Mechanical Properties of Materials - II

Instructor : Prof. Bishakh Bhattacharya
Dept. of Mechanical Engineering
IIT Kanpur
India

E-mail : *bishakh@iitk.ac.in*

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Contents

- ✓ Hardness
  - Qualitative testing
  - Quantitative testing
- ✓ Creep
- ✓ Damping

HARDNESS

- It is a measure of a material's **resistance** to localized **plastic deformation** (e.g., a small **indentation** or a **scratch**).

❖ Advantages of Hardness testing

- **Simple and inexpensive** – no special specimen preparation is needed and the apparatus is relatively cheaper.

- **Non-destructive method** – small indentation is the only deformation.

- **Other mechanical properties** like tensile strength (S_u) can be **obtained** from the hardness data **(HB)** by using the following **Tabor** relationship:

$$\boxed{\frac{S_u}{HB} = \frac{1-x}{2.62}\left(\frac{10x}{1-x}\right)^x}$$

x = *n*-2, n varies between 2 to 2.7 and is known as **Meyer Index**

Qualitative method – Mohs Scale

- Old method
- Based on ability of one material to scratch another.
- Hardness measured on the scale – 1 (softest)

Mohs scale of hardness

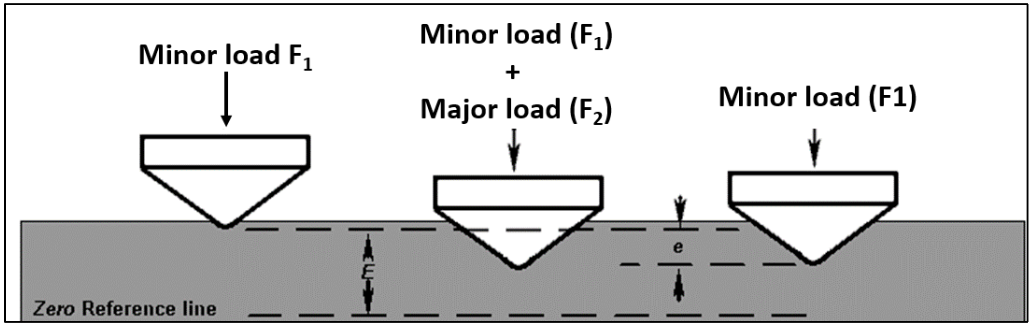
Mohs Hardness	Mineral	Chemical formula	Absolute hardness
1	Talc	$Mg_3Si_4O_{10}(OH)_2$	1
2	Gypsum	$CaSO_4.2H_2O$	3
3	Calcite	$CaCO_3$	9
4	Fluorite	CaF_2	21
5	Apatite	$Ca_5(PO_4)_3(OH^-,Cl^-,F^-)$	48
6	Feldspar	$KAlSi_3O_8$	72
7	Quartz	SiO_2	100
8	Topaz	$Al_2SiO_4(OH^-,F^-)_2$	200
9	Corundum	Al_2O_3	400
10	Diamond	C	1600

Quantitative - Hardness Tests

- **Macro-Hardness test**
  - Rockwell Hardness Test
  - Brinell Hardness test
  - Vickers Hardness Test
- **Micro-Hardness Test**
  - Knoop Micro-Hardness Test
  - Vickers Micro-Hardness Test

Rockwell Hardness Test

- A **minor load** is first applied for **good contact** between the indenter and the sample surface followed by **major load** and the **depth** of **indentation** is **recorded** on a **dial gage** after removing major load.



- A **cone shaped indenter** (for **harder materials**) **or** a small diameter **steel ball** is pressed into a specimen.

e = permanent increase in depth of penetration due to major load

E = a constant depending on form of indenter- 100 units for diamond indenter, 130 units for steel ball indenter

HR = Rockwell hardness number = E - e

Rockwell testing

Rockwell Scale	Hardness Symbol	Indentor	Load (Kg)	Typical material tested
A	HRA	Cone	60	Carbides, Ceramics
B	HRB	Steel ball	100	Non-ferrous metals
C	HRC	Cone	150	Ferrous metals, tool steels

Image courtsey: http://www.gordonengland.co.uk/hardness/rockwell.htm

Brinell Hardness Test

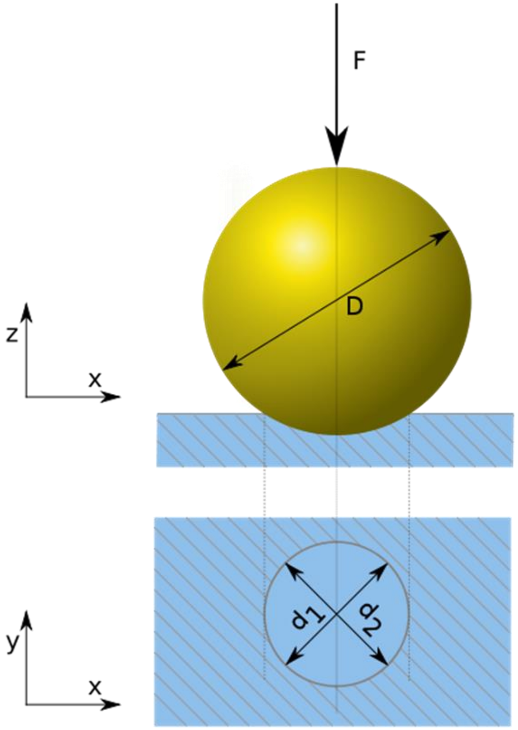
- Used for testing metals and non-metals of low to medium hardness.

- A hardened steel (or cemented carbide) ball of **10mm** diameter (D) is pressed into the surface of a specimen using load (P) of **500**, **1500**, or **3000 kg** for a specified time (between 10-30s) .

$$HB = \frac{2P}{\pi D\left[D - \sqrt{(D^2 - d^2)}\right]}$$

$$where, mean\ indentation\ diameter\ (mm), d = \frac{d_1 + d_2}{2}$$

Thumb rule for steel alloys , Tensile strength (MPa) = 3.45 X HB



Brinell testing

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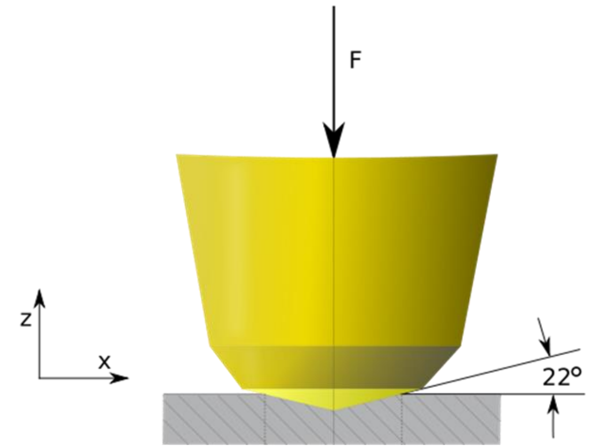
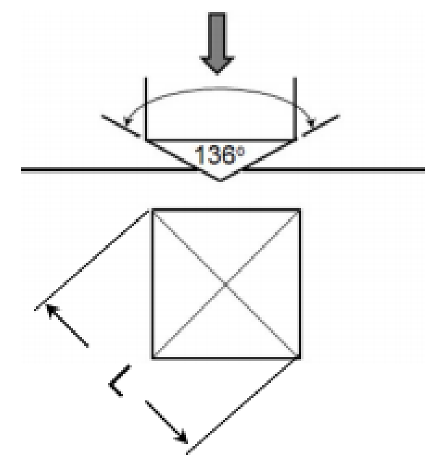
Vickers Hardness Test

- Vickers test uses a square-base diamond pyramid indenter having an angle of 136° between the opposite faces.
- The hardness is obtained by dividing the load (1–120 kg) with the surface area of the indentation.
- The surface area is calculated from the diagonals length of the impression.





Vickers Hardness Test

$$\boxed{VHN = \frac{1.854\,F}{L^2}}$$

F = Applied load (kg)
L = Diagonal length of the impression made by the indenter (mm)

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Micro Hardness test

- Sometime **hardness** determination is needed over a **very small area**. For example, hardness of **carburized** steel **surface**, **coatings** or individual phases or constituents of a material.
- The **load** applied is much **smaller** compared to macro-hardness.
- The indentation is very small and an optical microscope is used to observe it.
- **Sample preparation** is **needed**.

✓ Two methods are used for micro-hardness testing.

❑ Knoop hardness

❑ Vickers Micro hardness

Knoop Hardness Test

- It is a micro-hardness test - a test for mechanical hardness used particularly for **very brittle materials or thin sheets.**
- A pyramidal diamond point is pressed into the polished surface of the test material with a known force, for a specified dwell time, and the resulting indentation is measured using a microscope
- Length-to-width ratio of the pyramid is 7:1

$$\boxed{HK = \frac{14.2\,F}{l^2}}$$

- HK = Knoop hardness value; F = load (kg); l = long diagonal of the impression (mm)

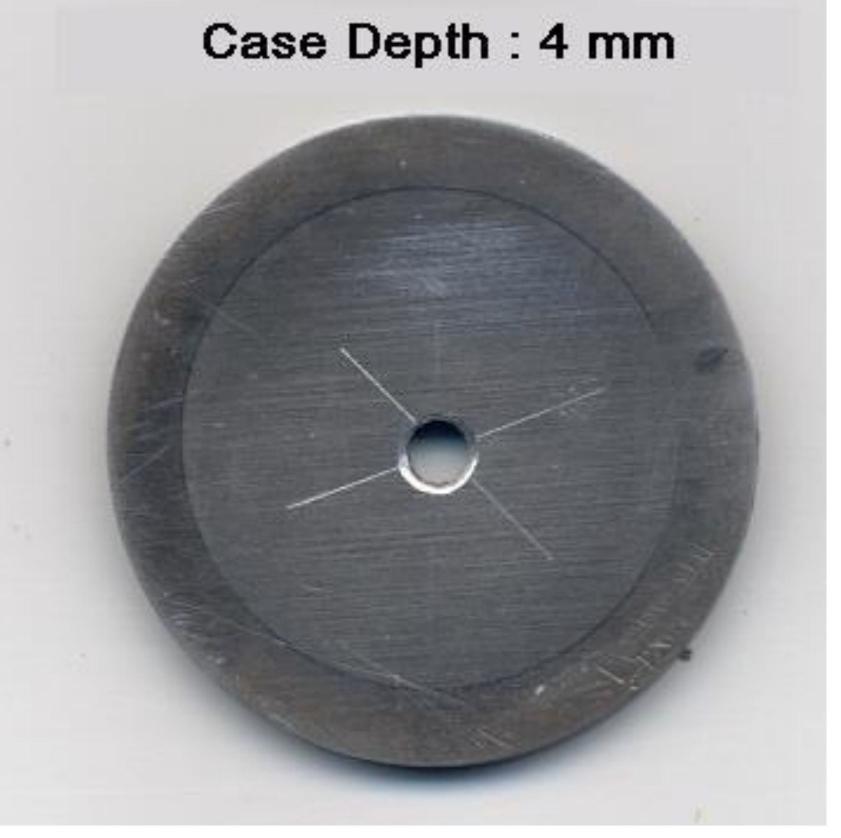
Vickers Micro-hardness

- This is same as Vickers hardness except that the applied load is much smaller so as to cover a small area.
- The applied load range is 1 – 100 g.

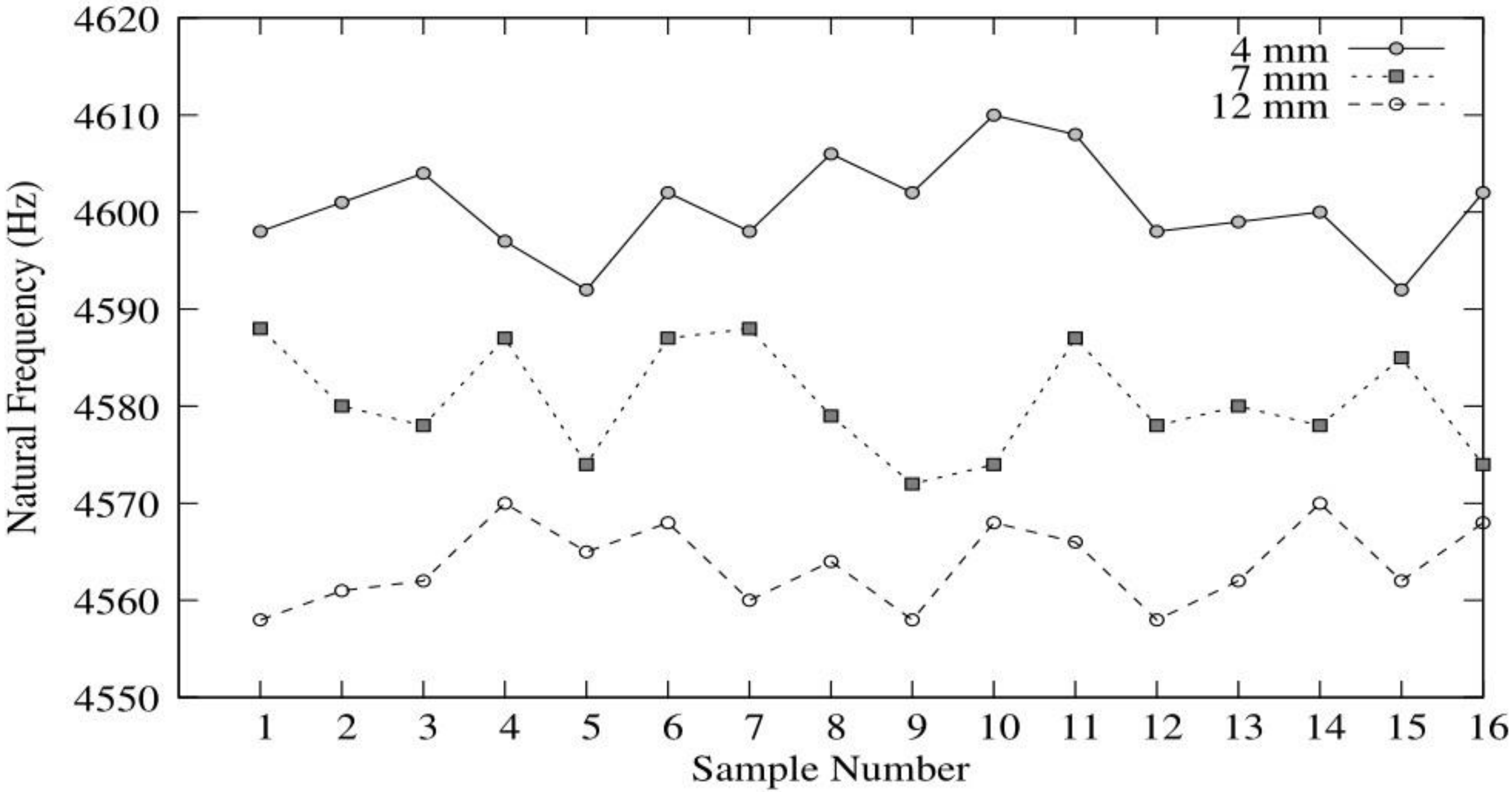
Induction heating(IH): A controlled Process

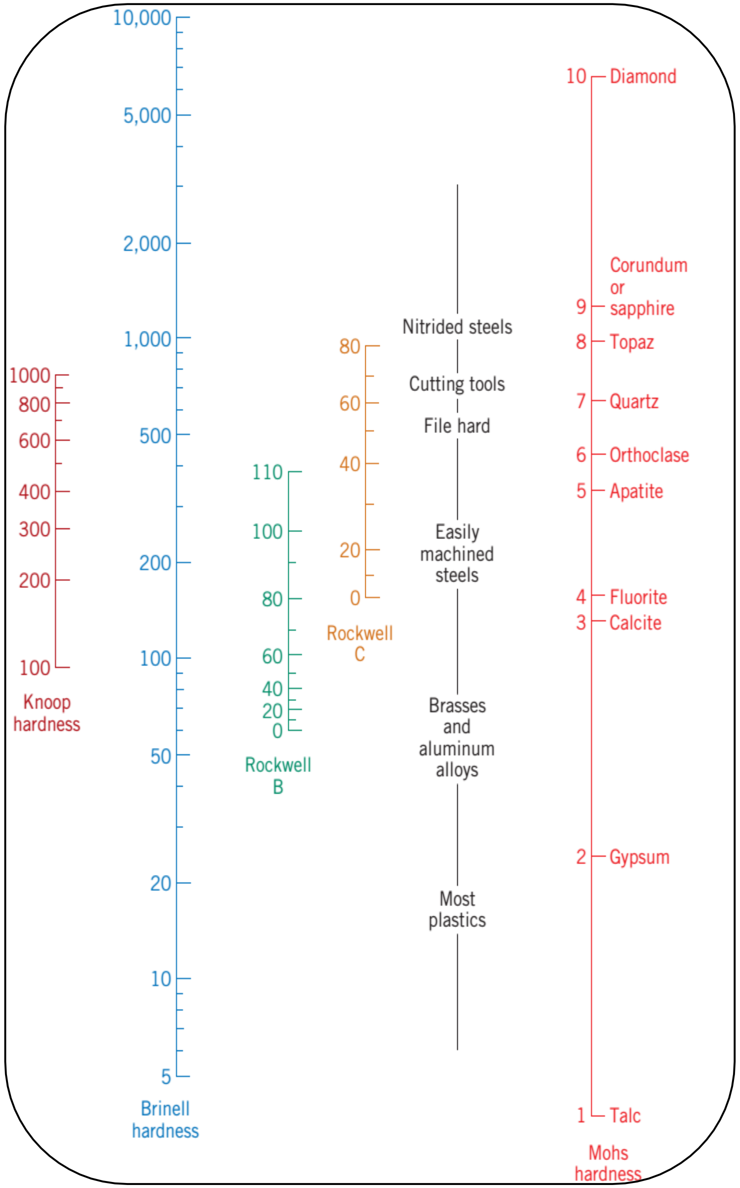
Quality parameters for Output

- Case depth &
- Hardness



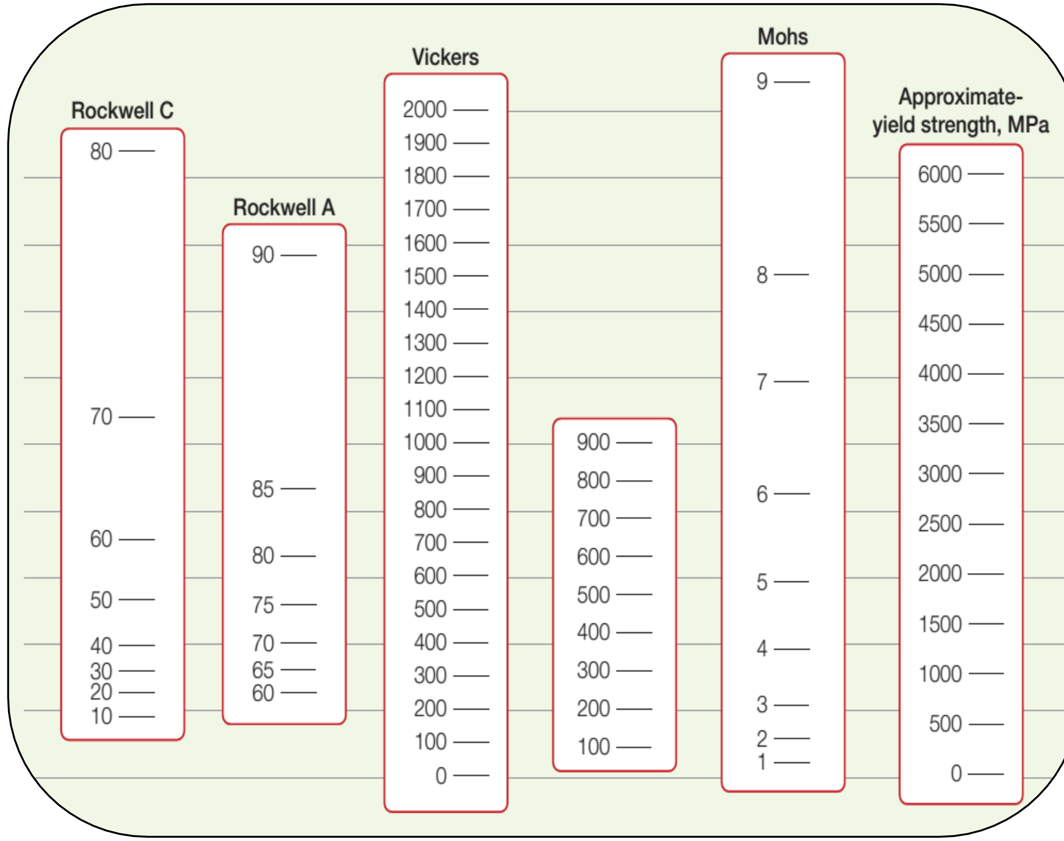
Dynamic Response: Natural frequency of hardened samples





Comparison of several hardness scales

Reference: W.D Callister, 7Ed.



Relating hardness to yield strength

Reference: Engineering Materials 1: Ashby & Jones, 4th Ed.

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Creep

- **Permanent deformation** under constant **load** over a **period of time**.
- **Dependent** on **temperature**.
- A **creep test** involves a tensile specimen under a **constant load** maintained at a **constant temperature**.
- At relatively high temperatures creep appears to occur at all stress levels, but the creep rate increases with increasing stress at a given temperature.
- Applications – **studying** material **behavior** at **elevated temperature** such as turbine blades, nuclear reactor components, jet engines, heat exchangers, etc.

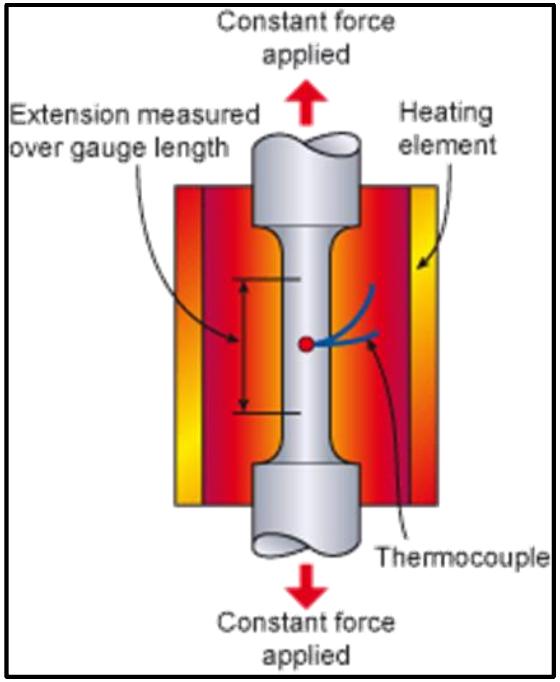


Image: http://www.twi-global.com/

Creep occurs in three stages:

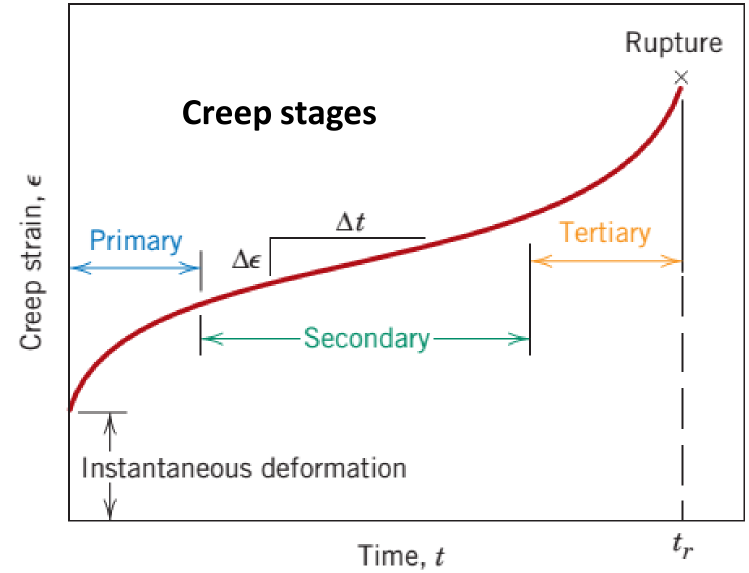
Primary Stage: Occurs at the beginning of the tests, and creep is mostly transient.

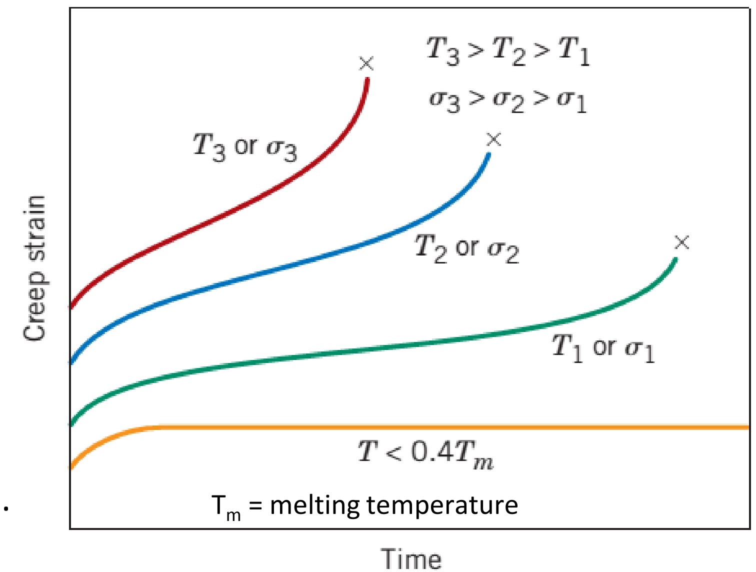
Secondary Stage: Creep rate roughly steady.

Tertiary Stage: Creep rate begins to accelerate as the cross sectional area decreases due to necking, followed by failure.

- At $T < 0.4T_m$ and after the initial deformation, the strain is virtually independent of time.
- With either increase in stress or temperature
  - ✓ Creep strain increases
  - ✓ Rupture life reduces

- **Nimonic 75** has been certified by the European Union as a **standard creep reference material**.
- **Nimonics** are **nickel-based** high-temperature low creep **super alloys**. They contain more than 50% nickel and 20% chromium with additives such as titanium and aluminium





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Reference: W.D Callister, 7Ed.

Damping

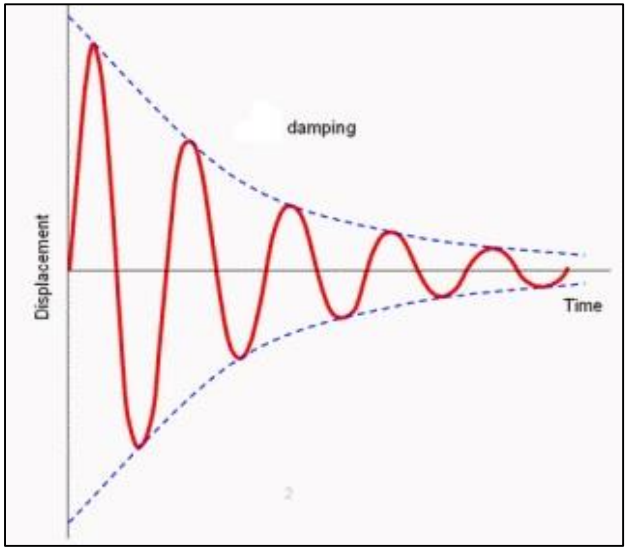
- Methods of vibration reduction
  - ✓ Increase damping capacity
  - ✓ Increase stiffness
- **Damping** refers to **dissipation** of **energy** from a vibrating system.
- Damping force magnitude is generally smaller than elastic and inertia forces.
- Even if damping force is smaller, it is important for controlling vibration particularly near resonance.

Advantages

✓ Shock absorption.

✓ Fatigue failure prevention.

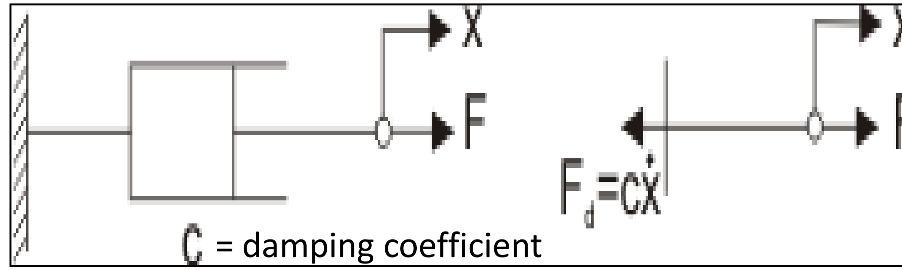
✓ Noise reduction.



Types of damping

1. Viscous Damping

- Represented by a viscous **dashpot**, which shows a **piston** moving relative to a **cylinder** containing a **fluid**.
- The **damping force** is taken to be **proportional** to the **velocity** across the damper, acting in the **direction opposite** to that of the **velocity**.
- This ideal linear relationship holds good so long as the **relative velocity** is **low**, ensuring a **laminar** fluid flow



Viscous damping model

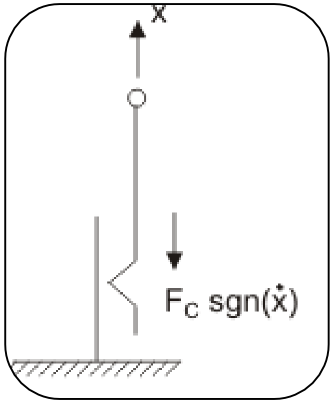
Viscous damper – seismic protection

Types of damping

2. Coulomb Damping

- **Dry friction** force between two **solid interfaces**
- In this model, the magnitude of **damping force** is assumed to be a **constant**, (F_d) i.e., **independent** of the relative velocity (or **slip velocity**) at the interface.
- $\dot{x}$ represents slip velocity at interface.
- Sgn($\dot{x}$) = 1, for $\dot{x}$ > 0

  = -1 for $\dot{x}$ < 0



Coulomb damping model

slotted-bolted dampers

Damping Ratio

3 Damping Ratio

- ***Damping Ratio*** is defied as *the ratio of damping constant to the critical damping.* For a single degree of freedom model with mass *m* and stiffness *k*, the damping ratio ζ is:

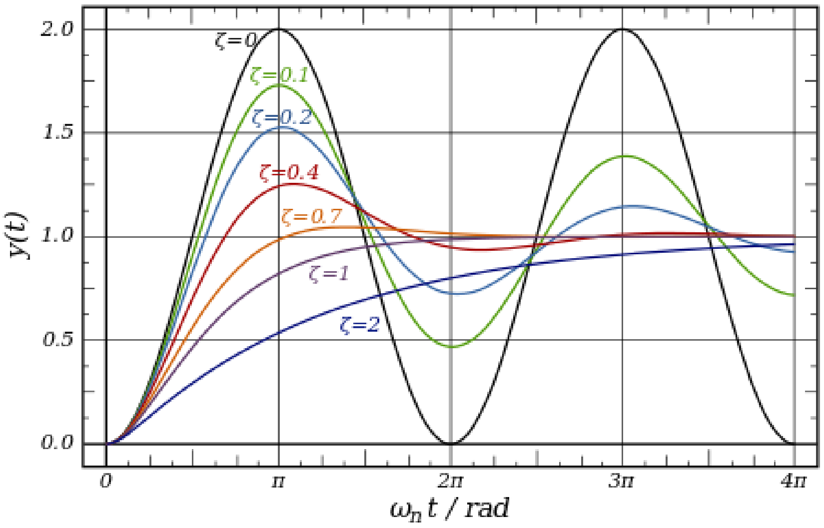
$$\varsigma = \frac{C}{C_c}, \; C_c = 2\sqrt{k\,m}$$

- Thus, for a critically damped system

$$\varsigma = 1$$

- While for an under-damped system

$$\varsigma \langle\langle 1$$



A typical response of single degree of freedom system with varied damping ratio
Image Source:
https://en.wikipedia.org/wiki/Damping_ratio

Another associated term is the Quality factor, Q, which determines the degree of under-damping. It is typically the ratio of bandwidth to the central frequency.

Loss-Factor

4 <u>Loss-Factor</u>

- Loss-Factor is defied as *the ratio of energy dissipated from the system to the energy stored in the system* for every oscillation. It is often useful to relate the loss factor to the damping ratio such that viscous damping models can be used for analysis. At resonance, loss factor (η) is related to the damping ratio by the following relationship:

$$\varsigma = 1/(2Q) = (1/2)[\sqrt{1+\eta} - \sqrt{1-\eta}]$$

Material	Approximate Loss Factor
Aluminum	0.007 - 0.005
Steel	0.05 - 0.10
Neoprene	0.1
Butyl Rubber	0.4