Creep Test of Metallic Materials

Objective:

In this test the student will inspect the property of creep in metals..

Introduction

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 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 take place simultaneously. A consequence of this is that steel under a constant stress at an elevated temperature will continuously deform with time, which is creep.

Creep in steel is important only at elevated temperatures. In general creep becomes significant at temperatures above about 0.4 $\mathbf{T_m}$ where $\mathbf{T_m}$ is the absolute melting temperature. However, materials having low melting temperatures will exhibit creep at ambient temperatures. Good examples are lead and various types of plastic. For example, lead has a melting temperature of 326°C (599K), and at 20°C (293K or about 0.5 $\mathbf{T_m}$), it exhibits similar creep characteristics to those of iron at 650°C.

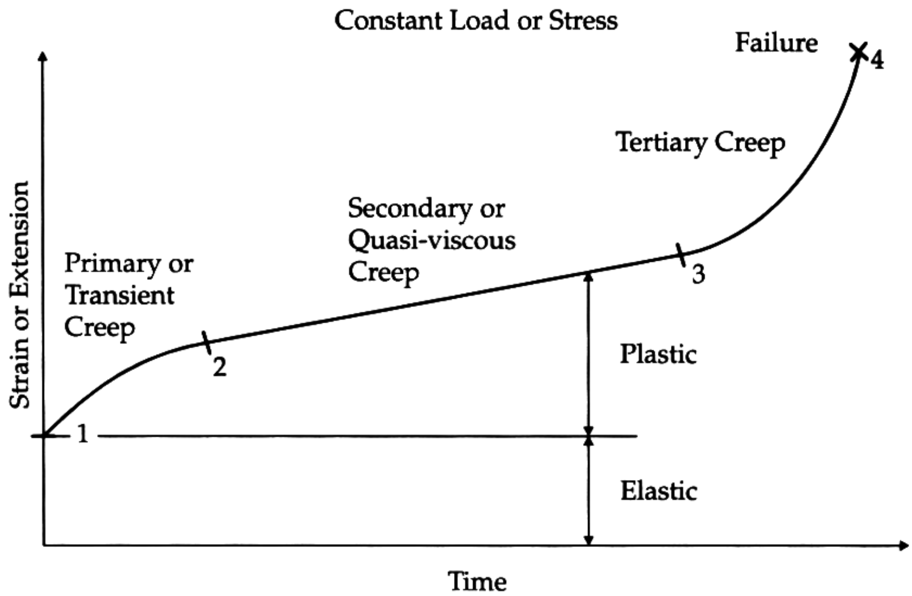

Figure 1 Typical Extension-Time Curve

Creep in Metals

A creep test is carried out by applying a constant load to a specimen and observing the increase in strain (or extension) with time. A typical extension- time curve is shown in Figure 1. Three regions can be readily identified on the curve:

1 to 2 Primary Creep:

Creep proceeds at a diminishing rate due to work hardening of the metal.

2 to 3 Secondary Creep:

Creep proceeds at a constant rate because a balance is achieved between the work hardening and annealing (thermal softening) processes.

3 to 4 Tertiary Creep:

The creep rate increases due to necking of the specimen and the associated increase in local stress. Failure occurs at point 4.

In terms of dislocation theory, dislocations are being generated continuously in the primary stage of creep. With increasing time, more and more dislocations are present and they produce increasing interference with each others movement, thus causing the creep rate to decrease. In the secondary stage, a situation arises where the number of dislocations being generated is exactly equal to the number of dislocations being annealed out. This dynamic equilibrium causes the metal to creep at a constant rate. Eventually, however, the creep rate increases due to localized necking of the specimen (or component); void and micro crack formation at the grain boundaries, and various metallurgical effects such as coarsening of precipitates.

When in service, an engineering component should never enter the tertiary stage of creep. It is therefore the secondary creep stage which is of prime importance as a design criterion. Components which are subject to creep spend most of their lives in the secondary stage, so it follows that the metals or alloys chosen for such components should have as small a secondary creep rate as possible. In general it is the secondary creep rate which determines the life of a given component.

Secondary creep rate for a particular metal or alloy depends on several variables, the most important of which are stress and temperature. The most commonly used expression for relating secondary creep rate **ε** to stress **σ** and absolute temperature **T** has the form:

$$\varepsilon = A\sigma^{n} e^{-E/RT} \quad \text{………………………………………………………………} (1)$$

The equation shows that the creep rate is increased by raising either the stress or the temperature. Taking natural logarithms gives:

$$Ln\ \varepsilon = Ln\ A + n\ Ln\ \sigma - \frac{E}{RT} \quad \text{……………………………………………………...} (2)$$

Where:

ε is the creep rate.
n is constants and equals to 10
R is the universal gas constant (8.31 J/mol.K)
E is the activation energy for creep in metals (120 kJ/mol).
σ is the stress.
A and **B** are constants.
α is a constant and approximately equals to 0.85

Most metals have a stress exponent of about (**n** = 5) and this value is also applicable in the case of lead, but only when the stress is below about 5 N/mm. At higher stress levels the exponent **n** increases to about 10, and eventually the simple power law of Equation 2 ceases to apply. Instead an exponential expression more adequately fits the experimental data:

$$\varepsilon = B\ e^{\alpha\sigma} e^{-E/RT} \quad \text{……………………………………………………………………..} (3)$$

Where:

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A plot of Ln **ε** against σ will therefore yield a straight line of slope α. If the stress is in units on N/mm^2 (or MN/m^2) the value of α is approximately 0.8 to 0.9 and also varies somehow with stress level.

Apparatus

The SM106 MkII Creep Measurement Apparatus, illustrated in Figure 3.1, uses a simple lever to apply a steady load to the specimen. The specimen is attached at one end to the lever mechanism by a steel pin and fixed at the other end to the bearing block by another steel pin.

Loads are applied to the lever arm by placing weights on the weight hanger, which is pinned to the lever arm. The weight hanger has two pinning positions:

1. The uppermost is used to pin the hanger in the rest position.
2. The lower hole is used to pin the hanger in the loaded position.

The lever arm has a mechanical advantage of 8. The mass of the arm is 0.367 kg, the weight hanger mass is 0.16 kg, and the pins used for pinning the weight hanger and specimen are 0.04 kg each. The load on specimen can be found by taking moments about the pivot bearing as illustrated in Figure 3.

If a mass m is added to the weight hanger then the tensile pull on the specimen (F) is:

$F = (2.84 + 8m)g$ (N)………………………………………………………… (4)

Where

g = acceleration due to gravity

Figure 2 Components of the SM106 Mk II Apparatus

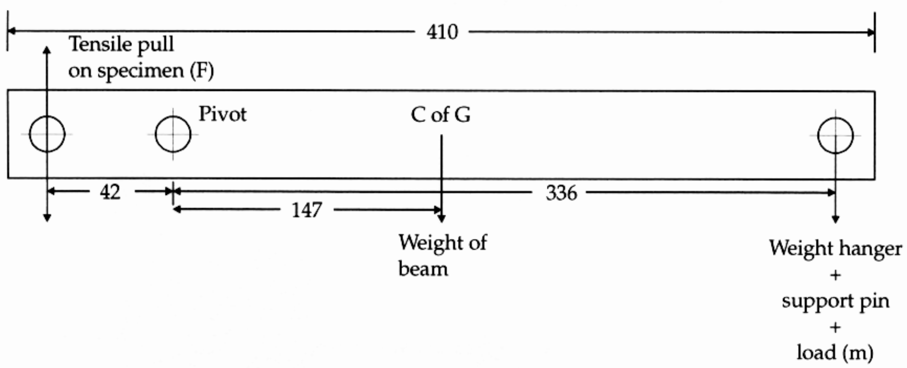


Figure 3 Details of the Lever Arm

Note: The mass m does not include the mass of the hanger: this is included in the constant 2.84.

The specimen extension is measured by a dial test indicator (DTI). A tube fixed to the bearing block is the housing for the DTI and a nylon pinch screw is used to restrain the DTI under steady load conditions. The top of the DTI is attached to the lever mechanism by means of a grooved plate which is bolted to the lever arm. The arrangement is such that the groove in this plate is twice the distance from the pivot than that of the centre of the specimen. Therefore the extension given by the DTI is twice the extension of the specimen.

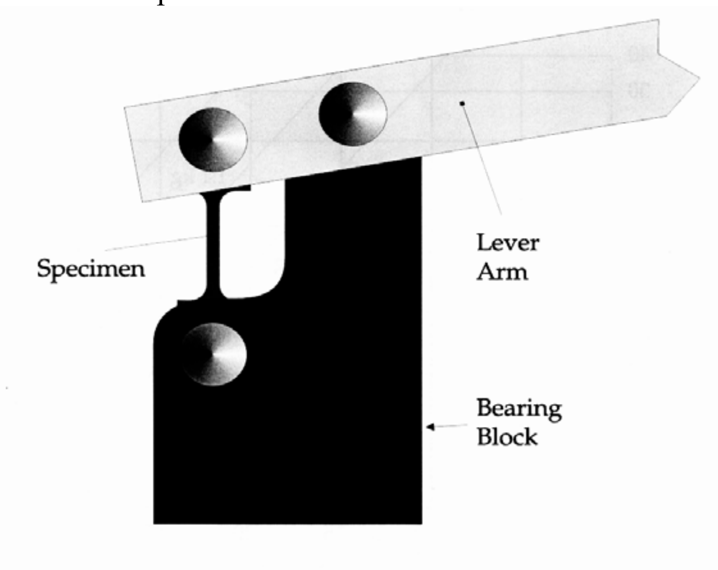


Figure 4 Details of Specimen Loading Arrangement

Procedure

Lead Specimens at Room Temperature

1. Gently raise the lever arm and pin in the rest position.
2. Remove the thumb nut retaining the grooved plate on the lever arm and slacken the nylon pinch screw retaining the Dial Test Indicator (DTI) in the tube.
3. Using both hands, gently lift the DTI and the grooved plate clear of the apparatus. Separate the plate from the DTI and stow in a safe place.
4. Remove the specimen retaining pins from the lever arm and bearing block.
5. Measure and record the thickness and width of the gauge length of the specimen.
6. Fit the top of the specimen into the lever arm and replace the specimen retaining pin.
7. Fit the bottom of the specimen into the bearing block and replace the specimen retaining pin (it may be necessary to remove the rest pin to allow some movement of the lever arm; if this is done, then replace the rest pin when the specimen has been fitted).
8. Refit the DTI and grooved plate but do not tighten up the nylon pinch screw.
9. Remove the rest pin and gently lower the lever arm to take up any free movement. Zero the DTI and turn the nylon pinch screw until it is finger tight.
10. Refit the rest pin.
11. Record the ambient temperature and reset the stop watch to zero ready to start the test.
12. Load the weight hanger with the required load, remove the rest pin and gently lower the lever arm to take up any slack.
13. Raise the hanger to the load position and refit the pin. Gently release the load and start the stop watch.
14. Record extension readings from the DII every 15 seconds for the primary stage of creep. When the extension rate slows down then record readings every minute. As the test approaches the tertiary stage record readings every 15 seconds until fracture occurs or the weight hanger bottoms.

Data and results sheet:

Specimen type : ....

Specimen Dimensions:

- Thickness : ....
- Width : ....
- Gage length : ....

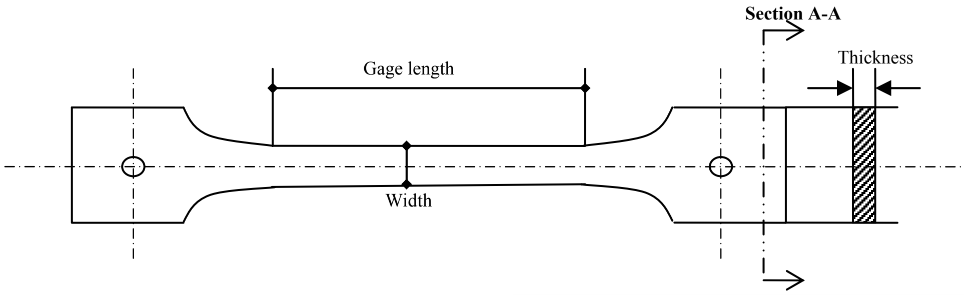
Tensile force (F) : ....

Stress (N/mm^2) : ....

Ambient temperature (^oC) : ....

Time (minutes)	Extension (mm)*	Time (minutes)	Extension (mm)*

Note: * Extension = (dial test indicator reading)/2.



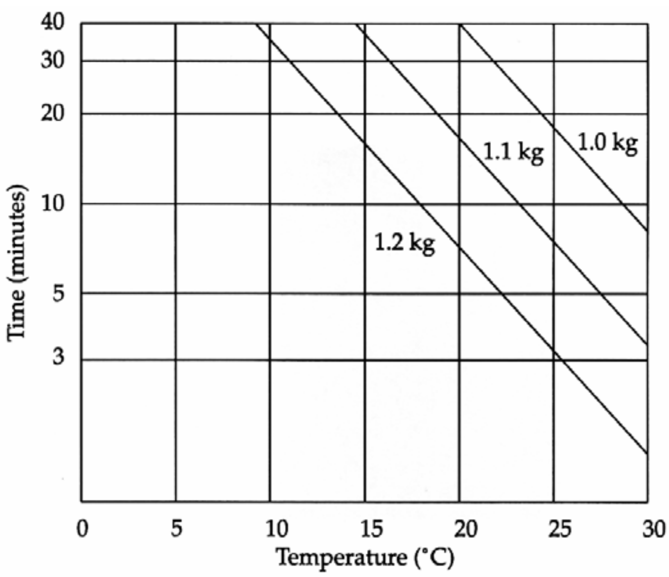


Figure 4: Typical test times for lead specimens at various loads (m) and temperatures.

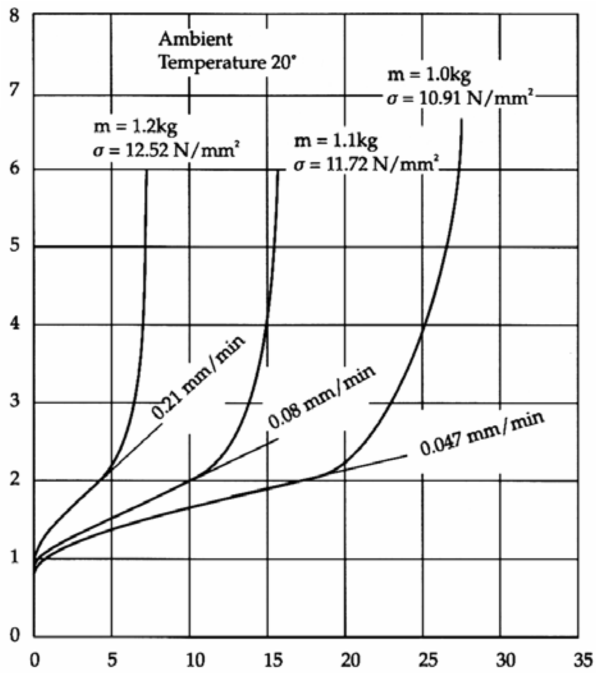


Figure 5: Creep curves for lead specimens at various stress levels.

Analysis:

Time (min)	Extension (mm)
0.25	0.975
0.50	1.060
0.75	1.128
1.00	1.195
1.25	1.220
1.50	1.255
1.75	1.290
2.00	1.320
2.25	1.345
2.50	1.373
2.75	1.395
3.00	1.418
4.00	1.500
5.00	1.580
6.00	1.658
7.00	1.783
8.00	1.825
9.00	1.898
10.00	2.043
11.00	2.160
11.50	2.235
12.00	2.355
12.25	2.398
12.50	2.423
12.75	2.470
13.00	2.575
13.25	-
13.50	2.735
13.75	2.840
14.00	3.085
14.25	3.300
14.50	3.510
14.75	3.705
15.00	3.900
15.25	4.125
15.50	4.475
15.75	4.900
16.00	6.000

Table: Typical results for lead specimens.

1. Plot the results obtained from the test using the graph paper and obtain a curve similar to that shown in **figure 1.**

$$Extension = \frac{reading}{100 * 2 * web\ length} \quad \text{….. (Why?)}$$

2. Plot Extension against time, the slope of the curve at the secondary region is the creep rate **ε**.
3. from the plot obtained, find:
   - The time required for the secondary creep and the tertiary creep.
   - Find the value of the constant **B** from equation 3 for the specimen.
4. Discuss the advantages that can form obtained by the plot.
5. State 3 applications where the creep test is essential in elements and members design.