بسم الله الرحمن الرحيم

Benha University
Shoubra Faculty of Engineering

Energy & sustainable energy Dep.
1st year

27.04.2019 – Week 12

Impact, Creep & Fatigue testing

Dr. Mahmoud Khedr

Outline

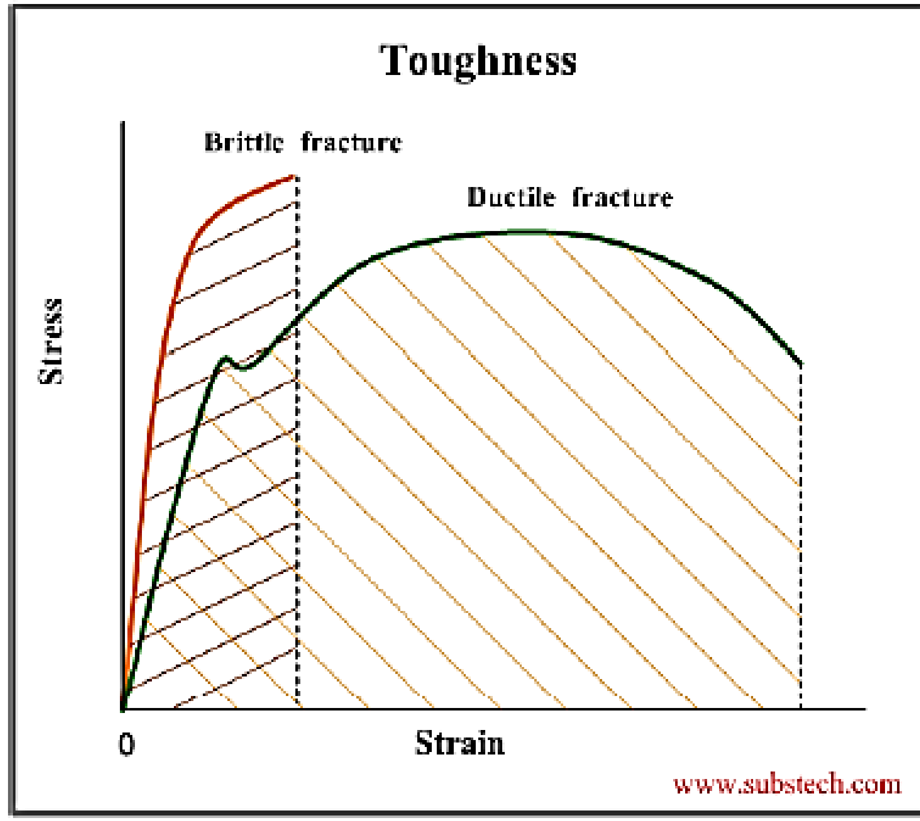
- Impact testing.
- Izod impact test.
- Charpy impact test.
- Creep testing & Creep stages.
- Effect of Temperature & stress level.
- Mechanism of Creep.
- Stresses cycles.
- Fatigue test apparatus & Failure modes.
- S-N curves, Soderberg & Goodman lines.

Introduction

Toughness is ability of material to resist fracture or to withstand impact. The general factors, affecting the toughness of a material are: temperature, strain rate, relationship between the strength and ductility of the material and presence of stress concentration (**notch**) on the specimen surface.

Fracture toughness is indicated by the area below the curve on stress-strain diagram (see the figure).

Fracture toughness may not represent the true behaviour of metals under impact loads.



Purpose of Impact Testing

- *The purpose of impact testing is to* ***measure*** *an object's* ***ability to resist high-rate loading.***
- *It is usually thought of in terms of two objects striking each other at* ***high relative speeds.***
- *A part, or* ***material's ability to resist impact often is one of the determining factors in the service life*** *of a part, or in the suitability of a designated material for a particular application.*
- *Impact resistance can be one of* ***the most difficult properties to quantify****.*
- *The ability to quantify this property is a great advantage in* ***product liability and safety****.*

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Impact testing

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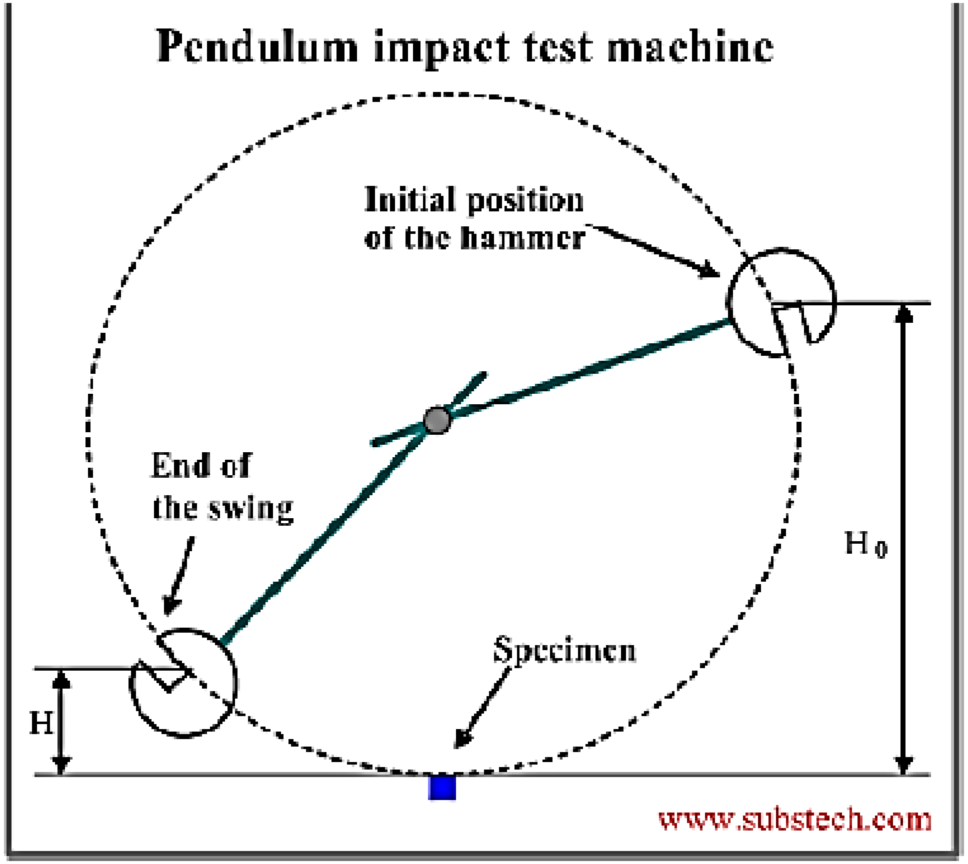
Impact test

Impact test is used for measuring toughness of materials and their capacity of resisting impact loads "shock".

In this test the pendulum is swing up to its starting position (height **Ho**) and then it is allowed to strike the notched specimen, fixed in a vice.

The pendulum fractures the specimen, spending a part of its energy. After the fracture the pendulum swings up to a height **H**.



Impact test

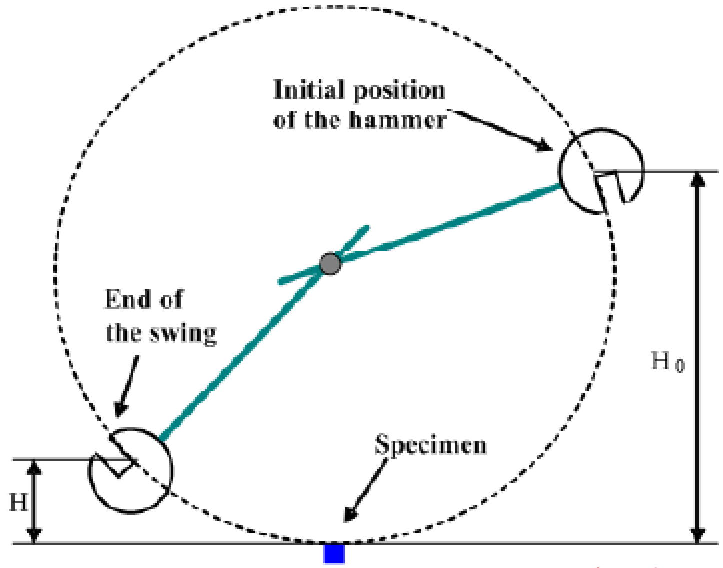
The **impact toughness** of the specimen is calculated by the formula:

- **Q = U / A**

Where

- **Q**-impact toughness,
- **U** – the work, required for breaking the specimen
- **$U = M*g*H_0 – M*g*H$**
- **M:** the pendulum mass,
- **A:** cross-section area of the specimen at the notch.

Pendulum impact test machine



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Izod test

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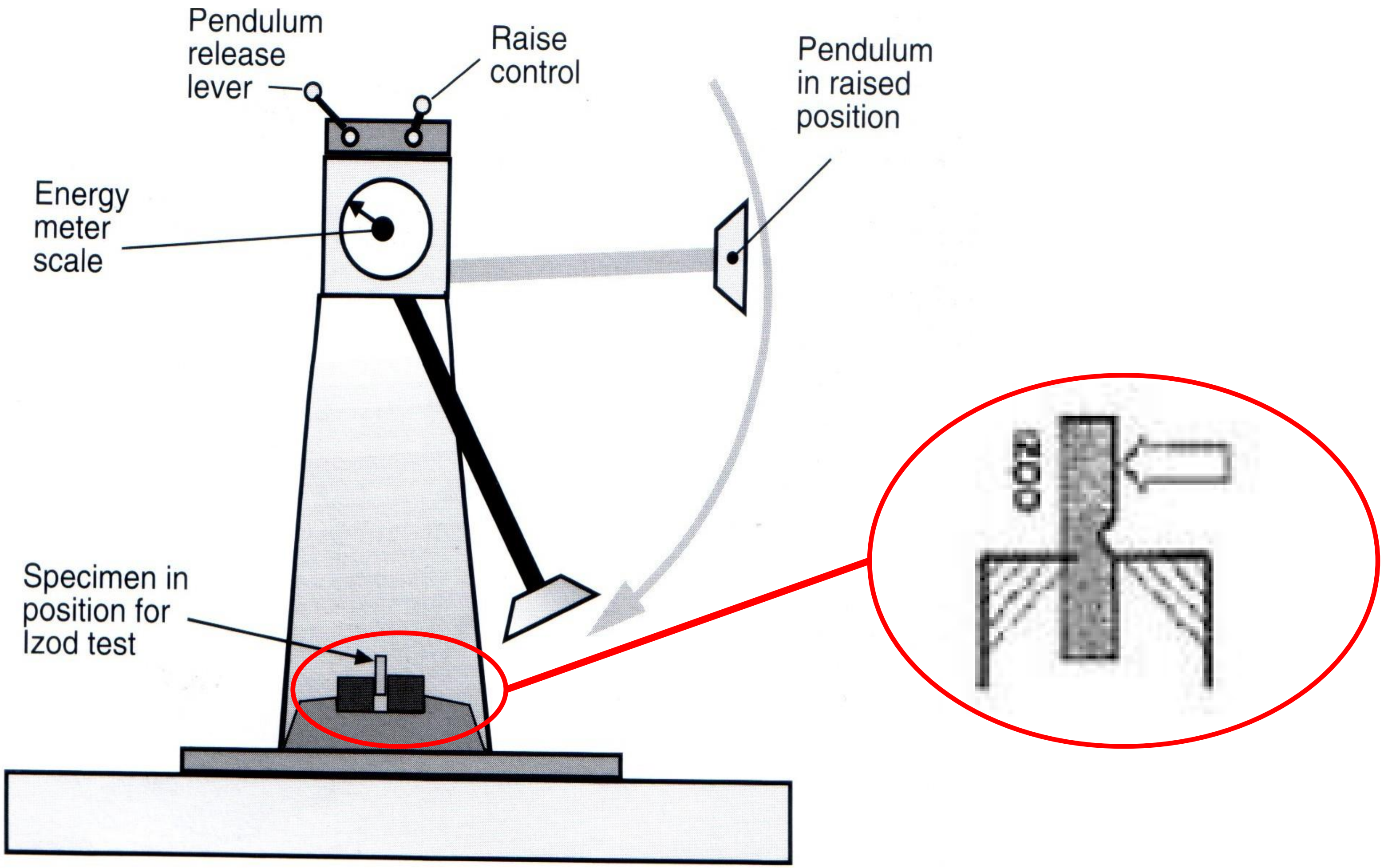
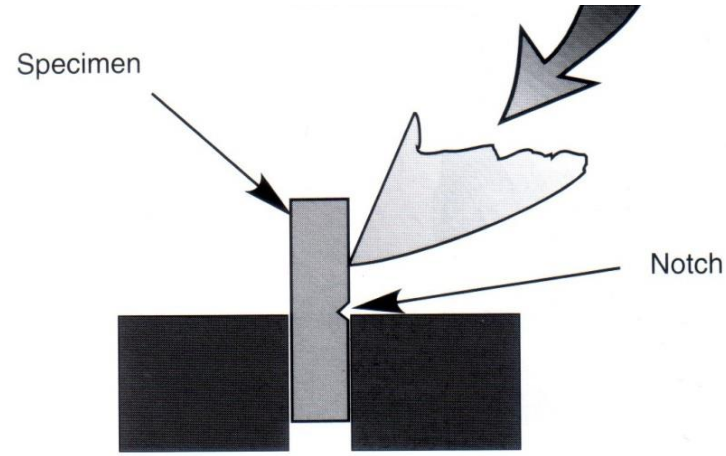
<u>Izod</u> Impact Test



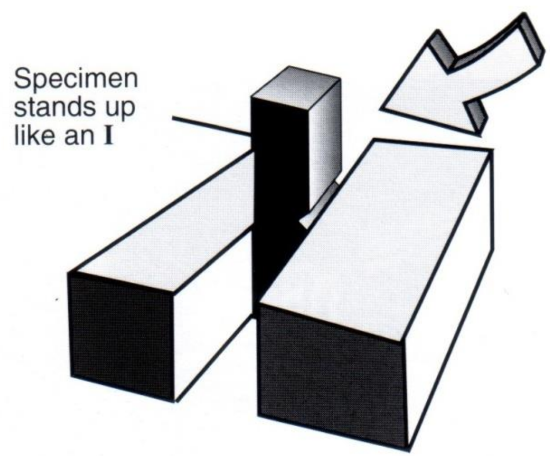
A different striker is fitted for Charpy testing and the specimen is held in a horizontal position with the notch facing away from the pendulum

Izod Impact Test

- Strikes at 167 Joules.
- Test specimen is held vertically.
- Notch faces striker.



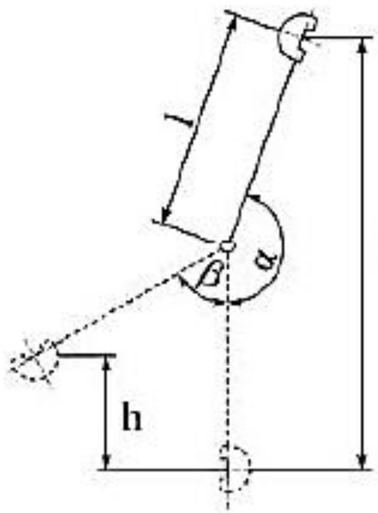
This is how a specimen is held for carrying out an Izod test

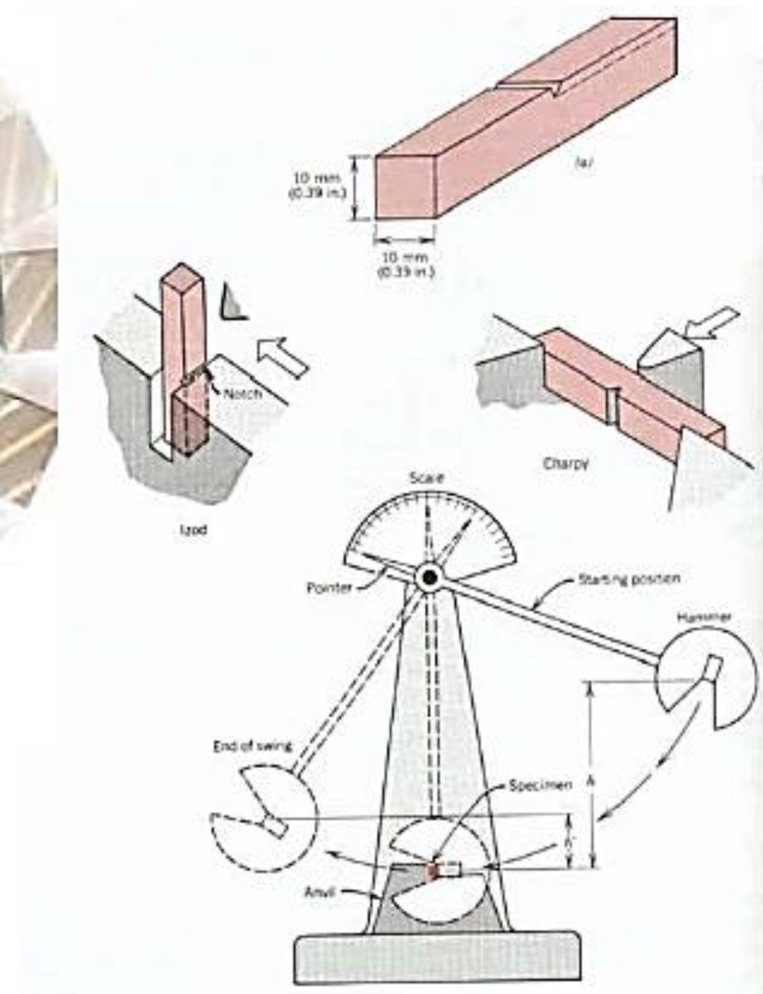


Izod impact test

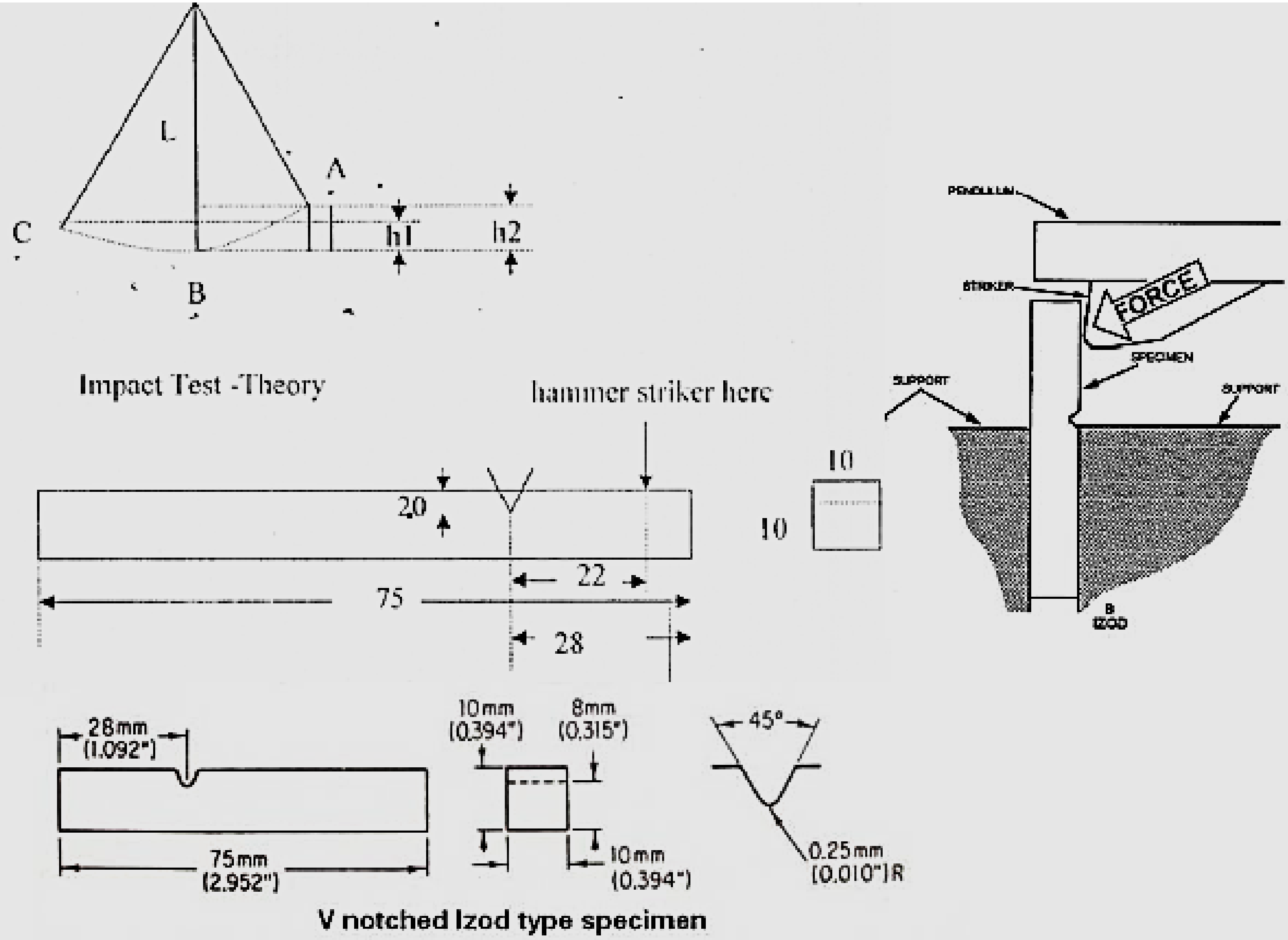
- The Izod impact test is the most common test in North America. **ASTM D256** and **ISO 180**.
- *A pendulum swings on its track and strikes a notched,* ***cantilevered*** *plastic sample.*
- *The energy lost (required to break the sample) as the pendulum continues on its path is measured from the distance of its follow through.*
- *Sample thickness is usually 1/8 in. (3.2 mm) but may be up to 1/2 in. (12.7 mm).*
- The result of the Izod test is reported in energy lost per unit cross-sectional area at the notch (J/m^2).

Izod impact test





Izod impact test



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Charpy test

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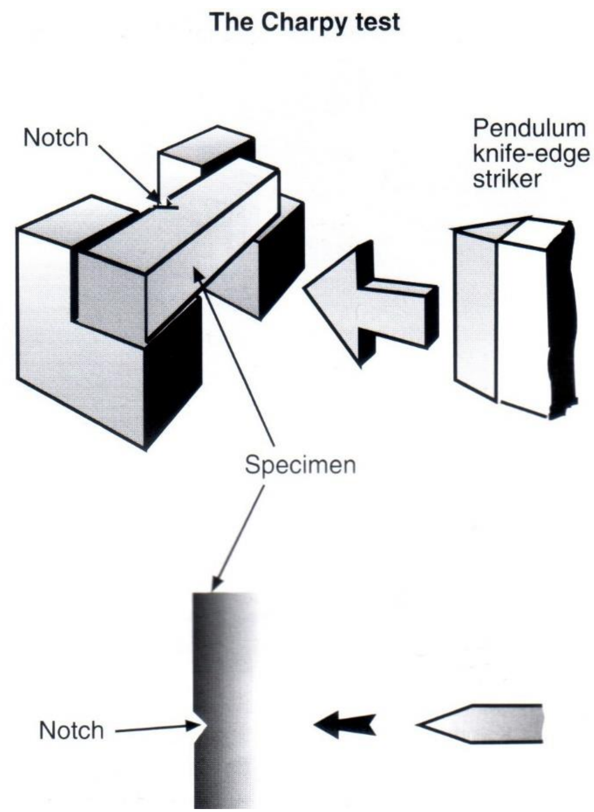
<u>Charpy</u> impact test

- Strikes form higher position with 300 Joules.
- Test specimen is held horizontally.
- Notch faces away from striker.



Charpy impact test

The **Charpy impact test**, also known as the **Charpy v-notch test**, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture.

This absorbed energy is a measure of a given material's toughness and acts as a tool to study temperature-dependent brittle-ductile transition.

It is widely applied in industry, since it is easy to prepare and conduct and results can be obtained quickly and cheaply. But a major disadvantage is that all results are only comparative.

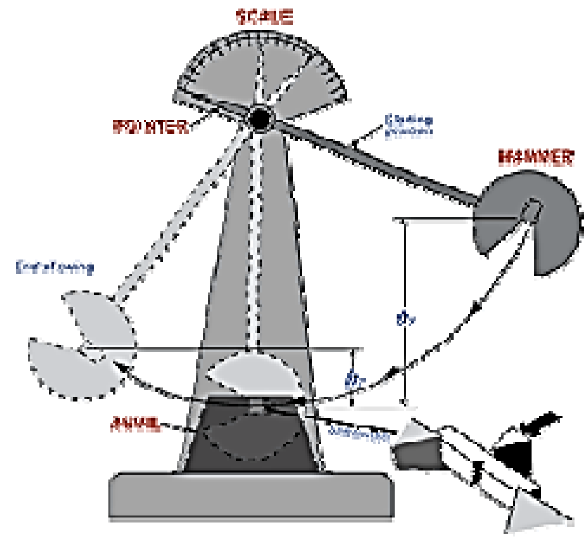
Charpy impact test

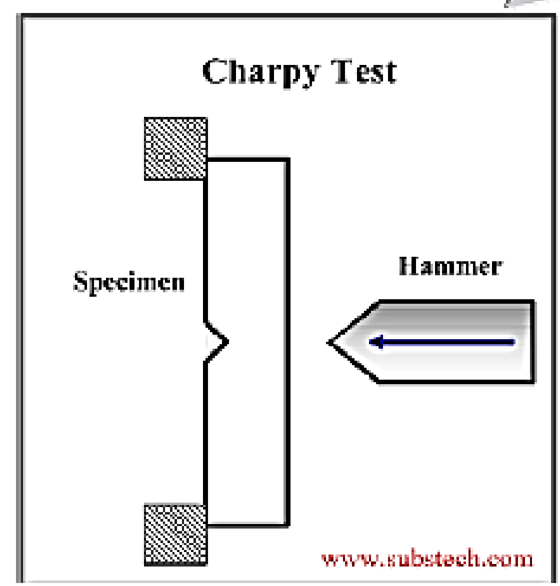
The apparatus consists of a pendulum axe swinging at a notched sample of material.

The energy transferred to the material can be inferred by comparing the difference in the height of the hammer before and after a big fracture.

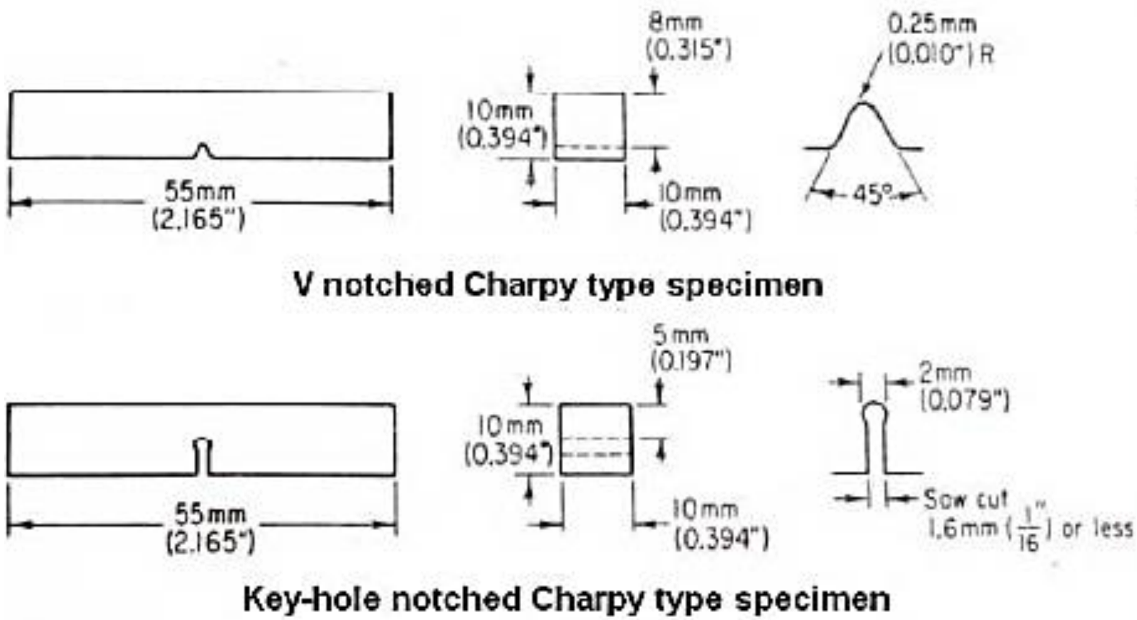
The notch in the sample affects the results of the impact test, thus it is necessary for the notch to be of regular dimensions and geometry.

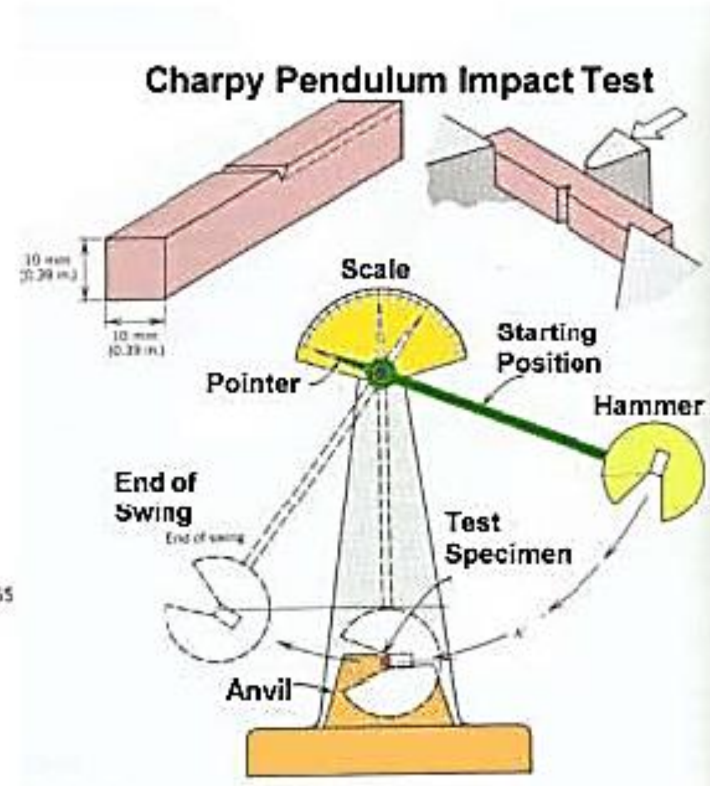
The "Standard methods for Notched Bar Impact Testing of Metallic Materials" can be found in ASTM E23, ISO 148-1 or EN 10045-1, where all the aspects of the test and equipment used are described in detail.



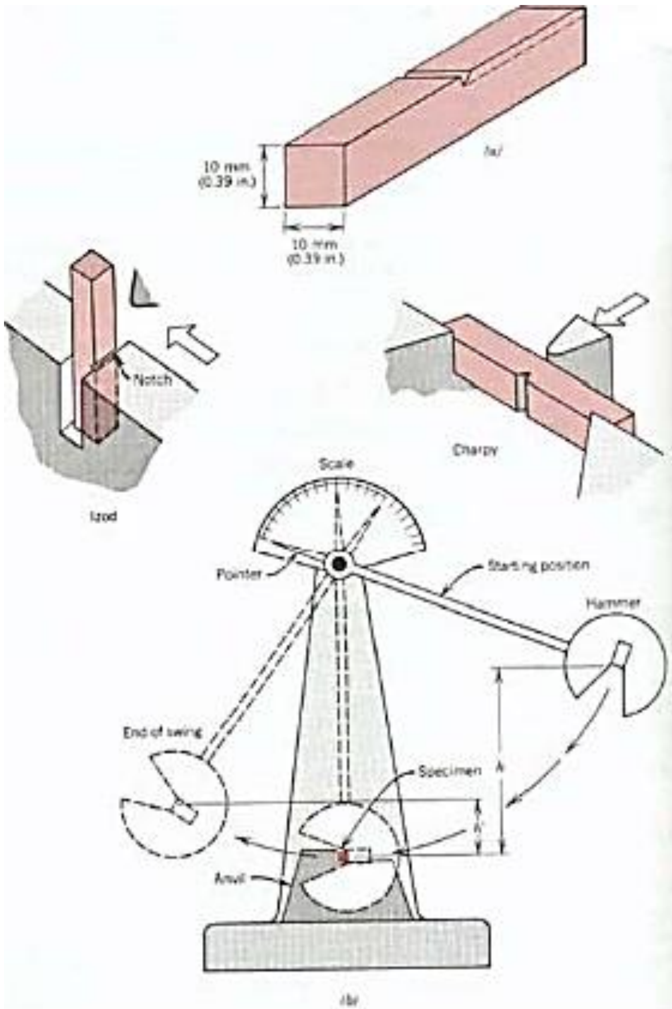


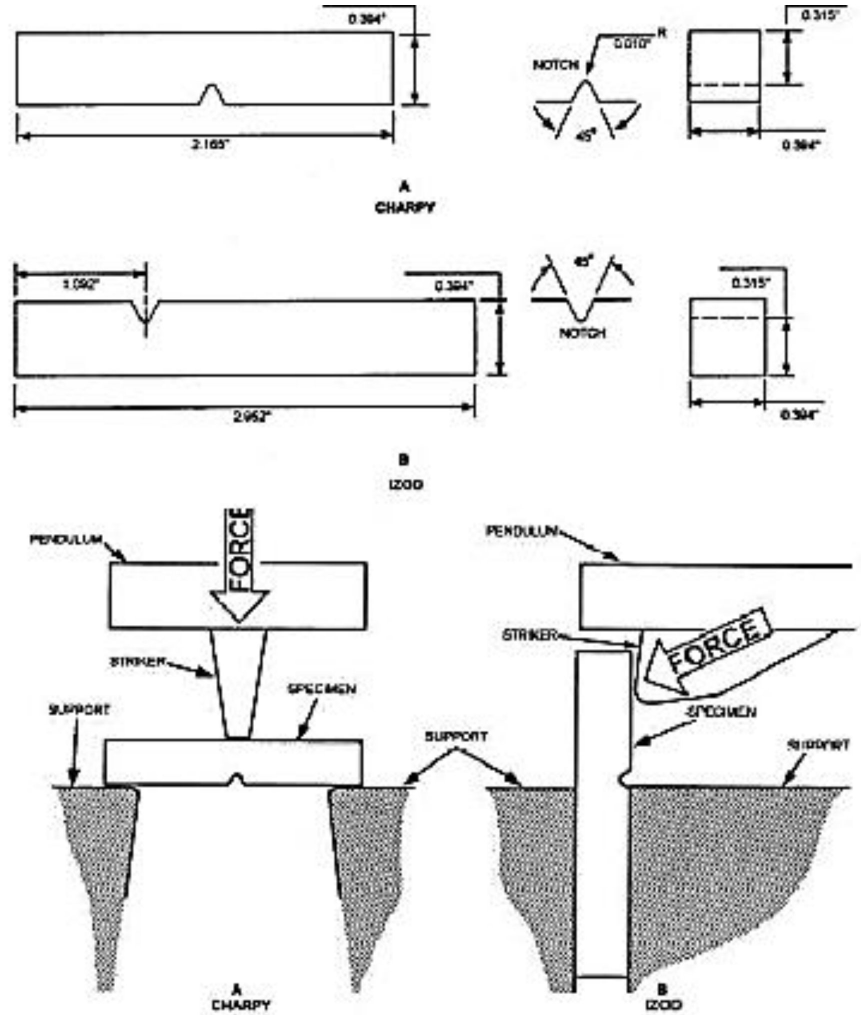
Charpy impact test





Comparison between Impact Tests





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Watching the tests

1 Izod

2 Charpy

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Failure modes

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Strain energy

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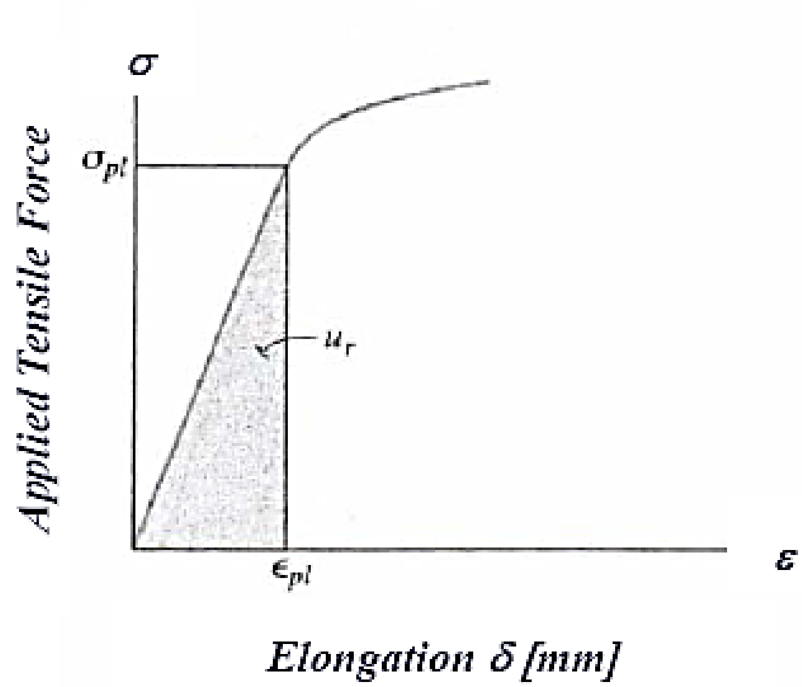
Strain Energy under Impact Tension

A material's resilience represents the ability of the material to absorb energy without any permanent damage to the material. In particular, when the load a reaches the proportional limit, the strain-energy density, is calculated by and is referred to as the *modulus of resilience Ur.* Mathematically it is the area under the straight line "elastic region" of the load-deformation curve per unit volume.

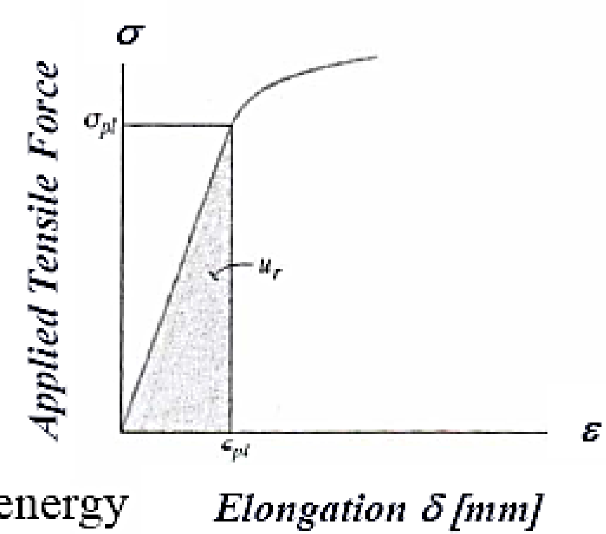
$$U_r = \frac{P_{PL} * \delta_{PL}}{2 * A * L}$$



Internal strain energy

Under uniaxial impact tension, the strain energy U within the elastic zone may be less than the *modulus of resilience Ur*. Mathematically it is the area under the ***PART*** of the straight line in the "elastic region" of the load-deformation curve per unit volume. This ***internal*** strain energy is simply the ***external*** impact energy.

$$U = \frac{P * \delta}{2 * A * L} = \frac{\sigma * \varepsilon}{2} = \frac{\sigma^2}{2 * E} = \frac{E * \varepsilon^2}{2}$$



(a)

U is the ***strain energy per unit volume*** of the membe

P is the equivalent static load,

δ is the axial deformation due to the external impact energy

E is the modulus of elasticity,

A is the cross sectional area of the specimen,

L is the length of the specimen.

External strain energy

If a load W is falling from a height H causing uniaxial tension in the member of length L, cross sectional area A and modulus of elasticity E produces an extension d in the member, then the Total *external* impact energy is given as

$$External\ Energy = W\,(H + \delta)$$

P is the equivalent static load,
δ is the axial deformation due to the external impact energy
E is the modulus of elasticity,
A is the cross sectional area of the specimen,
L is the length of the specimen.

Elastic Impact tension

By equating the Total ***external*** impact energy with the internal strain energy ***strain energy per unit volume*** of the member X the member volume we get

External Energy = Internal Strain Energy

$$W(H+\delta) = \tfrac{1}{2} P * \delta$$

$$= \tfrac{1}{2}\ \sigma * A * \delta$$

$$= \tfrac{1}{2} E * \varepsilon * \delta * A$$

$$W(H+\delta) = \tfrac{1}{2} E * \delta^2 * A * L$$

P is the equivalent static load,

δ is the axial deformation due to the external impact energy

E is the modulus of elasticity,

A is the cross sectional area of the specimen,

L is the length of the specimen.

Solved example

A falling weight of 65 kN is falling from the top of a 2000 mm aluminum bar. If the aluminum bar has a modulus of elasticity = 70 MPa and 50 mm diameter, then calculate:

(i). The maximum tensile stress in the aluminum bar.

(ii). The maximum distance "measured from the top of the aluminum bar" that the falling weight will reach during falling.

(i). External energy = Internal strain energy

$W (L + \Delta) = \frac{1}{2} \Delta^2 E A / L$

$65 * (2000 + \Delta) = \frac{1}{2} \Delta^2 * 70 * (\pi 50^2 / 4) / 2000$

$\frac{1}{2} \Delta^2 * 70 * (\pi 50^2 / 4) / 2000 - 65 * \Delta - 130x10^3 = 0$

$34.36 \Delta^2 - 65 * \Delta - 130x10^3 = 0$

By trial and error: $\Delta = 62.46$ mm

Maximum distance = 2000 + 62.46 = 2062.46 mm below the top of the aluminum bar

(ii). $\sigma = E * \Delta / L$

$= 70 * 62.46 / 2000$

$= 2.18$ MPa.

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Creep test

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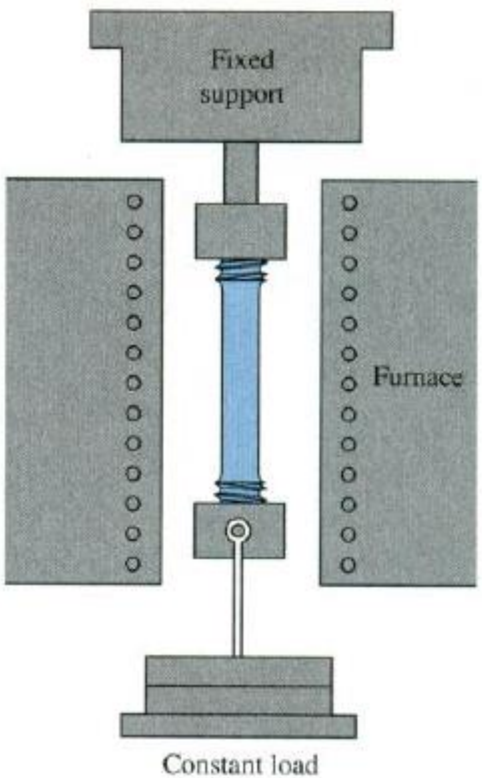
Creep

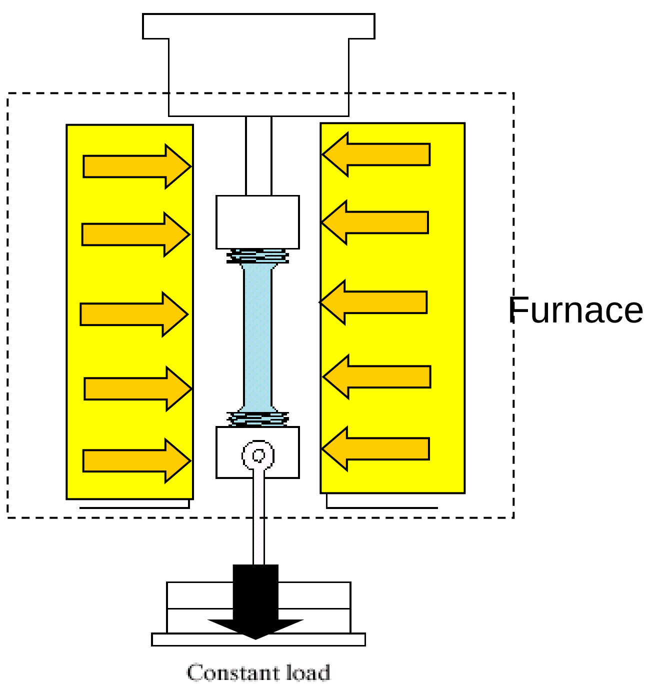
When a weight is hung from a piece of lead and left for a number of days the lead will stretch. This is said to be creep. Problems with creep increase when the materials are subject to high temperature or the materials themselves have low melting points such as lead. Creep can cause materials to fail at a stress well below there tensile strength.

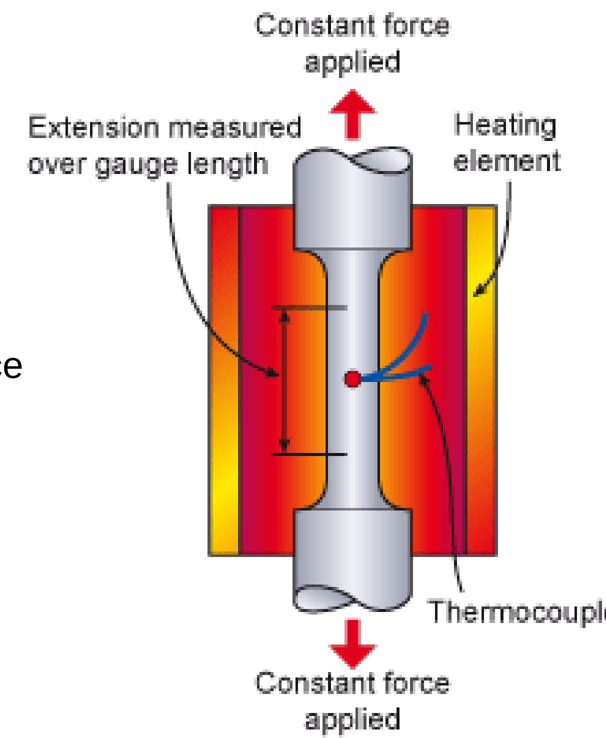
Creep Test

Time-dependent deformation due to constant load at high temperature (> 0.4 T_m)

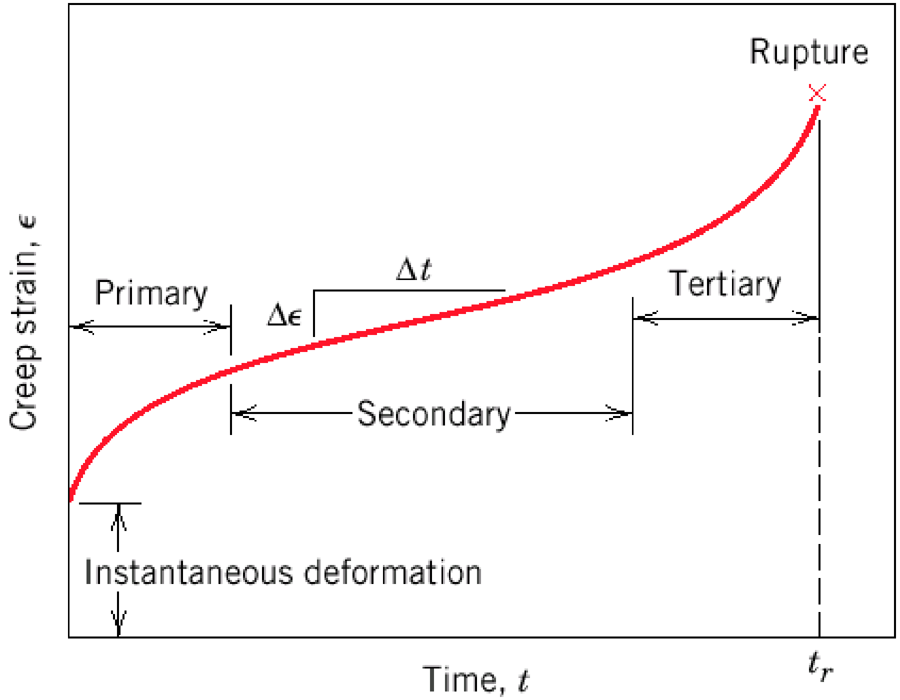
Examples: turbine blades, steam generators.





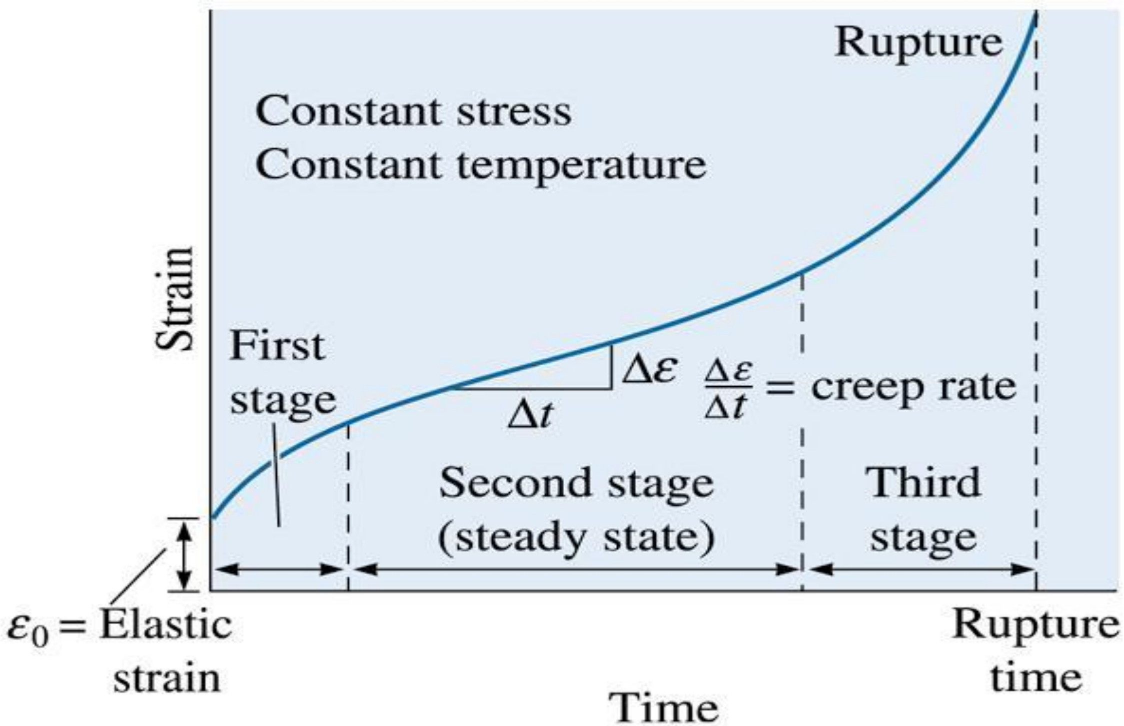


Stages of Creep



1. **Instantaneous deformation, mainly elastic.**
2. **Primary/transient creep. Slope of strain vs. time decreases with time: work-hardening**
3. **Secondary/steady-state creep. Rate of straining constant: work-hardening and recovery.**
4. **Tertiary. Rapidly accelerating strain rate up to failure: formation of internal cracks, voids, grain boundary separation, necking, etc.**

Typical Creep Curve



A typical creep curve showing the strain produced as a function of time for a constant stress and temperature

The Creep curve shown in Fig. demonstrates three stages:

Primary creep: $\varepsilon = A\, t^{1/3}$

Secondary creep: $\varepsilon = \varepsilon_o + \beta\, t$ **minimum creep rate , a dynamic equilibrium between stress and microstructure.**

The minimum creep rate β is used in computations of the useful life.

Stages of Creep

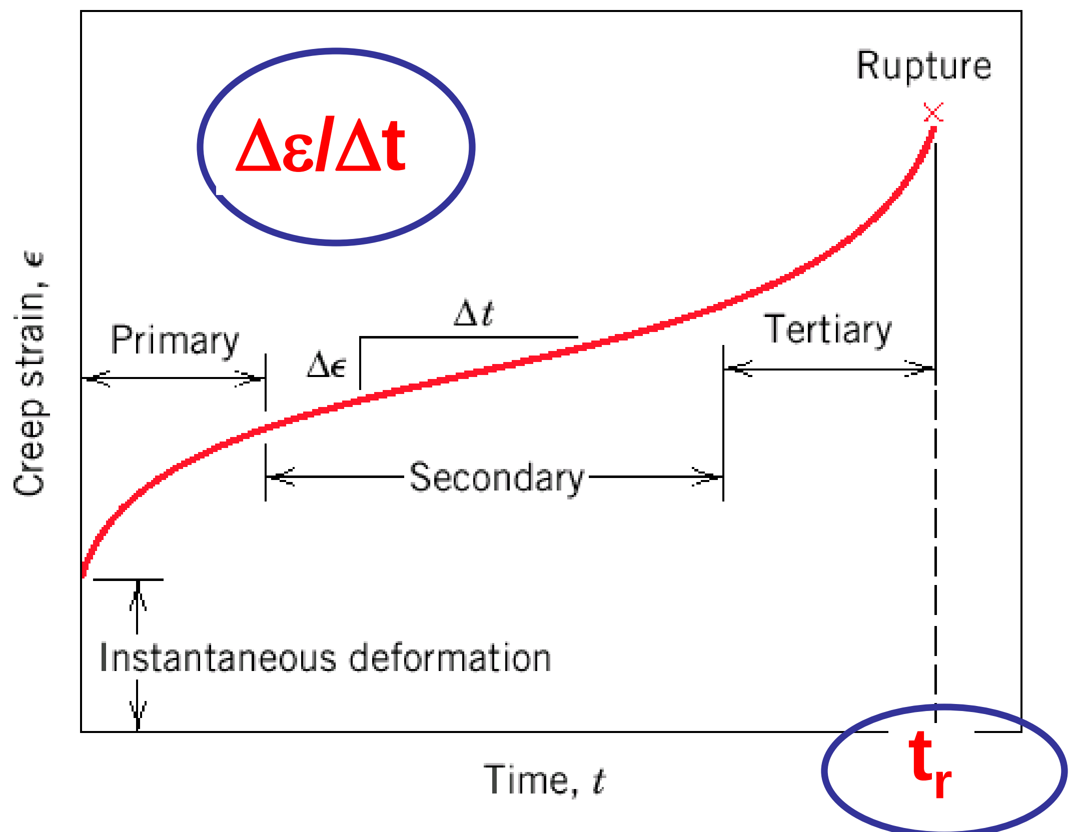
Secondary/steady-state creep:

Longest duration

Long-life applications

Time to rupture (rupture lifetime, t_r): $\dot{\varepsilon}_s = \Delta\varepsilon / \Delta t$

Important for short-life creep



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Watching the test

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Effect of Temperature & stress level

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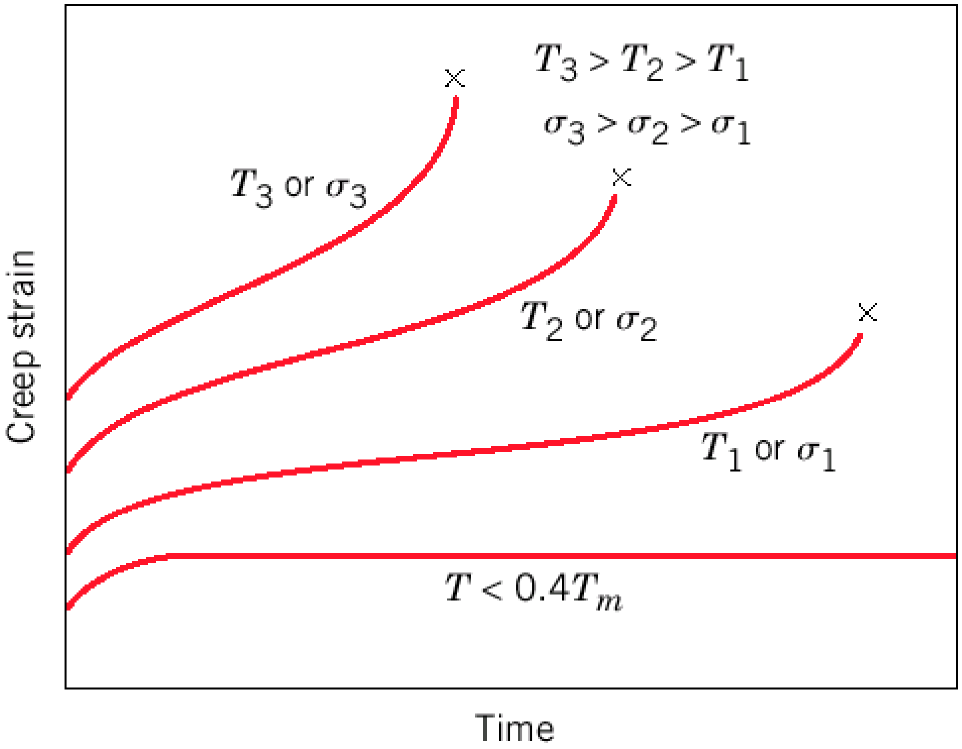
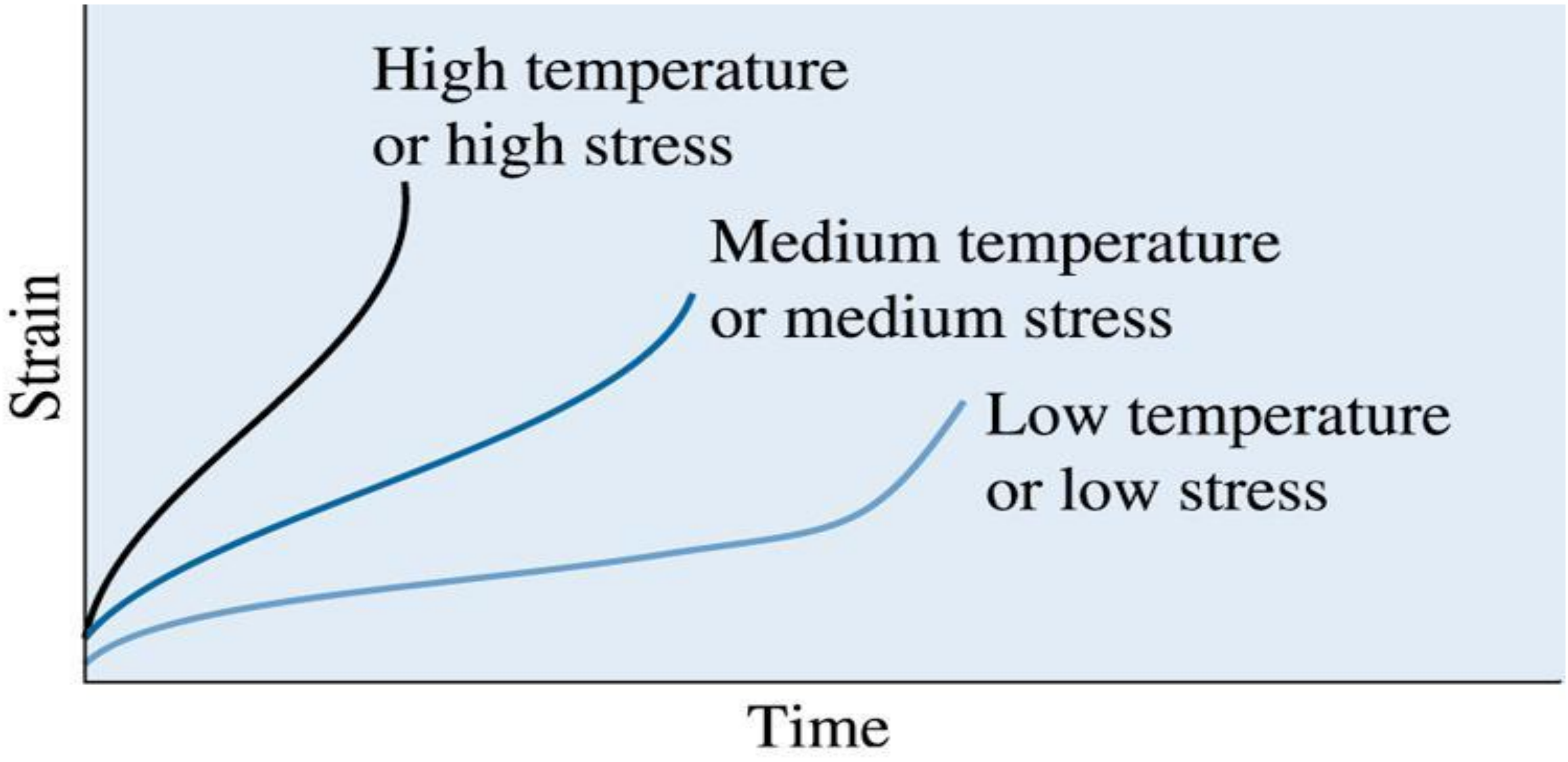
Effect of Temperature

With increasing stress or temperature:

- **The instantaneous strain increases**
- **The steady-state creep rate increases**
- **The time to rupture decreases**



Effect of Temperature



The effect of temperature or applied stress on the creep curve

Stages of Creep

increasing stress or temperature:

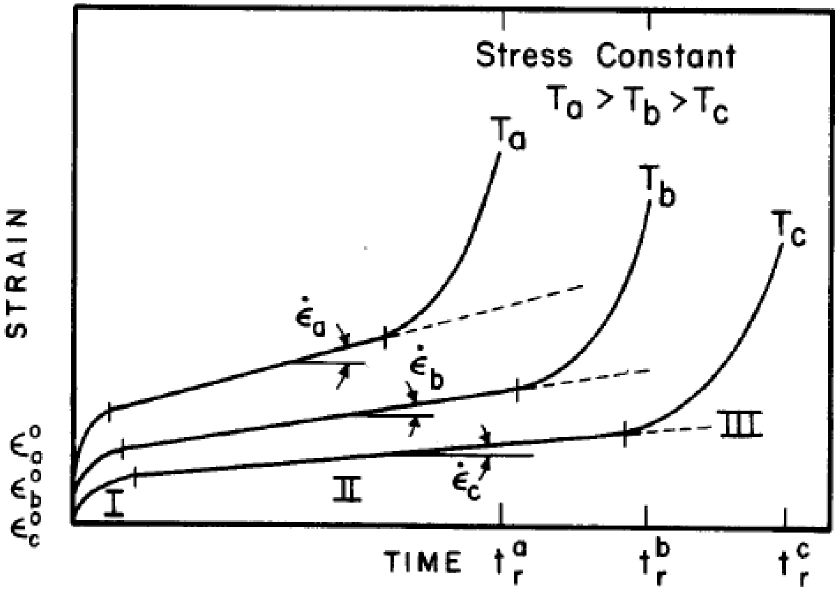


Figure 13.2 Creep strain vs. time at a constant engineering stress and different temperatures.

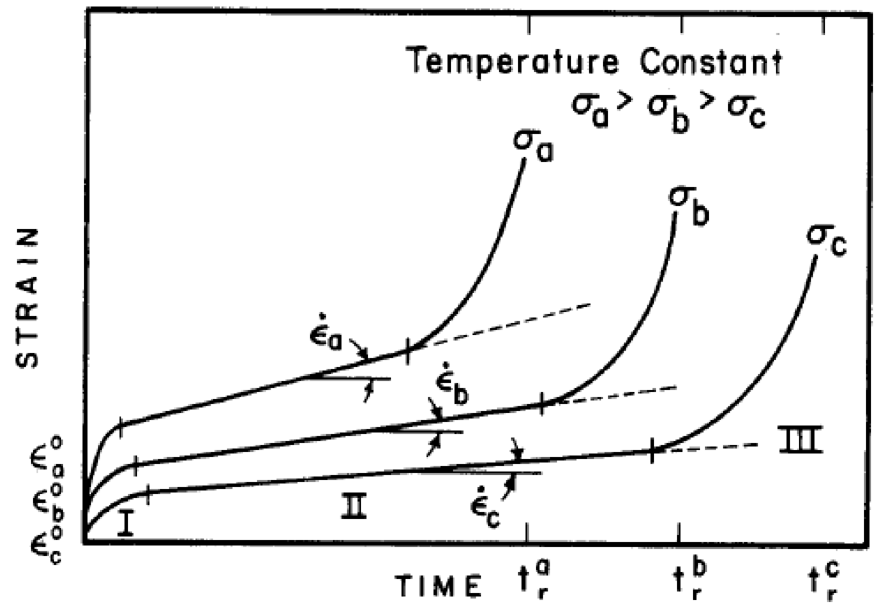


Figure 13.1 Creep strain vs. time at difference constant stress levels and temperature.

Characteristics

Creep characteristics of the metals are affected by;

Melting Temp.

Elastic Modulus

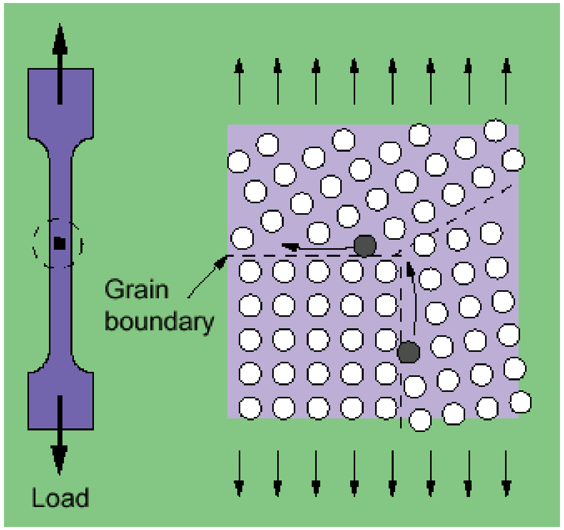
Grain Size.

The higher the melting temperature, the greater the elastic modulus and the larger the grain size, the better is a material's resistance to creep. Smaller grains permit more grain boundary sliding.

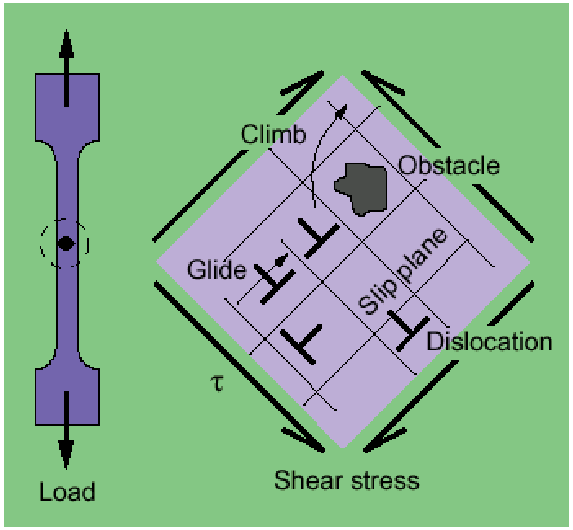
Mechanism of Creep

Different mechanisms act in different materials and under different loading and temperature conditions:

- **Stress-assisted vacancy diffusion**
- **Grain boundary diffusion**
- **Grain boundary sliding**
- **Dislocation motion**

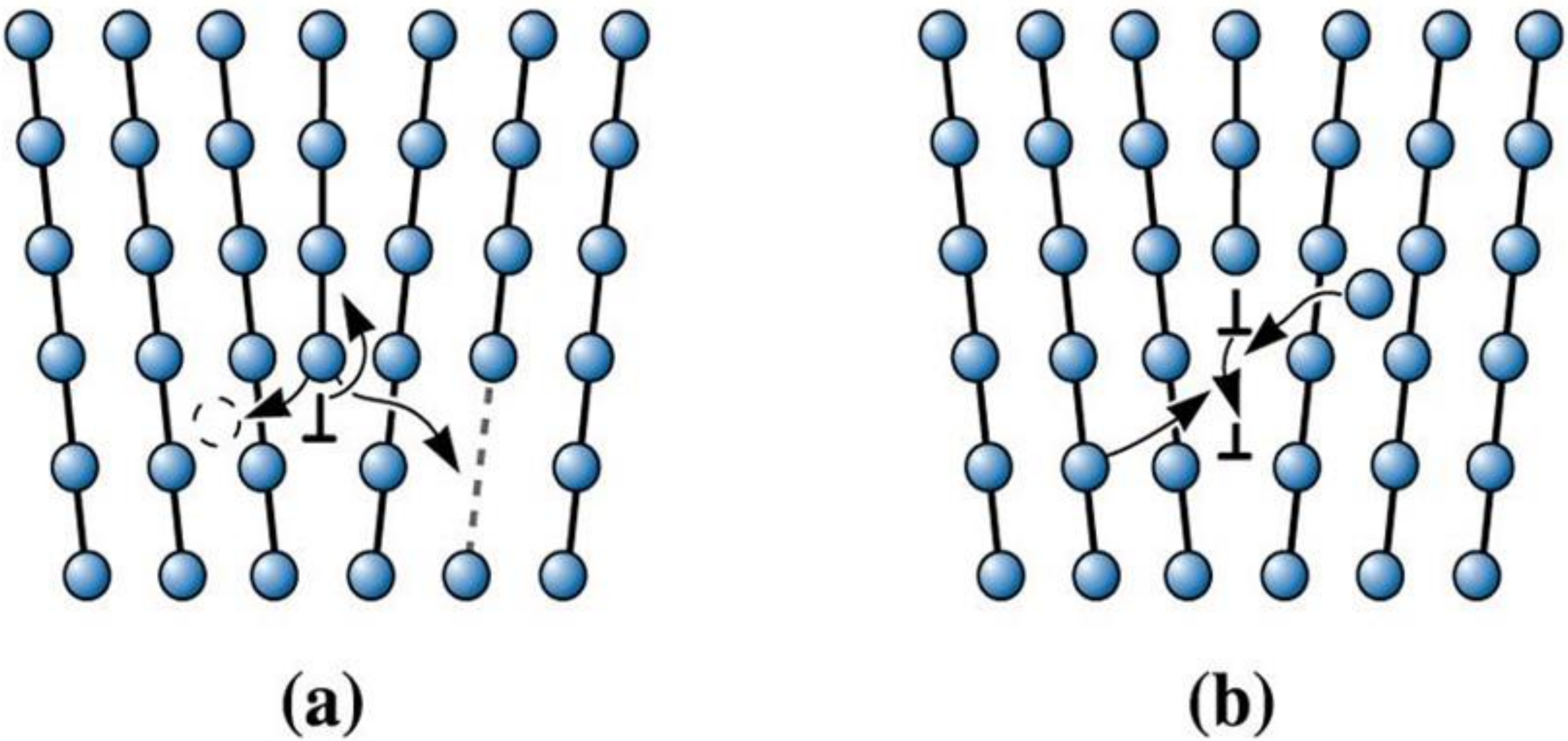


Grain boundary diffusion



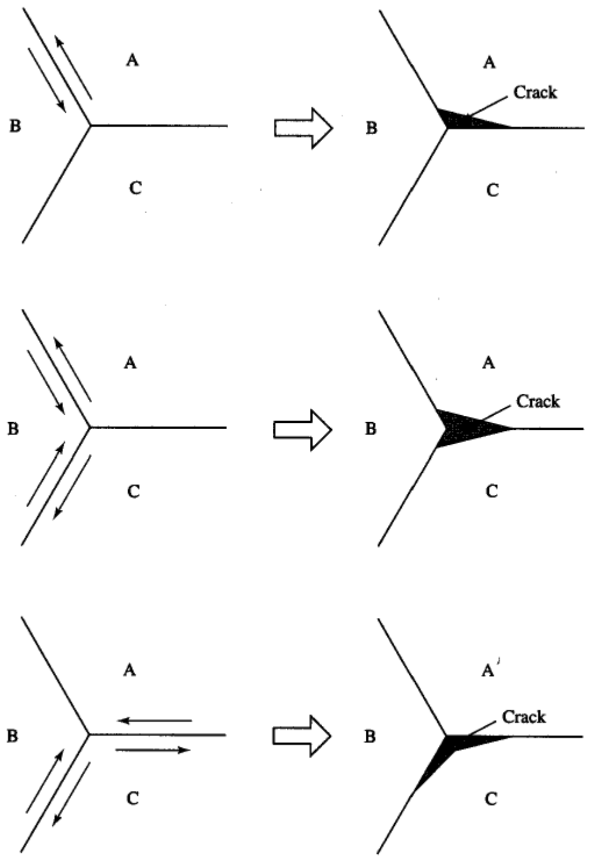
Dislocation glide and climb

Dislocation Movement



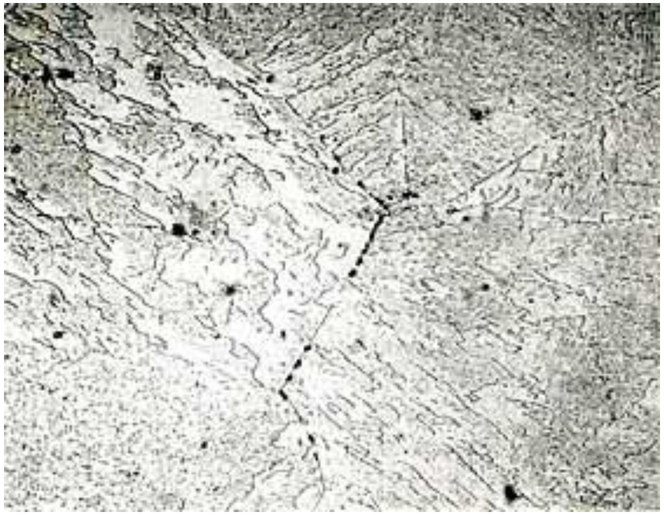
Dislocations can climb (a) when atoms leave the dislocation line to create interstitials or to fill vacancies or (b) when atoms are attached to the dislocation line by creating vacancies or eliminating interstitials

Crack formation



–7 Grain boundary sliding and the resultant cracks that form at triple points.

Cavitation & cracking under SEM



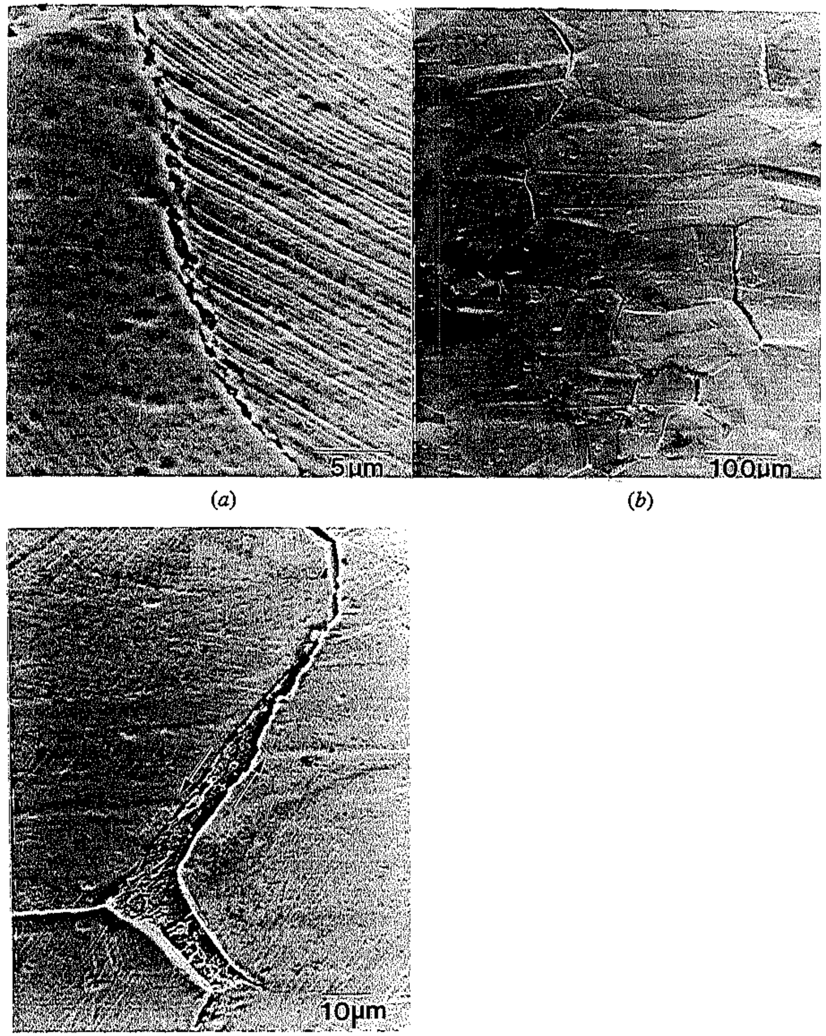
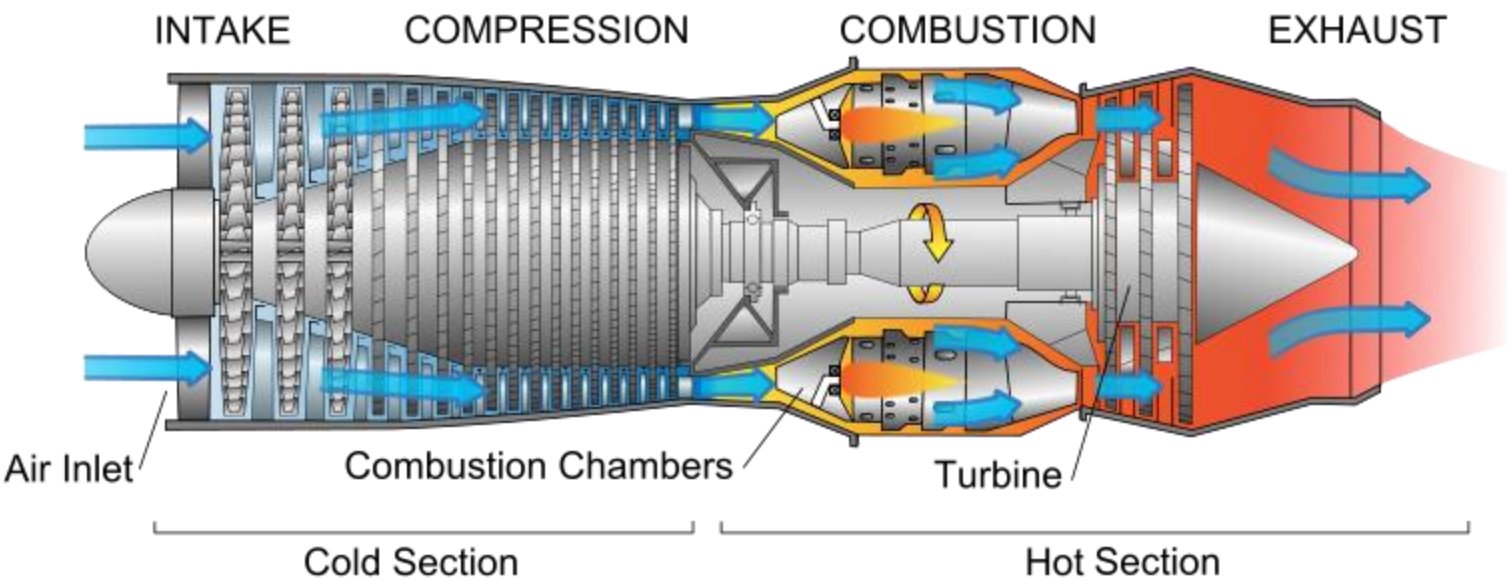
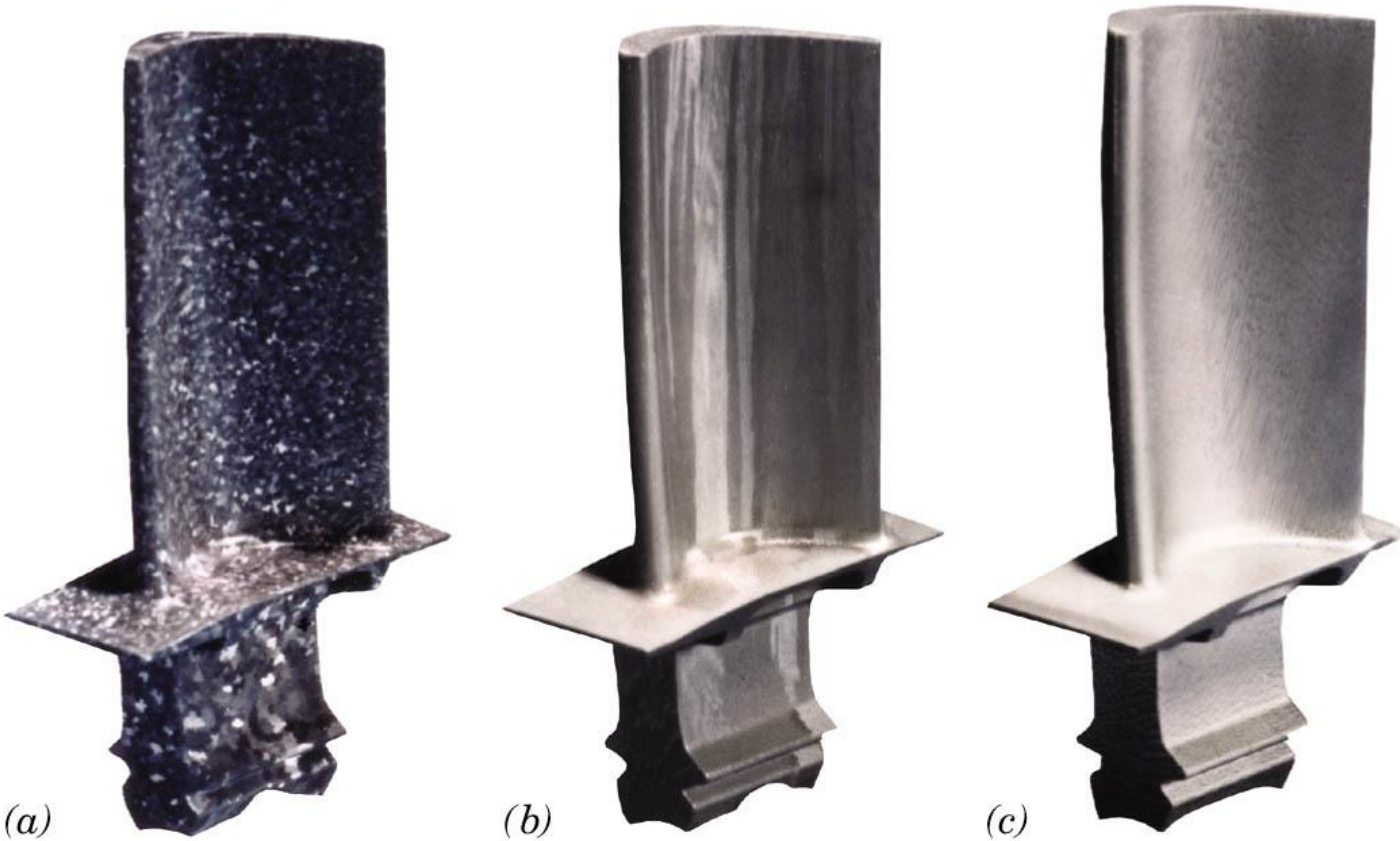


FIGURE 5.37 **Cavitation and cracking in UHP Ni-16Cr-9Fe allow after 35% elongation at 360°C in argon. Initial strain rate was 3×10^{-7} sec^{-1}. (*a*) slip-boundary induced cavitation. (*b*) intergranular cracking in UHP alloy; (*c*) triple point cracking. Note involvement of grain boundary sliding (i.e., displacement of fudiciary markings) and grain boundary microvoid coalescence on new fracture surface. (Courtesy Jason L. Hertzberg.)**

Typical Engine

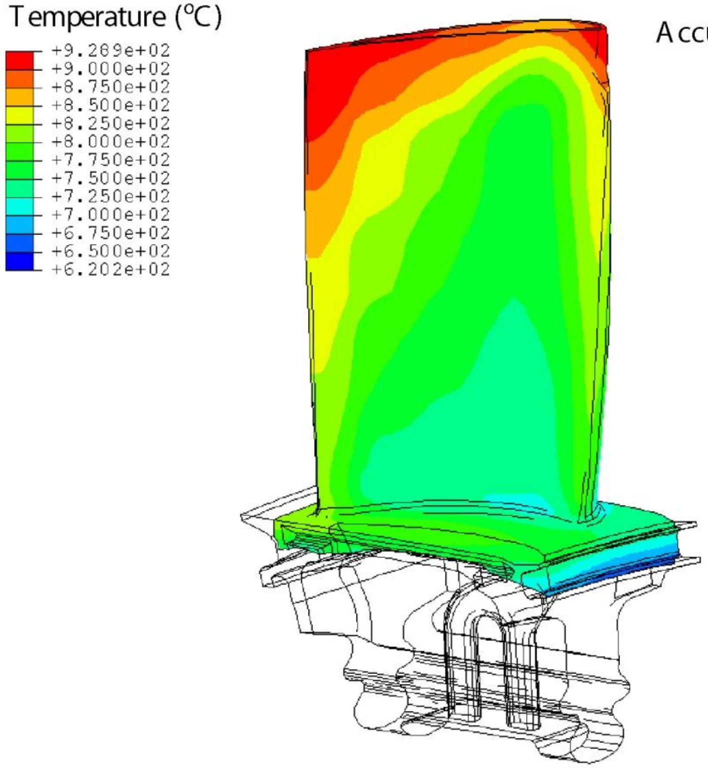


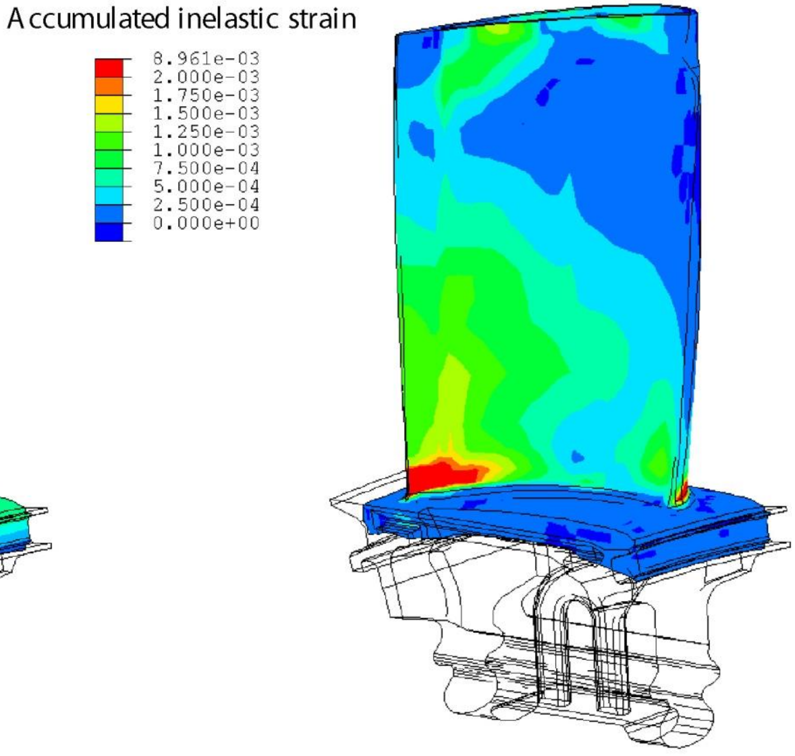
Gas Turbine Blades



Conventional casting | Columnar grain | Single crystal

Temp. and Strain





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Use of Creep Data

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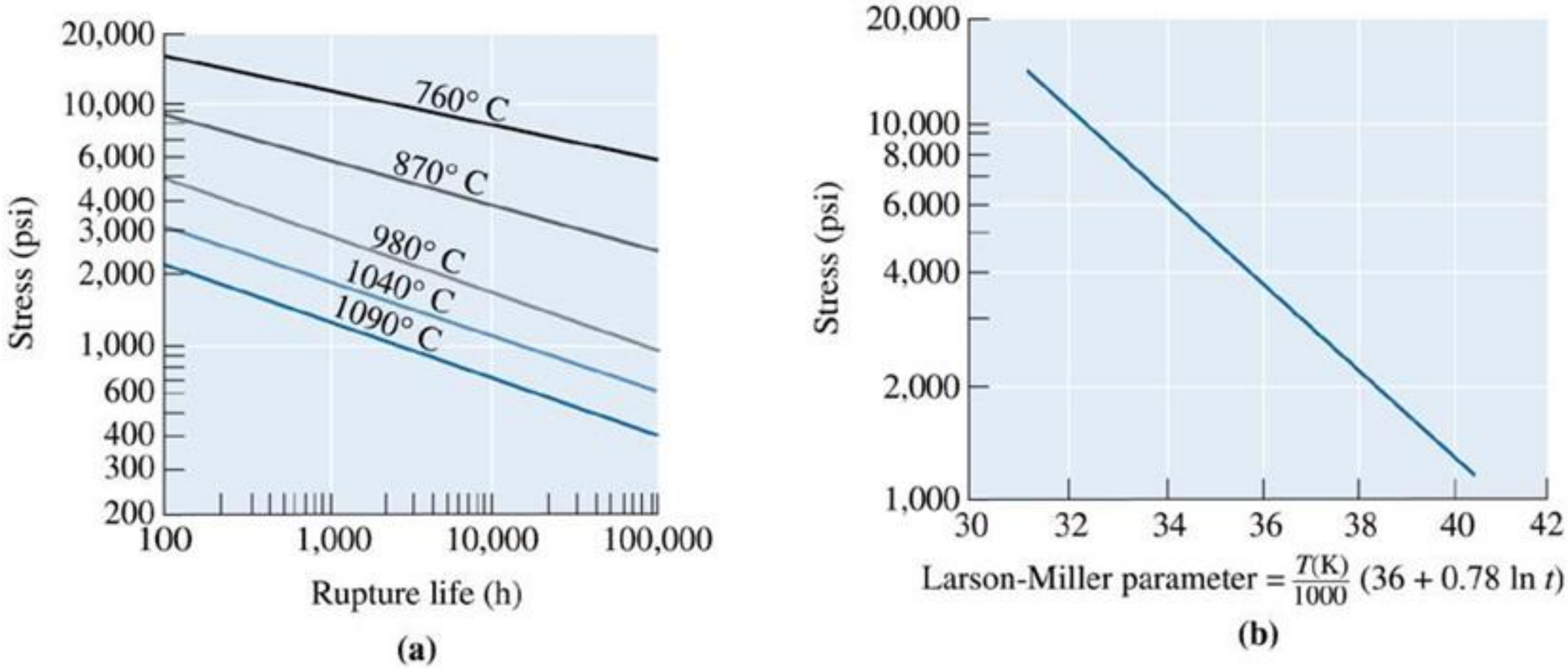
Use of Creep Data

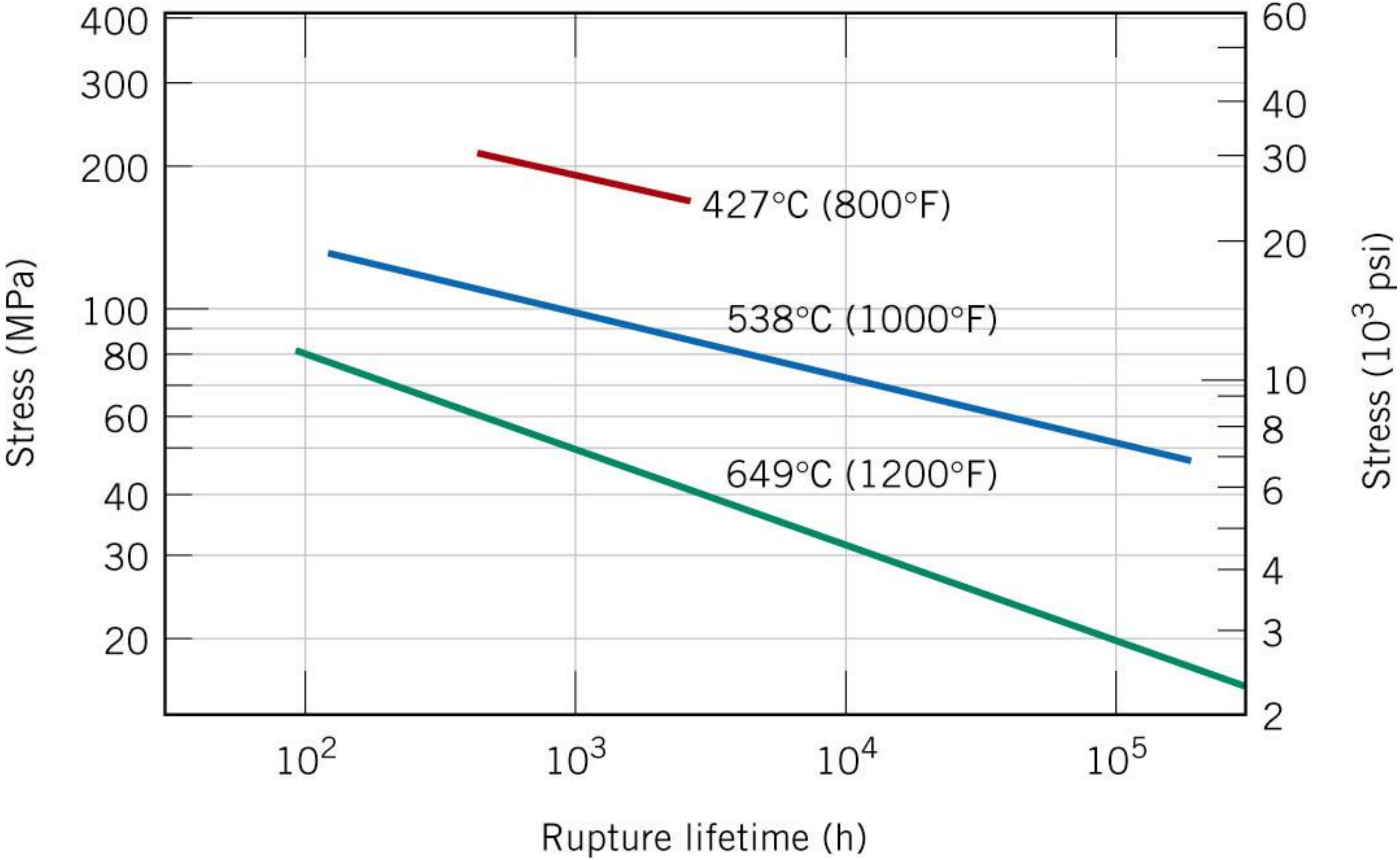
- Stress-rupture curve - A method of reporting the results of a series of creep tests by plotting the applied stress versus the rupture time.
- ***Larson-Miller parameter*** - A parameter used to relate the stress, temperature, and rupture time in creep.

Use of Creep Data

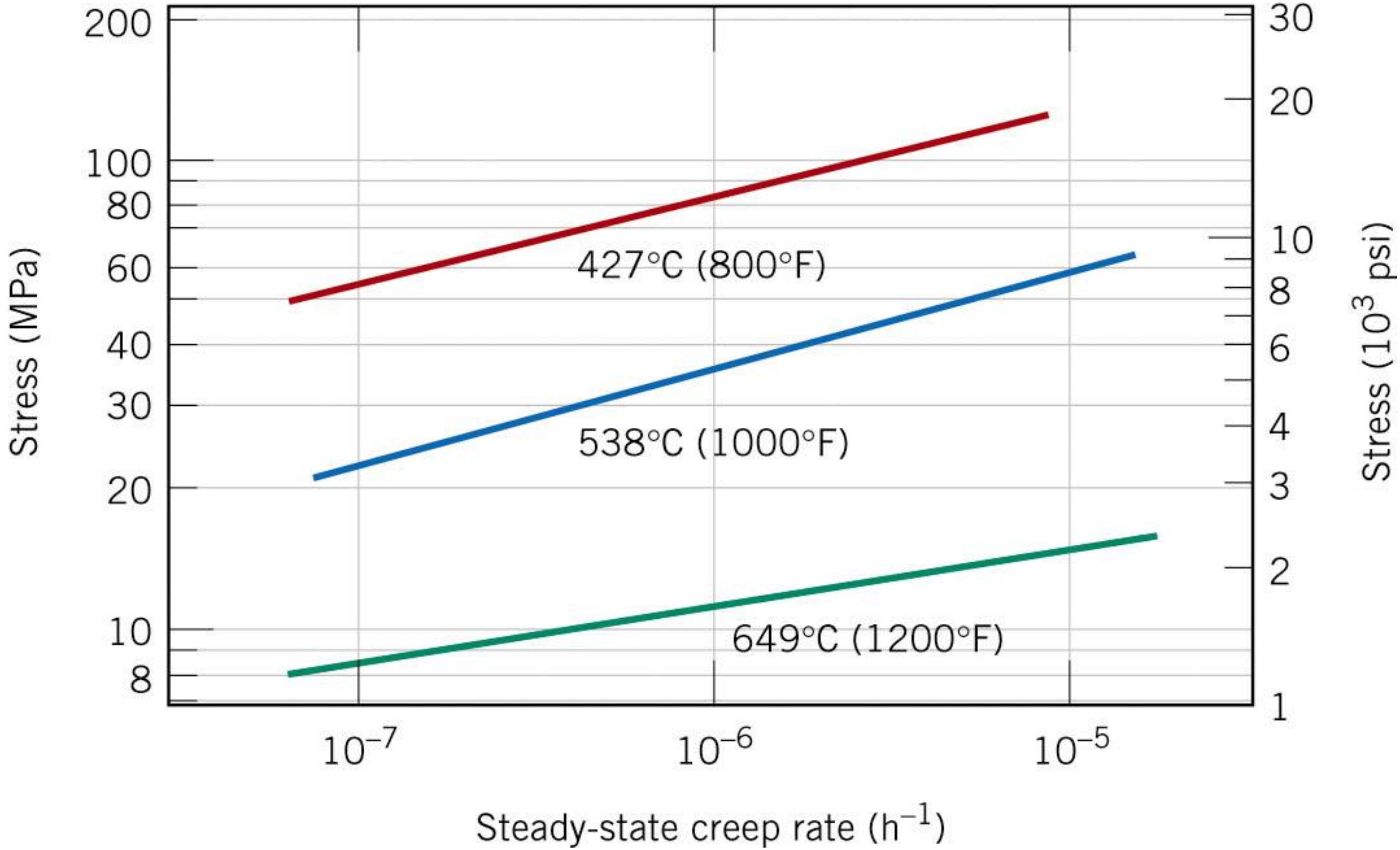


Results from a series of creep tests. (a) Stress-rupture curves for an iron-chromium-nickel alloy and (b) the Larson-Miller parameter for ductile cast iron

Use of Creep Data



Use of Creep Data



Larsen-Miller parameter

O **Larsen-Miller parameter** $P_{LM} = T\,(C + \log t_R)$

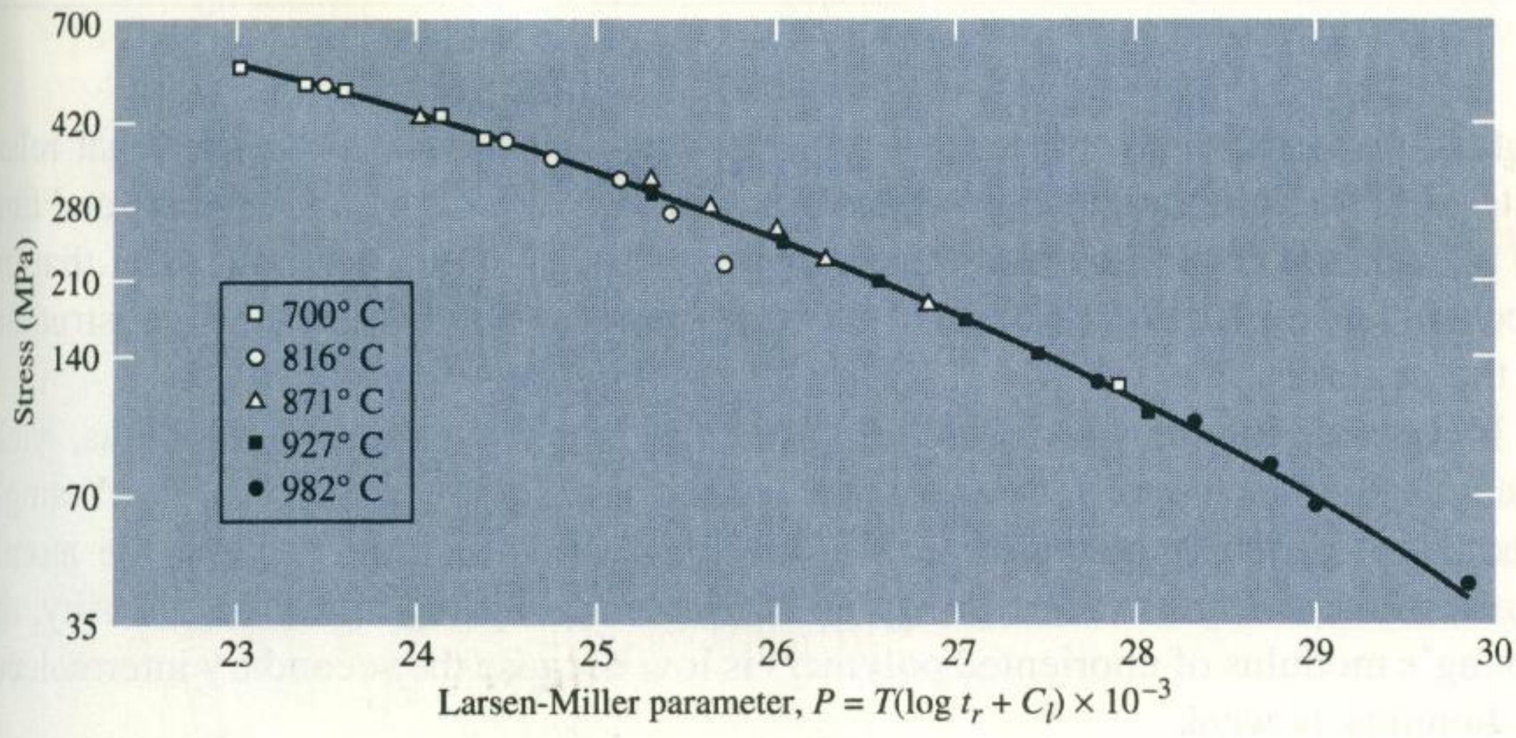


Figure 9.6–10 Master curve plotting creep rupture data at various temperatures for Astroly. Such a plot is called a Larsen–Miller diagram.

Solved example

An Astroloy jet engine blade will be used at 871°C at $\sigma = 200$ MPa

a. Determine the life of the blade (C=20)

b. Estimate the maximum service temperature if a life of 500 hours is required

From the curve above: at $\sigma = 200$ MPa $P_{LM} = 26500$

$26500 = (871+273)[\,20 + \log t_R]$

$\log t_R = 3.164$ $t_R = 1460$ hours (a)

$26500 = T\,(20 + \log 500)$

$T = 1167\ K = 894°C$ (b)

i.e. an increase of 23°C in service temperature cuts the rupture life to about one third of its value.