Creep Deformation in Materials

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Agenda

- Define creep and discuss its importance in materials engineering.
- Identify the primary mechanisms of creep deformation.
- Creep model parameters.
- Detail experimental ways to determine creep.
- Discuss design options to minimize creep deformation.

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Useful concepts revision…

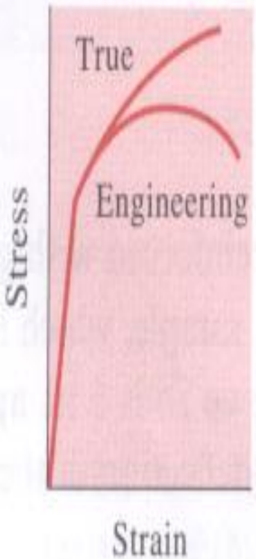

FIGURE 6-10 The relationship between the true stress–true strain diagram and the engineering stress–engineering strain diagram.

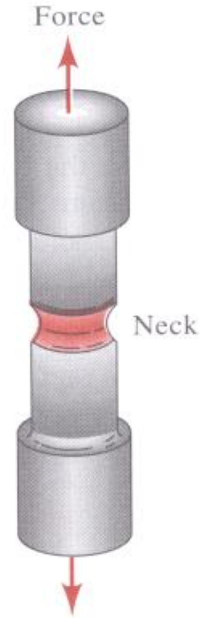

FIGURE 6-4 Localized deformation of a ductile material during a tensile test produces a necked region.

$$\text{Engineering stress} = \sigma = \frac{F}{A_0}$$

$$\text{Engineering strain} = \varepsilon = \frac{l - l_0}{l_0}$$

$$\text{True stress} = \sigma_t = \frac{F}{A'}$$

$$\text{True strain} = \varepsilon_t = \int_{l_0}^{l'} \frac{dl}{l} = \ln\left(\frac{l'}{l_0}\right) = \ln\left(\frac{A_0}{A'}\right)$$

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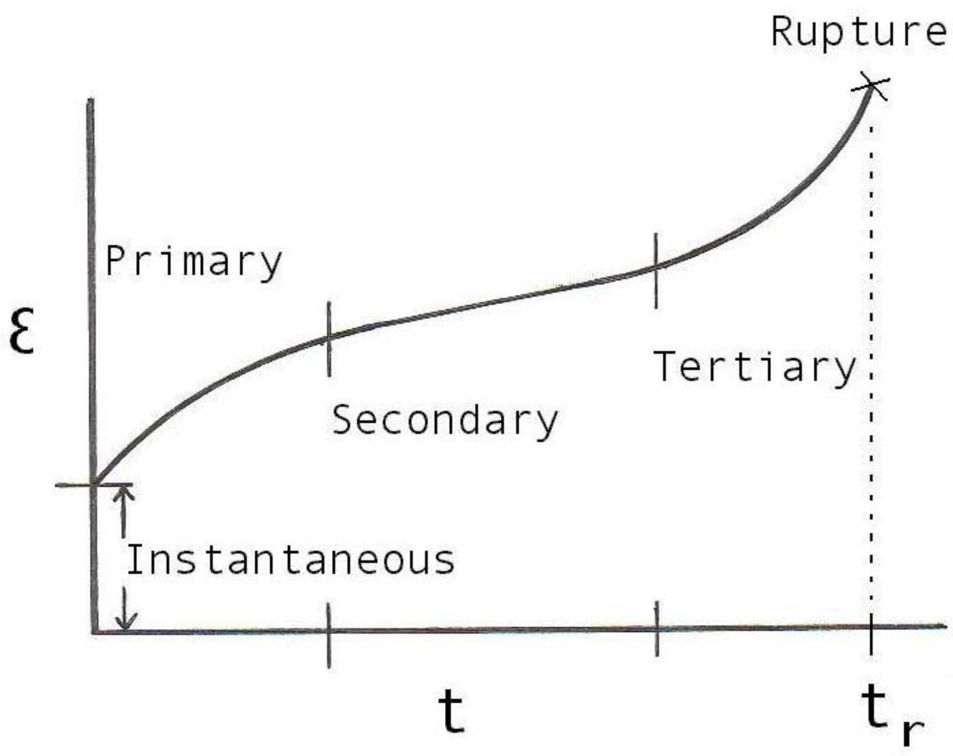
Creep

- It is a time- dependent deformation under a certain applied load.
- Generally occurs at high temperature (thermal creep), but can also happen at room temperature in certain materials (e.g. lead or glass), albeit much slower.
- As a result, the material undergoes a time dependent increase in length, which could be dangerous while in service.

Classical Creep Curve

- The rate of deformation is called the creep rate. It is the slope of the line in a Creep Strain vs. Time curve.



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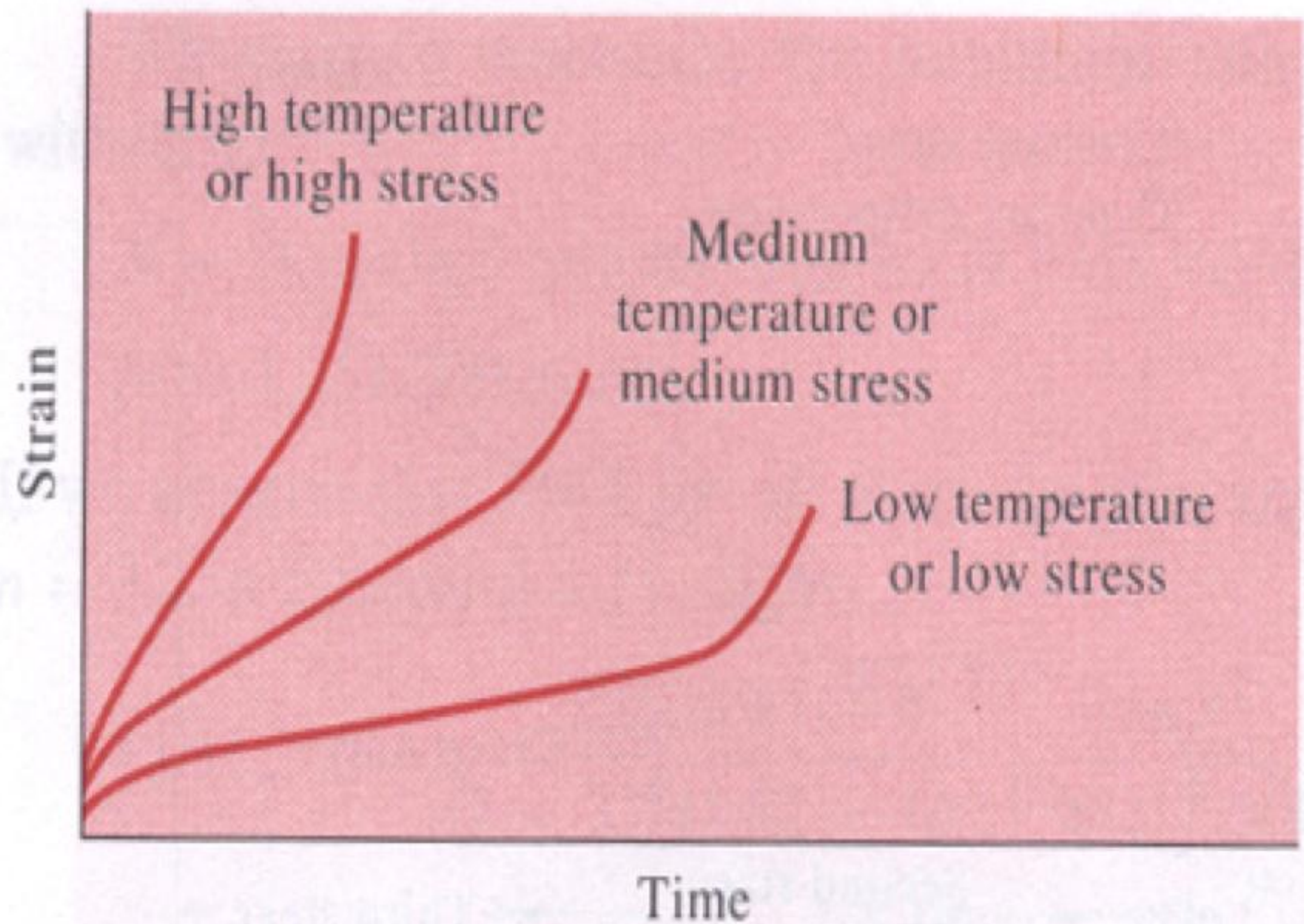
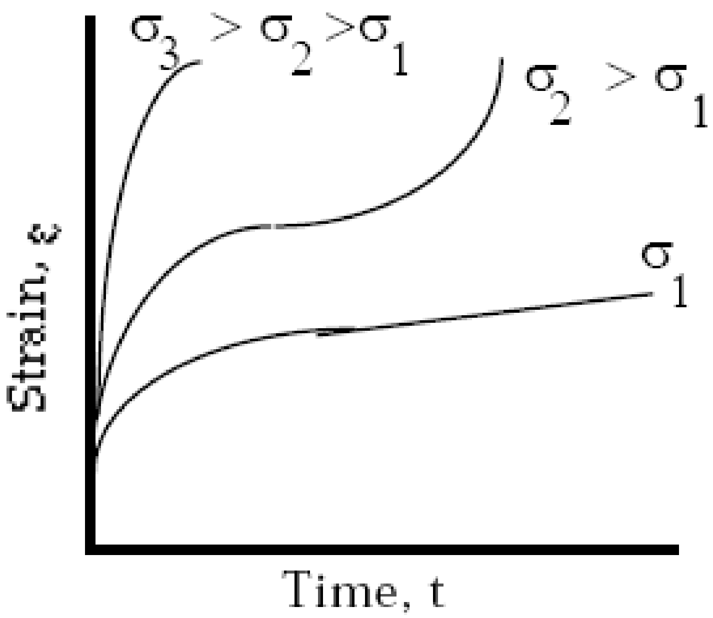
Creep Stages

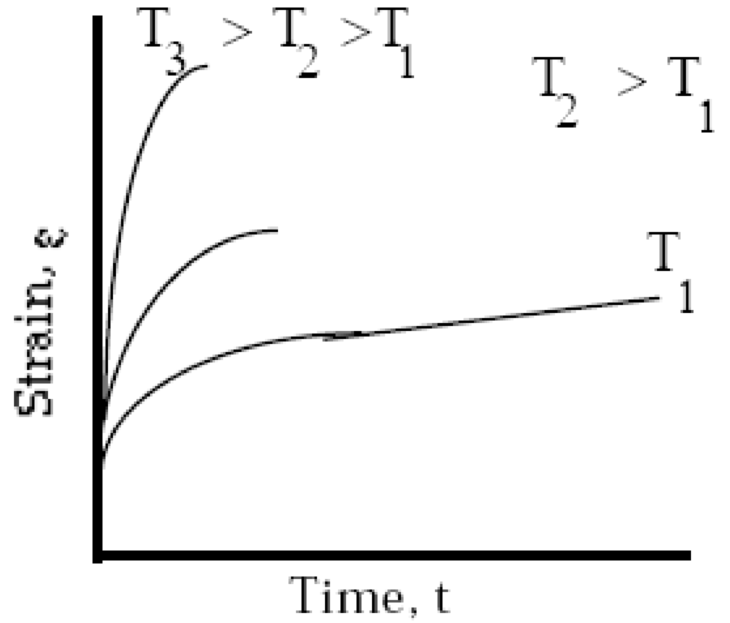
- Primary Creep: starts at a rapid rate and slows with time.
- Secondary Creep: has a relatively uniform rate.
- Tertiary Creep: has an accelerated creep rate and terminates when the material breaks or ruptures. It is associated with both necking and formation of grain boundary voids.

Effect of Temperature & Stress



Effect of Individual Variable





Characteristics of Creep

- Creep in service is usually affected by changing conditions of loading and temperature
- The number of possible stress-temperature-time combinations is infinite.
- The creep mechanisms is often different between metals, plastics, rubber, concrete.

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Creep Mechanisms

- Bulk Diffusion (Nabarro-Herring creep)
  - Creep rate decreases as grain size increases
- Grain Boundary Diffusion (Coble creep)
  - Stronger grain size dependence than Nabarro Herring
- Dislocation climb/creep
  - Controlled by movement of dislocations, strong dependence on applied stress.
- Thermally activated glide
  - Occurs in polymers and other viscoelastic materials

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Creep Test

- Measures dimensional changes accurately at constant high temperature and constant load or stress.
- Useful for modeling long term applications which are strain limited.
- Provides prediction of life expectancy before service. This is important for example turbine blades.

Creep Test cont'd

- Measures strain vs. time at constant T and Load (Similar to graph seen previously).
- Relatively low loads and creep rate
- Long duration 2000 to 10,000 hours.
- Not always fracture.
- Strain typically less than 0.5%.

Creep Test cont'd

- Creep generally occurs at elevated temperatures, so it is common for this type of testing to be performed with an environmental chamber for precise heating/cooling control.
- Temperature control is critical to minimize the effects of thermal expansion on the sample.

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Creep Test: General Procedure

- The unloaded specimen is first heated to the required T and the gage length is measured.
- The predetermined load is applied quickly without shock.
- Measurement of the extension are observed at frequent interval.
- Average of about 50 readings should be taken.

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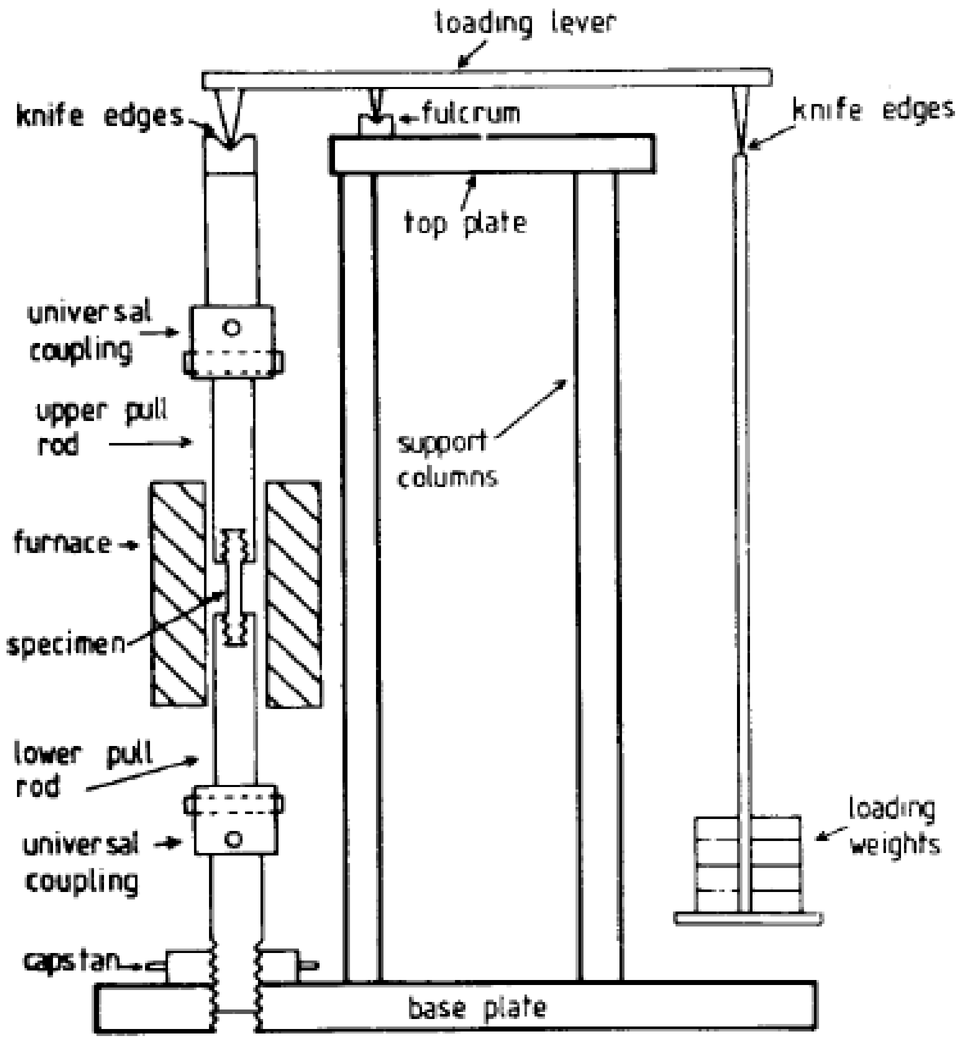
Creep Test Apparatus



Creep Parameters

- To predict the stress and time for long lives on the basis of much shorter data.
- Plant life 30 to 40 years
- Creep data is usually not available beyond lives of more than 30000 hrs.
- Larson Miller Parameter and other material specific models are used.

Larson Miller Parameter

- Model based on Arrhenius rate equation.

$$LMP = T(C + \log t_r)$$

Where T = temperature (K or ºR)

t_r = time before failure (hours)

C= material specific constant

- Predicts rupture lives given certain temperature and stress.
- First used by General Electric in the 50's to perform research on turbine blades.

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Stress Rupture Tests

- Determines the time necessary for material to result in failure under a overload.
- Useful in materials selection where dimensional tolerances are acceptable, but rupture cannot be tolerated.
- Generally performed at elevated temperatures.
- Smooth, notched, flat specimens or samples of any combination can be tested.

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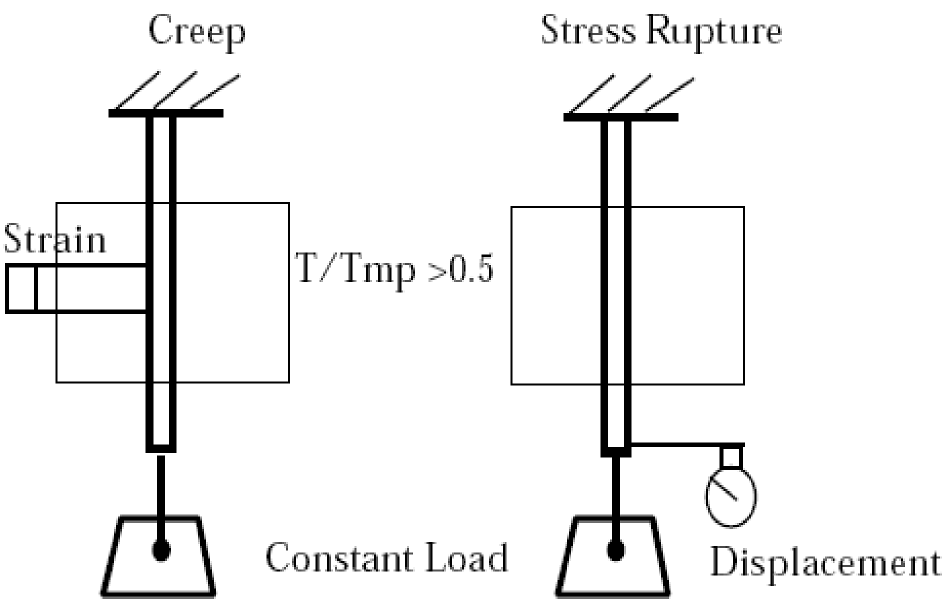
Creep vs. Stress Rupture Test



- Low Loads
- Precision Strain Measurement (ε f<0.5%)
- Long term (2000-10,000 h)
- Expensive equipment

Emphasis on minimum strain rate at stress and temperature

- High Loads
- Gross Strain Measurement (ε f up to 50%)
- Short term (<1000 h)
- Less expensive equipment

Emphasis on time to failure at at stress and temperature

Design Considerations to avoid Creep

- Reduce the effect of grain boundaries:
  - Use single crystal material with large grains.
  - Addition of solid solutions to eliminate vacancies.
- Employ materials of high melting temperatures.
- Consult Creep Test Data during materials Selection
  - Type of service application
  - Set adequate inspection intervals according to life expectancy.

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References

- Abbaschian, Reed-Hill. *"Physical Metallurgy Principles"*. 4th edition. 2009
- Dowling, Norman E. *Mechanical Behavior of Materials.3rd edition*. 2007
- "Larson Miller Parameter" http://www.twi.co.uk/technical-knowledge/faqs/material-faqs/faq-what-is-the-larson-miller-parameter/

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