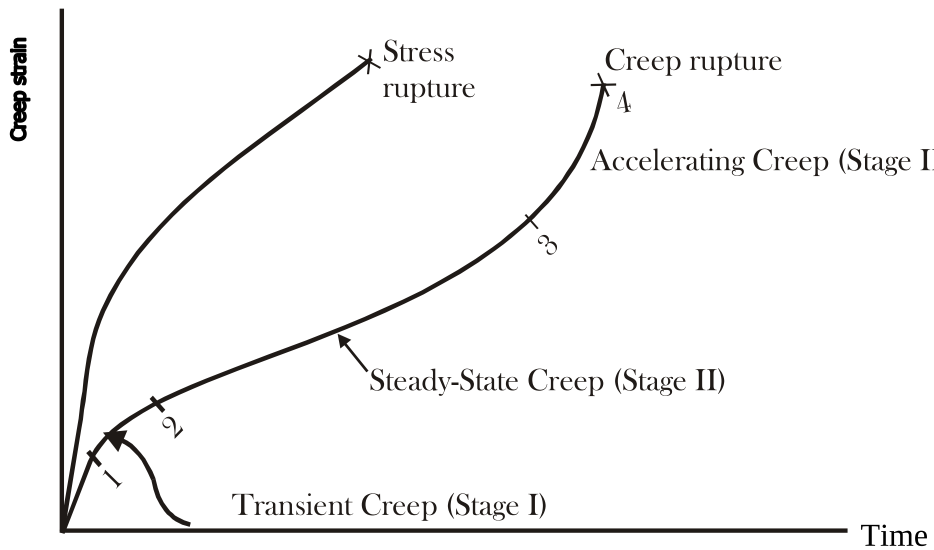

Figure1: Progressive nature of creep; Difference between stress rupture and creep rupture (Myer, 2002)

The selected engineering materials whose creep responses are to be investigated are:

Lead	}	For low temperature creep analysis
Polypropylene		
Aluminum alloy		For high temperature creep analysis

Creep in steel is important only at elevated temperatures. Creep strains of engineering significance are not usually encountered until the operating temperature reach a range of approximately 35 – 70% of the melting point on a scale of absolute temperature. In general, creep becomes significant above about $0.4T_m$ where T_m is the absolute melting temperature (Larson and Miller, 1952; *International Directory of Testing Laboratories, 2001;* Penny and Marriot, 1995; Annual Book of ASTM standards, 2000). However, materials having low melting temperatures will exhibit creep at ambient temperatures. Good examples are lead and various types of plastics. For example, lead has a melting temperature of 326^oC (599K), and at 20^oC (293K, or about $0.5T_m$), it exhibits similar creep characteristics to those of Iron at 650^oC.

When a material like steel is plastically deformed at ambient temperatures, its strength is increased due to work hardening. This work hardening effectively prevents any further deformation from taking place if the stress remains approximately constant. Annealing the deformed steel at an elevated temperature removes the work hardening and restores the steel to its original condition. However, if the steel is plastically deformed at an elevated temperature, then both work hardening and annealing takes place simultaneously. A consequence of this is that steel under a constant stress at an elevated temperature will continuously deform with time, that is, it is said to "creep".

Creep deformation and rupture are initiated in the grain boundaries and proceed by sliding and separation. The creep rupture failures are inter-crystalline, in contrast, for example, to the trans-crystalline failure surface exhibited by room temperature fatigue failures (Myer, 2002; Penny and Marriot, 1995; Kuhn and Medlin, 2000). Although creep is a plastic flow phenomenon, the inter-crystalline failure path gives a rupture surface that has the appearance of brittle fracture (*International Directory of Testing Laboratories, 2001*). Creep rupture typically occurs without necking and without warning. Current state-of-the-art knowledge does not permit a reliable prediction of creep or stress rupture properties on a theoretical basis. Furthermore, there seems to be little or no correlation between the creep properties of a material and its room temperature mechanical properties.

Therefore, test data and empirical methods of extending these data are relied on heavily for prediction of creep behaviour under anticipated service conditions. Metallurgical stability under long-time exposure to elevated temperatures is mandatory for good creep-resistant alloys. Prolonged time at elevated temperatures acts as a tempering process, and any improvement in properties originally gained by quenching may be lost. Resistance to oxidation and other corrosive media are also usually important attributes for a good creep-resistant alloy. Larger grain sizes may also be advantageous since this reduces the length of grain boundary, where much of the creep process resides (Myer, 2002; Wiley and Hetenyi, 1950). The most commonly used expression for relating secondary creep rate $\acute{\varepsilon}$ to stress σ and absolute temperature T has the form:

$$\boldsymbol{\acute{\varepsilon} = A\sigma^{n}e^{-E/RT}} \qquad (1) \textit{ for metals}$$

Where A is a constant dependent on the material and the particular creep mechanism and n is a constant - stress index. E is the activation energy for creep in the metal and R is the universal gas constant (8.31 J/mol K). The equation shows that the creep rate is increased by raising either the stress or the temperature. If however, it is deemed necessary to consider all stages of the creep process, the creep strain expression becomes much more complex. The most general expression for the creep process is

$$\varepsilon = {}^{\delta}/_{E} + k_1\delta^{m} + k_2\,(1 - e^{-qt})\,\delta^{n} + k_3t\delta^{p} \qquad (2)$$

Where ε = total creep strain, δ/E = initial elastic strain, $k_1\delta^m$ = initial plastic strain, $K_2(1 - e^{-qt})\delta^n$ = anelastic strain, $K_3t\delta^p$ = viscous strain, δ = stress, E = modulus of elasticity, m= reciprocal of strain hardening exponent, k_1 = reciprocal of strength coefficient, q = reciprocal of Kelvin retardation time, k_2 = anelastic coefficient, n = empirical exponent, k_3 = viscous coefficient, t = time.

To utilize this empirical nonlinear expression in a design environment requires specific knowledge of the constants and exponents that characterize the material and temperature of the application. In plastics, creep occurs by chains untangling and slipping relative to one another (Thomas, 2000; TecQuipment SM106 MkII Manual). The mathematical equation which applies to some of the common engineering plastics has the form:

$$\varepsilon = \varepsilon_o + B\delta^m t^k \quad (3)$$

where ε is the tensile creep strain after a time t, δ is the applied creep stress, ε_0 is the instantaneous or initial strain produced on loading, and B, m, k are constants for a given polymer.

MATERIALS AND METHODS

The test-pieces used for the study are standard size specimens of Lead (BS1178), Polypropylene, and Wrought Aluminium alloy (2618 – T61) typical of the equipment used. Tests on the low melting temperature materials were carried out using TecQuipment SM106 MkII Apparatus while for the high temperature creep tests on Aluminium alloy, Instron A6 Series creep testing machine with LVDT displacement measuring transducer was used. Vernier caliper, stop watch, thermometer, and dead-weights are the ancillary gadgets required for the tests. The primary components of the test include a static load frame, furnance, and high-temperature extensometry. Creep deformation was examined by applying a constant true stress to a material held at a specified temperature. When the material was first loaded, a small permanent loading strain occurs and the creep strain rate gradually decreases. Static dead weights were employed for these tests and the experimental procedure for the low melting point materials (Pb & PP) is as detailed in TecQuipment SM106 MkII Manual while the basic methodology for the high temperature test is captured in the ASTM E139 – 11 handbook. Experiments were carried out at the Strength and Properties of Materials Lab, Akanu Ibiam Federal Polytechnic, Unwana.

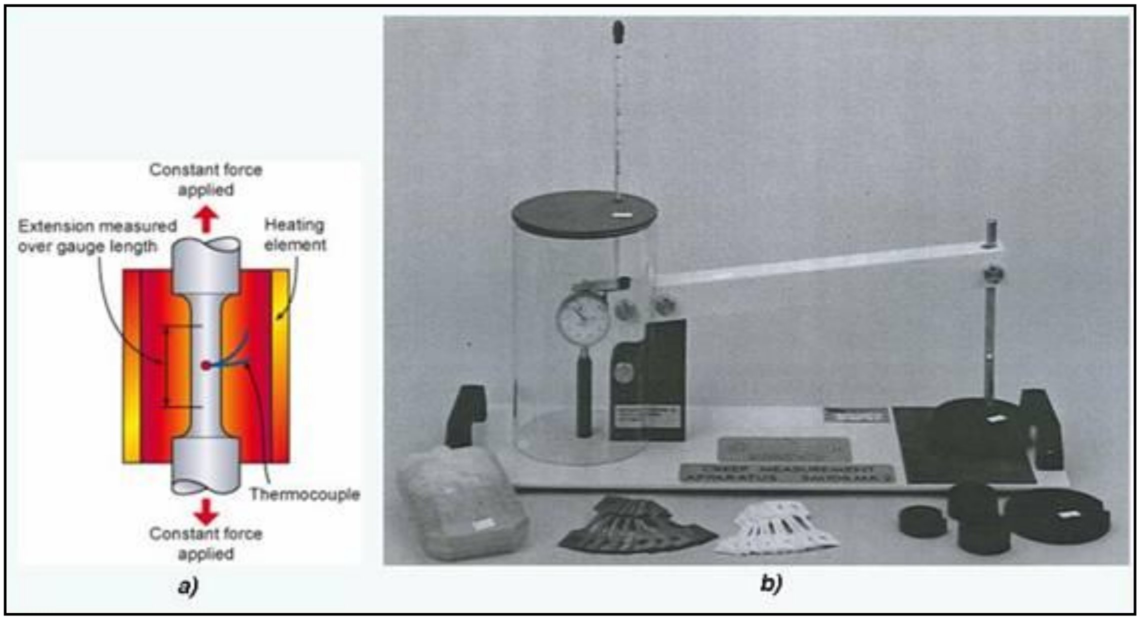

Figure 2: Creep testing configurations

Typically the creep test is conducted to characterize the deformation features (Penny and Marriot, 1995). Response function is the creep deformation while the control parameters are temperature and stress levels. However, one input signal is controlled while the other is kept constant at any instant. The creep test is carried out to investigate any dimensional changes of specimen with time during high temperature test. Typically, a creep specimen is gripped at both ends (similar to that of tensile test) encased within a furnace set at a desired test temperature as shown in figure 2. While a constant load is applied, time and dimensional change are recorded and plotted to give a creep curve. Further analysis may be conducted on the primary data, as required, with the view of establishing empirical values of creep properties for any given test material (TecQuipment SM106 MkII Manual; ASTM E139 – 11 handbook).

RESULTS AND DISCUSSION

After conducting the experiment, the results obtained for the test-specimens as are shown below:

Results of Lead Specimen

Material specification: Lead creep specimen (BS1178)

Thickness, t	= 1.85mm	
Breadth, b	= 4.80mm	
Gauge length, L_g	= 20mm	
Load on hanger, m	= 0.8 kg	
∴ Tensile pull, F	= (2.96 + 8m)g	= 91.82 N
Stress Applied, **σ**	= $\underline{91.82}$	= 10.34 MPa

(1.85 x 4.8)
Test Temperature, T = 33^{0}C
Sensitivity of DTI = 0.01mm

Table 1: Derived Table of Values

S/No	Time (mins)	Extension, e (5x10^-3mm)	Strain, ε (x10^-3)	Strain Rate, έ (10^-3 min^{-1})	%ε	ln (Time)	Ln (%ε)
0	0	3	0.75	#DIV/0!	0.075	#NUM!	-2.5903
1	0.25	203	50.75	203	5.075	-1.3863	1.6243
2	0.50	227	56.75	113.500	5.675	-0.6931	1.7361
3	0.75	244	61.00	81.333	6.100	-0.2877	1.8083
4	1.00	258	64.50	64.500	6.450	0.0000	1.8641
5	1.25	270	67.50	54.000	6.750	0.2231	1.9095
6	1.50	281	70.25	46.833	7.025	0.4055	1.9495
7	1.75	294	73.50	42.000	7.350	0.5596	1.9947
8	2.00	308	77.00	38.500	7.700	0.6931	2.0412
9	2.25	321	80.25	35.667	8.025	0.8109	2.0826
10	2.50	340	85.00	34.000	8.500	0.9163	2.1401
11	2.75	361	90.25	32.818	9.025	1.0116	2.2000
12	3.00	390	97.50	32.500	9.750	1.0986	2.2773
13	3.50	450	112.50	32.143	11.250	1.2528	2.4204
14	4.00	540	135.00	33.750	13.500	1.3863	2.6027
15	4.25	590	147.50	34.706	14.750	1.4469	2.6912
16	4.50	641	160.25	35.611	16.025	1.5041	2.7742
17	4.75	690	172.50	36.316	17.250	1.5581	2.8478
18	5.00	740	185.00	37.000	18.500	1.6094	2.9178
19	5.25	800	200.00	38.095	20.000	1.6582	2.9957
20	5.50	865	216.25	39.318	21.625	1.7047	3.0739
21	5.75	940	235.00	40.870	23.500	1.7492	3.1570
22	6.00	1020	255.00	42.500	25.500	1.7918	3.2387
23	6.25	1120	280.00	44.800	28.000	1.8326	3.3322
24	6.50	1250	312.50	48.077	31.250	1.8718	3.4420
25	6.75	1,400	350.00	51.852	35.000	1.9095	3.5553
26	7.00	1675	418.75	59.821	41.875	1.9459	3.7347

The initial elastic extension is found by dividing the creep stress 10.34 N/mm^2 by the tensile modulus of lead (13790 N/mm^2) which gives an elastic strain of 0.75x10^-3. For a gauge length of 20mm, this is equivalent to an extension of 0.015mm =3(x5x10^-3mm) ~*1st entry in column 3*

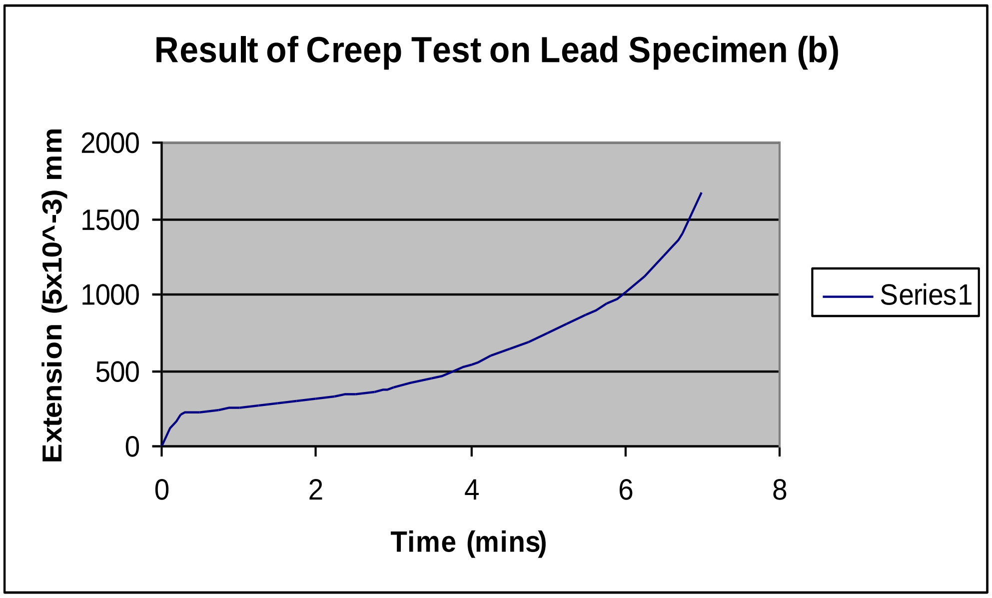

Figure 3**:** Extension Vs Time for lead specimen at 10.34 N/mm^2, 33 ^{0}C

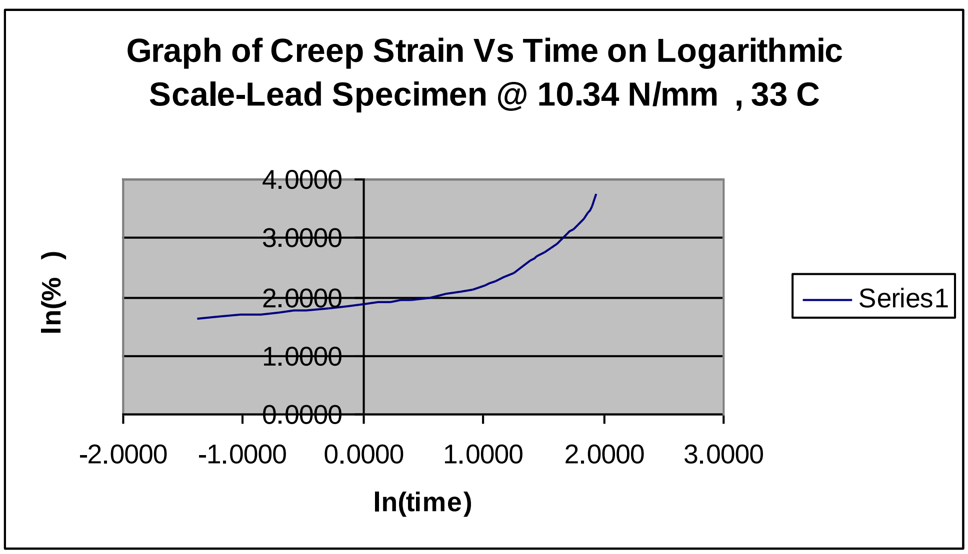

Figure 4: Strain vs. Time on log scales-lead specimen at 10.34 N/mm^2, 33^{0}C

From figure 3, the three stages of creep can be identified. Figure 4 is a good pointer of time-to-creep-failure. The point of departure of the graph from the straight line path when noted can be used as a design criteria for cumulative creep strain such that the tertiary stage of creep is never reached by the creep component under service condition.

Evaluation of the Activation Energy for Creep in Lead

The process of determining the values of activation energy for creep in metals is typified with the analysis below. Summary of the results for experiments carried out on three Lead creep specimens at constant temperature, T of 21 ^oC and different stress levels are shown in table 2:

Table 2: Creep rates vs Stress levels

M(kg)	1.2	1.1	1.0
σ(N/mm^2)	12.64	11.83	11.03
έ(mm/min)	0.21	0.08	0.047
ln**σ**	2.537	2.471	2.401
lnέ	-8.65	-9.62	-10.15

It would be seen that increasing the applied stress levels would lead to increase in creep strain rates at constant temperature. The value of activation energy E for lead can be determined from values of lnέ and 1/T, from two results at constant stress and different temperatures. For this purpose, another test was conducted at a temperature T_2 = 24.2 ^oC using a temperature module, and at a stress level **σ** = 11.83 N/mm^2. The technical interpretation of the result yielded a creep rate of 0.0503 mm/min. Taking log of equation 1 to base 'e' and then differentiating wrt the reciprocal of temperature, we obtain that

$$\frac{d(\ln \acute{\varepsilon})}{d(1/T)} = \frac{-E}{R} \qquad (4)$$

Expressing T in Kelvin, έ in Sec^{-1} and substituting R=8.31 Jmol^{-1}, we get **E=104.4kJmol^{-1}.**

By considering stress states σ_1 and σ_2,

ln(0.21) = (β - E/RT) + n.ln12.64 *i*

ln(0.042) = (β - E/RT) + n.ln11.03 *ii* β = n.lnA

Implying that: stress exponent, n= 11 and A = 0.069.

The computed value of E is reasonably in agreement with accepted values. It should however be noted that results can exhibit a fair degree of scatter; but generally for most metals, values in the range between 95 and 150 kJmol^{-1} should be expected. For the case of Lead under consideration, the stress exponent n has a value of 11. This value is considered high; the reason is because of the relatively high stress levels used for the tests in a bid to shorten laboratory test times. The constant A of equation (1) was found to be 0.069. Because of the apparent increase in value of the stress exponent n, the power law of equation (1) ceases to apply. Instead an exponential expression that more adequately fits the experimental data can be used to predict values of steady-state creep for a given condition of temperature and applied stress. The expression is:

$$\acute{\varepsilon} = Be^{(\propto\delta - E/RT)} \qquad (5)$$ *where B and ∝ are* constants (Myer, 2002)

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Results of Polypropylene Specimens

Material specification: Polypropylene creep specimen
Gauge Length, Lg = 20mm
Thickness, t = 1.00mm
Width, b = 4.80mm
Load on hanger m = 0.5kg
Ambient Temperature: 33^0C
Tensile pull, F = (2.96+8m) g = (2.96 + 8x 0.5) x 9.81 = 68.28N;
Tensile stress $= F/A = \mathbf{14.22\ N/mm^2}$

Table 3 shows the experimental results and some derived values for the test on Polypropylene. The concept of creep recovery has been demonstrated. In real-time practice or application, this concept is usually applied by relieving the component of the impressed load, usually just before the tertiary creep stage with the aim of prolonging further the service life (Meyers and Chawla, 1999).

Table 3 Comprehensive Table of Values – PP Specimen

S/No	Time, *t* (mins)	Extension, e (5x10^-3mm)	Strain, ε (x10^-3)	Strain Rate,έ (10^-3 min-1)	% έ	ln(Time)	ln(%έ)
0	0.00	45.5	11.375	#DIV/0!	1.1375	#NUM!	0.1288
1	0.25	170.0	42.500	170.00	4.25	-1.3863	1.4469
2	0.50	203.0	50.750	101.50	5.08	-0.6931	1.6243
3	0.75	218.0	54.500	72.67	5.45	-0.2877	1.6956
4	1.00	228.0	57.000	57.00	5.70	0.0000	1.7405
5	1.25	237.0	59.250	47.40	5.93	0.2231	1.7792
6	1.50	244.0	61.000	40.67	6.10	0.4055	1.8083
7	1.75	250.0	62.500	35.71	6.25	0.5596	1.8326
8	2.00	256.0	64.000	32.00	6.40	0.6931	1.8563
9	2.25	260.0	65.000	28.89	6.50	0.8109	1.8718
10	2.50	265.0	66.250	26.50	6.63	0.9163	1.8909
11	2.75	269.0	67.250	24.45	6.73	1.0116	1.9058
12	3.00	273.0	68.250	22.75	6.83	1.0986	1.9206
13	3.25	277.5	69.375	21.35	6.94	1.1787	1.9369
14	3.50	281.0	70.250	20.07	7.03	1.2528	1.9495
15	4.00	287.5	71.875	17.97	7.19	1.3863	1.9723
16	4.50	293.0	73.250	16.28	7.33	1.5041	1.9913
17	5.00	299.8	74.950	14.99	7.50	1.6094	2.0142
18	5.50	305.0	76.250	13.86	7.63	1.7047	2.0314
19	6.00	310.0	77.500	12.92	7.75	1.7918	2.0477
20	6.50	315.0	78.750	12.12	7.88	1.8718	2.0637
21	7.00	319.8	79.950	11.42	8.00	1.9459	2.0788
22	7.50	324.0	81.000	10.80	8.10	2.0149	2.0919
23	8.00	328.0	82.000	10.25	8.20	2.0794	2.1041

24	8.50	332.0	83.000	9.76	8.30	2.1401	2.1163
25	9.00	336.0	84.000	9.33	8.40	2.1972	2.1282
26	9.50	340.0	85.000	8.95	8.50	2.2513	2.1401
27	10.00	344.0	86.000	8.60	8.60	2.3026	2.1518
28	10.50	347.0	86.750	8.26	8.68	2.3514	2.1604
29	11.00	350.5	87.625	7.97	8.76	2.3979	2.1705
30	12.00	357.5	89.375	7.45	8.94	2.4849	2.1903
31	13.00	364.0	91.000	7.00	9.10	2.5649	2.2083
32	14.00	370.0	92.500	6.61	9.25	2.6391	2.2246
33	15.00	376.0	94.000	6.27	9.40	2.7081	2.2407
34	16.00	381.5	95.375	5.96	9.54	2.7726	2.2552
35	17.00	387.0	96.750	5.69	9.68	2.8332	2.2695
36	18.00	392.0	98.000	5.44	9.80	2.8904	2.2824
37	19.00	396.5	99.125	5.22	9.91	2.9444	2.2938
38	20.00	401.0	100.250	5.01	10.03	2.9957	2.3051
39	21.00	405.5	101.375	4.83	10.14	3.0445	2.3162
40	22.00	410.0	102.500	4.66	10.25	3.0910	2.3273
41	23.00	415.0	103.750	4.51	10.38	3.1355	2.3394
42	24.00	419.0	104.750	4.36	10.48	3.1781	2.3490
43	25.00	422.3	105.575	4.22	10.56	3.2189	2.3568
44	26.00	425.7	106.425	4.09	10.64	3.2581	2.3649
45	27.00	430.0	107.500	3.98	10.75	3.2958	2.3749
46	28.00	433.5	108.375	3.87	10.84	3.3322	2.3830
47	29.00	437.0	109.250	3.77	10.93	3.3673	2.3911
48	30.00	440.5	110.125	3.67	11.01	3.4012	2.3990
49	31.00	444.0	111.000	3.58	11.10	3.4340	2.4069
50	32.00	447.5	111.875	3.50	11.19	3.4657	2.4148
51	32.50	287.5					
52	33.00	277.5					
53	33.50	272.5					
54	34.00	269.5					
55	34.50	265.5					
56	35.00	261.5					

Elastic & Creep Recovery Raw Data

S/No	Time	Recovery
51	0.5	160
52	1.0	170
53	1.5	175
54	2.0	178
55	2.5	182
56	3.0	186

Initial elastic extension = Initial elastic strain x Gauge length

i.e.

$$e_0 = \left\{ \frac{\text{Applied Stress level, N/mm}^2}{\text{Elastic Modulus of Material, N/mm}^2} \right\} \mathbf{x\ Lg}$$

$$= \frac{14.22}{1250} \mathbf{x\ 20}$$

$$= 0.228\text{mm} \quad = 45.5(\text{x}5\text{x}10\text{^-}3)\text{ mm}$$

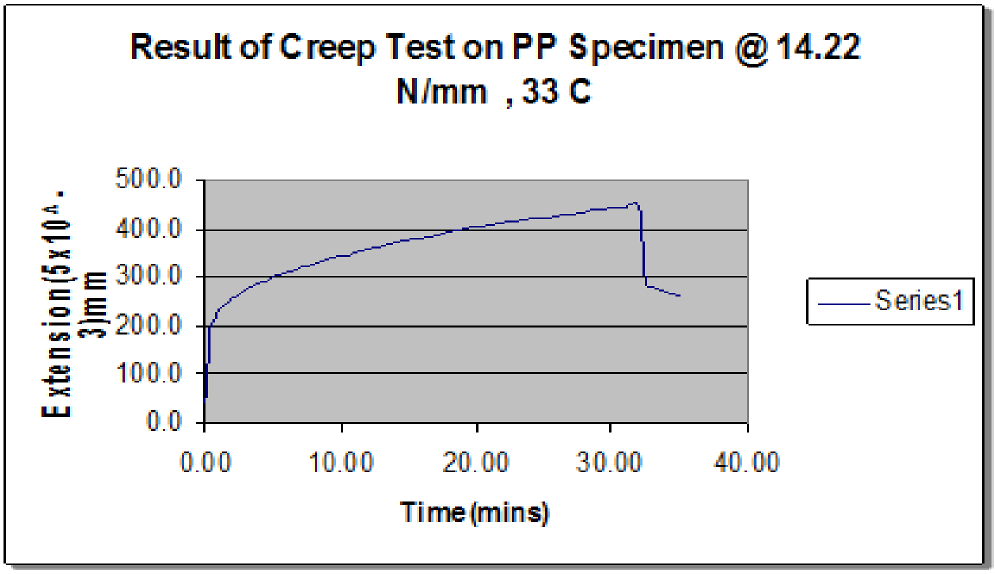

Figure 5: Graph of Extension Vs Time for PP Specimen @ 0.5Kg, 33 ^{0}C

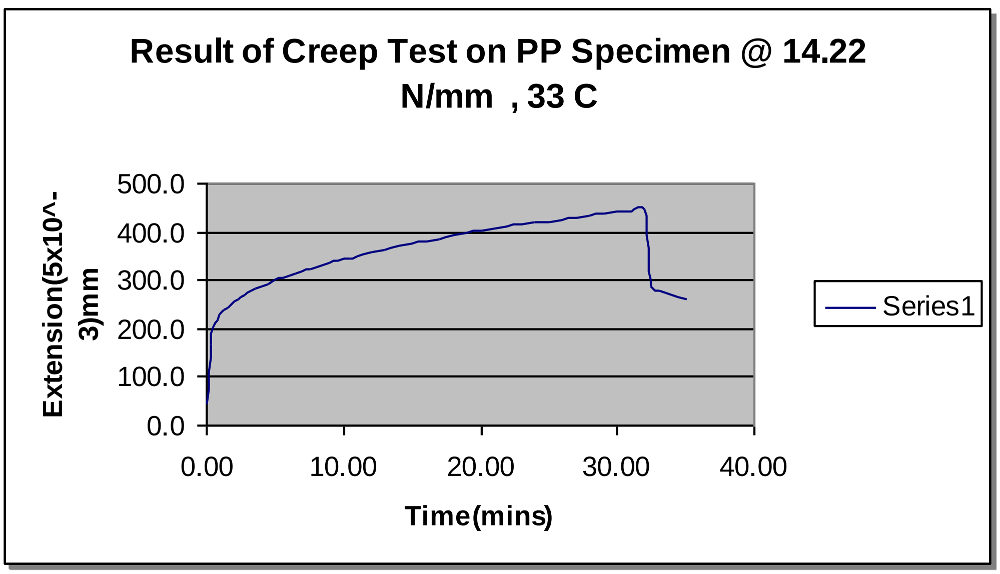

Figure 6: Graph of Strain Vs Time on Logarith- mic Scale for PP Specimen @ 0.5Kg, 33 ^{0}C

Analysis of Results for the Polypropylene Specimen

A typical creep curve for a polypropylene specimen is shown in figure 5. This was obtained in exactly the same way as for the lead specimens, but in addition the load was removed toward the end of the secondary creep stage and further readings taken to show the recovery of creep strain. The initial part of the characteristic shows the first two stages of creep, the basic shape being similar to that of lead. The elastic extension was calculated by dividing the creep stress by the tensile modulus of polypropylene (1250N/mm^2) which gives an elastic strain of 0.0114. For a gauge length of 20mm this is equivalent to an extension of 0.228mm. When the load was removed, this elastic extension was recovered immediately and this was followed by a more gradual recovery of creep strain. In this particular experiment the creep strain recovery was about 62.5%. Ostensibly, this relatively high recovery is due to the fact that tertiary creep stage was never reached.

Creep Test Results of Aluminium Alloy Specimens

Test result of a high temperature creep test is shown on table 5. Creep characteristics were investigated by subjecting test specimens to two stress levels while temperature was kept constant. The mechanical properties for the referenced material are shown on table 4.

Material Specification: Wrought Aluminium Alloy: 2618 – T61

Table 4: Mechanical Properties

Ultimate Tensile Strength	440 MPa
Tensile Yield Strength	370 MPa
% Elongation	10
Hardness: BHN (500Kg/10mm)	115 Kg/mm^2
Ultimate Shear Strength	2.60 MPa
Modulus of Elasticity	73GPa

* Elongation was measured over 500 – mm gauge length (5D) in 12.5 – mm diameter specimens

Test Conditions:

Temperature = 200 ^{0}C

Applied Stress Levels: $\boldsymbol{\sigma_1}$ =60MPa to sample I

$\boldsymbol{\sigma_2}$ =35MPa to sample II

Table 5: Table of Values- Creep Test of Al alloy

S/No	Time (hr)	Strain at 60 MPa ε_1 (x10^-3)	Strain at 35 MPa ε_2 (x10^-3)	ln{t(s)}	$\ln\varepsilon_1$	$\ln\varepsilon_2$
1	0	0.320	0.108	#NUM!	-8.04719	-9.13338
2	20	0.532	0.215	11.18442	-7.53887	-8.44487
3	60	0.815	0.332	12.28303	-7.11232	-8.01038
4	90	1.000	0.400	12.6885	-6.90776	-7.82405
5	120	1.200	0.477	12.97618	-6.72543	-7.64799
6	140	1.320	0.532	13.13033	-6.63012	-7.53887
7	170	1.477	0.610	13.32449	-6.51774	-7.40205
8	220	1.800	0.723	13.58232	-6.31997	-7.2321

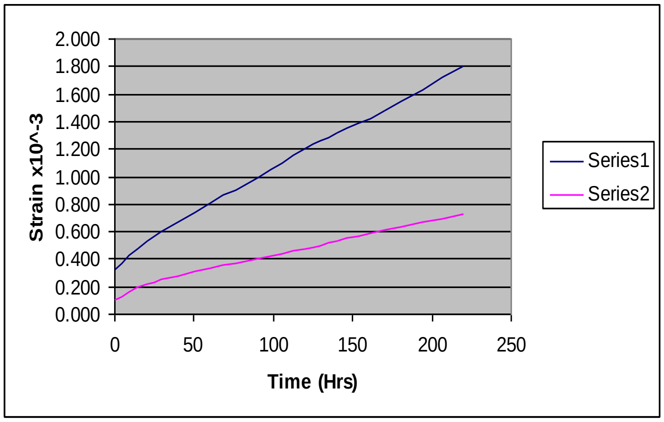

Figure 8: The Plot of Strain Vs Time- Creep Test of Aluminum alloy

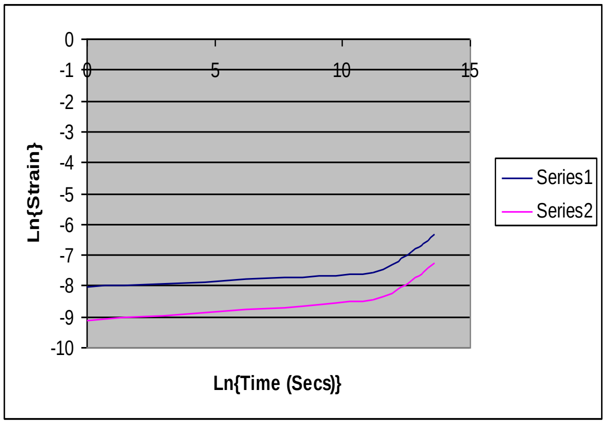

Figure 9: The Plot of Strain against Time on Logarithmic Scale

Given that for a typical application of the material, service condition or criteria is set such that minimum creep rate of $4.8x10^{-3}$ mmm^{-1} hr^{-1} ($\equiv 4.8$ $x10^{-6}$ per hour) must not be exceeded. To be able to satisfy this design purpose, we shall therefore work-out a critical stress level that would produce this limiting creep rate. We would therefore proceed as follows:
Plot the data on a spread-sheet to see that the period of the tertiary creep was never reached.

Now, @ 200 ^{0}C, 60 MPa Creep rate
$\acute{\varepsilon}_1 = 0.00554mmm^{-1}\ hr^{-1} = 0.00554/3.6x10^6\ s^{-1}$
At 200 ^{0}C, 35 MPa Creep rate
$\acute{\varepsilon}_2 = 0.00266mmm^{-1}\ hr^{-1} = 0.00266/3.6x10^6\ s^{-1}$
The values were obtained from the graph of the Creep strain against time by evaluating the slope of the secondary creep region.

Generally for metals, $\acute{\varepsilon} = A\sigma^n e^{-E/RT}$ (i)

and $\ln\acute{\varepsilon} = n\ln\sigma + \ln A - E/RT$ (ii)

From equation (ii)

$$\ln\left\{\frac{0.00544}{3.6x10^6}\right\} = n.\ln(60x10^6) + \ln A - E/RT \quad \text{(iii) and}$$

$$\ln\left\{\frac{0.00266}{3.6x10^6}\right\} = n.\ln(35x10^6) + \ln A - E/RT \quad \text{(iv)}$$

Solving Equations (iii) and (iv) above
Stress exponent, n = **1.33**
And $\ln A - E/RT = -44.13$

Thus the stress that would give rise to this creep rate of $1.33x10^{-9}\ s^{-1}$:

$\ln(1.33\times10^{-9}) = 1.33\ln\sigma - 44.13$

Or $\ln\sigma = 17.82$

$\Rightarrow \sigma = e^{17.82} = 54.58\times10^{6}\ N/m^{2}$

ie $\sigma = 54.58MPa$

This means a stress-state of 54.58MPa is required to give rise to a steady state creep rate of 4.8×10^{-3} mmm^{-1} hr^{-1} (=1.333×10^{-9} s^{-1}) in the aluminum alloy tested at 200 ^{0}C. It would be noted that the computed value of stress exponent n is typical of accepted values for most metals (Myer, 2002; Penny and Marriot, 1995). The higher creep resistant properties of the referenced Al alloy has portrayed its test condition as being less severe when juxtaposed with the test conditions for Pb. Computation of this nature are often necessary at the design stage so as to forestall catastrophic failures that may accompany cumulative creep damage in a component.

CONCLUSION

Creep occurred in Lead, Polypropylene and Aluminum alloy specimens exhibiting initial elastic or instantaneous deformation, primary or transient creep, secondary or steady-state creep, and tertiary or accelerating creep. The observations from the tests can be summarized as follows:

1. Creep resistance depends on the morphological structure of a material.
2. Creep damage can take place even at stress levels well below the UTS of the material.
3. The values of the creep constants A, n, and E defines the stability or resistance of a material to creep and the disposition of creep failure for a given service or test condition.
4. Creep effects on components are stress, time, and temperature dependent amongst other factors.
5. Time dependent effect of stress or load removal is due to recovery of the visco-elastic component of the creep strain.

The results show the important effects of creep on components life which cannot be ignored during the design stage, material specification and selection for high temperature application. Because creep describes the accumulation of plastic strain in a component subject to an elevated temperature and constant stress over a period of time, when in service, an engineering component should never enter the tertiary stage of creep.

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