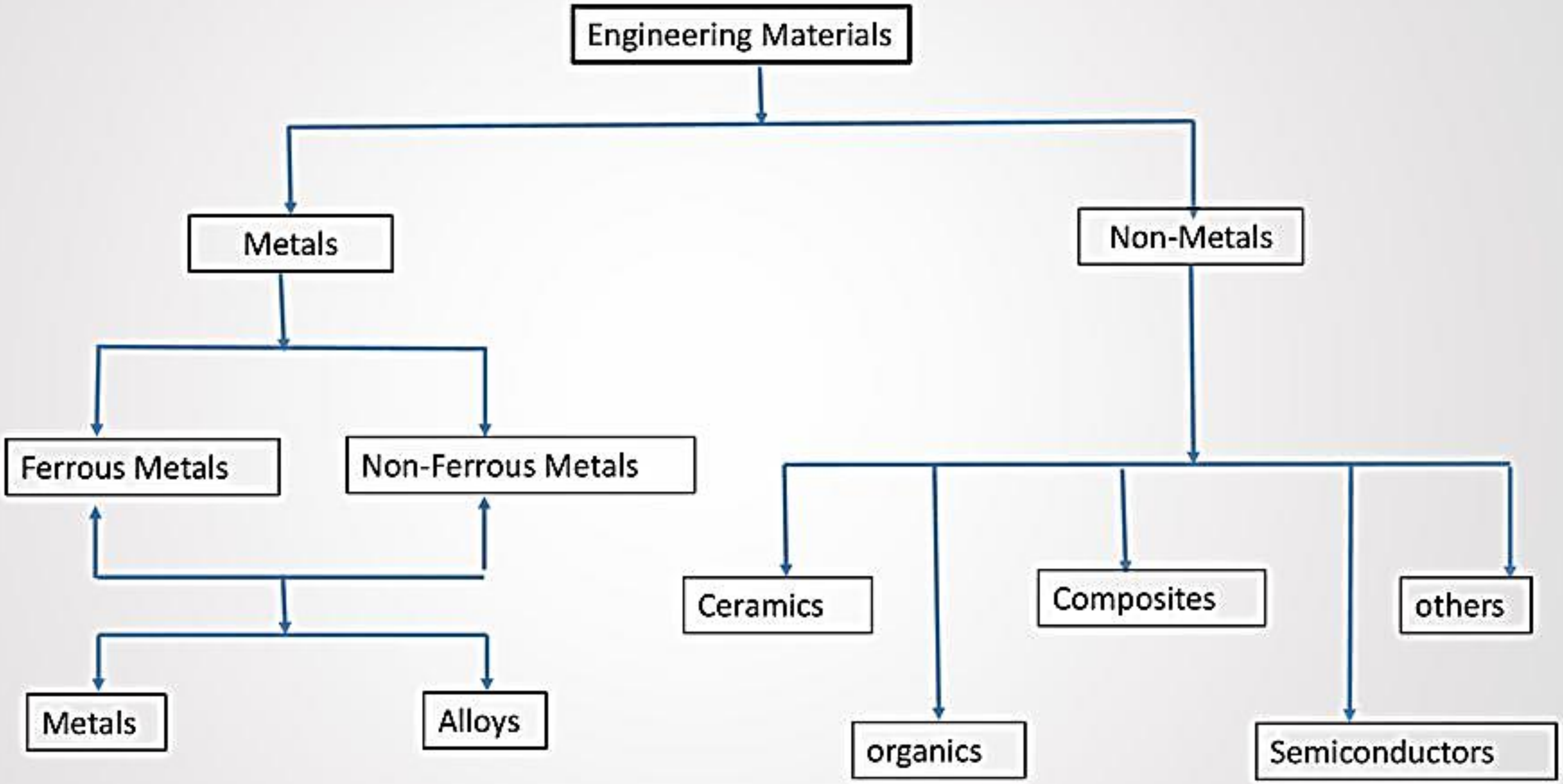
Module 5
Materials and Modelling

Classification of Engineering Material



Metals

Materials which are composed of one or more metallic elements (such as iron , aluminum, copper, titanium, gold, and nickel), are called Metals.

- They are good conductors of heat and electricity.
- They are also good electrical conductors, as the number of valence electrons are high which help in the creation of the metallic bond.

- **Ferrous Metals:** The metals which have the iron as their main constituent are called Ferrous Metals.
  Ex:- Cast Iron, Wrought Iron And Steel.
- ***Non-Ferrous Metals:*** The metals which do not contain iron in them are called Non-Ferrous Metals.
  Ex:- Copper, Aluminium, Brass, Tin, Zinc, etc.

Familiar objects that are made of metals and metal alloys: (from left to right) silverware (fork and knife), scissors, coins, a gear, a wedding ring, and a nut and bolt.

- **Alloys:** It is a mixture of two or more than two metals or non-metals to obtained the desired properties of metals. Ex: Stainless Steel (SS),High Speed Steel (HSS), Brass, Babbits etc.

Non-Metals

Non-Metals are those which do not exist naturally but made artificially. The non-metallic materials are used in engineering practice due to their low density, low cost, flexibility, resistant to heat and electricity.

- Ceramics:
  - Ceramics are compounds between metallic and nonmetallic elements.
  - They are hard and brittle material.
  - They are bad conductor of heat and electricity.
  - China Tea Cup, Building Bricks, Floor Tiles, Glass etc.

Common objects that are made of ceramic materials: scissors, a china tea cup, a building brick, a floor tile, and a glass vase.

- **Composites:** A composite is composed of two (or more) individual materials (metals, ceramics, and polymers). A composite is made to achieve a combination of properties that is not displayed by any single material. Ex:- Carbon Fiber Reinforced Polymer, Carbon Fiber.
- **Semi-conductors:** Those materials whose conductivity is lies between conductor and insulator are called semiconductors.

Mechanical Properties

The mechanical properties of the metals are those which are associated with the ability of the material to resist mechanical forces and load.

1. ***Strength:***

   It is the ability of a material to resist the externally applied forces without breaking or failure.

2. ***Stiffness*:**

   It is the ability of a material to resist deformation under stress.

3. ***Elasticity:***

   It is the property of a material to regain its original shape after deformation when the external forces are removed. This property is desirable for materials used in tools and machines.

4. ***Plasticity:***

   It is property of a material which does not regain its original shape after deformation when the external forces are removed. This property of the material is necessary for forgings, in stamping images on coins and in ornamental work.

5. ***Ductility*:**

It is the property of a material enabling it to be drawn into wire with the application of a tensile force.

Ex: Mild Steel, Copper, Aluminum, Nickel, Zinc, Tin and Lead.

6. ***Brittleness*:**

It is the property of a material opposite to ductility. It is the property of breaking of a material with little permanent distortion.

Ex: Cast Iron, Glass etc .

7. ***Malleability*:**

It is a special case of ductility which permits materials to be rolled or hammered into thin sheets.

Ex: lead, soft steel, wrought iron, copper and aluminium etc.

Overview Of Some Engineering Materials

- **Cast Iron:** The cast iron is obtained by re-melting pig iron with coke and limestone in a furnace known as cupola. It is primarily an alloy of iron and carbon. The carbon contents in cast iron varies from 1.7 % to 4.5 %.
- ***Grey cast iron***:
  - It is an ordinary commercial iron having the following compositions :

  Carbon = 3 to 3.5%; Silicon = 1 to 2.75%; Manganese = 0.40 to 1.0%; Phosphorous = 0.15 to 1% ; Sulphur = 0.02 to 0.15% ; and the remaining is iron.

  - Grey colour
  - carbon is present in the form of free graphite.
  - It has a low tensile strength, high compressive strength and no ductility.
  - It can be easily machined.
- ***White cast iron***. The white cast iron shows a white fracture and has the following approximate compositions :

  Carbon = 1.75 to 2.3% ; Silicon = 0.85 to 1.2% ; Manganese < 0.4% ; Phosphorus< 0.2% ; Sulphur <0.12%, and the remaining is iron.

  - The white colour is due to fact that it has no graphite and whole of the carbon is in the form of carbide (known as cementite) which is the hardest constituent of iron.
  - The white cast iron has a high tensile strength and a low compressive strength.

- ***Malleable cast iron.***
  - It is ductile and may be bent without breaking or fracturing the section.
  - The tensile strength of the malleable cast iron is usually higher than that of grey cast iron and has excellent machining qualities.
- **Wrought Iron:** It is the purest iron which contains at least 99.5% iron but may contain upto 99.9% iron. The typical composition of a wrought iron is

  Carbon = 0.020%, Silicon = 0.120%, Sulphur = 0.018%, Phosphorus = 0.020%, Slag = 0.070%, and the remaining is iron.
- **Steels:** It is an alloy of iron and carbon, with carbon content up to a maximum of 1.5%.
  - Dead mild steel — up to 0.15% carbon
  - Low carbon or mild steel — 0.15% to 0.45% carbon
  - Medium carbon steel — 0.45% to 0.8% carbon
  - High carbon steel — 0.8% to 1.5% carbon
- ***18-4-1 High speed steel*.** This steel, on an average, contains

  18 % tungsten, 4 % chromium and 1 % vanadium

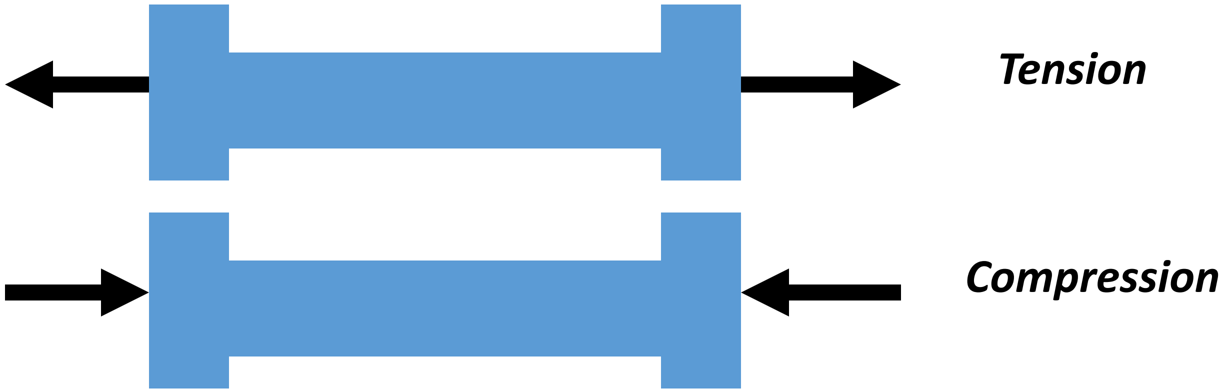
  It is considered to be one of the best of all purpose tool steels. It is widely used for drills, lathe, planer and shaper tools, milling cutters, reamers, broaches, threading dies, punches, etc.

Classifying Loads on Materials

- **Normal Load (Axial load): Load is perpendicular to the supporting material.**

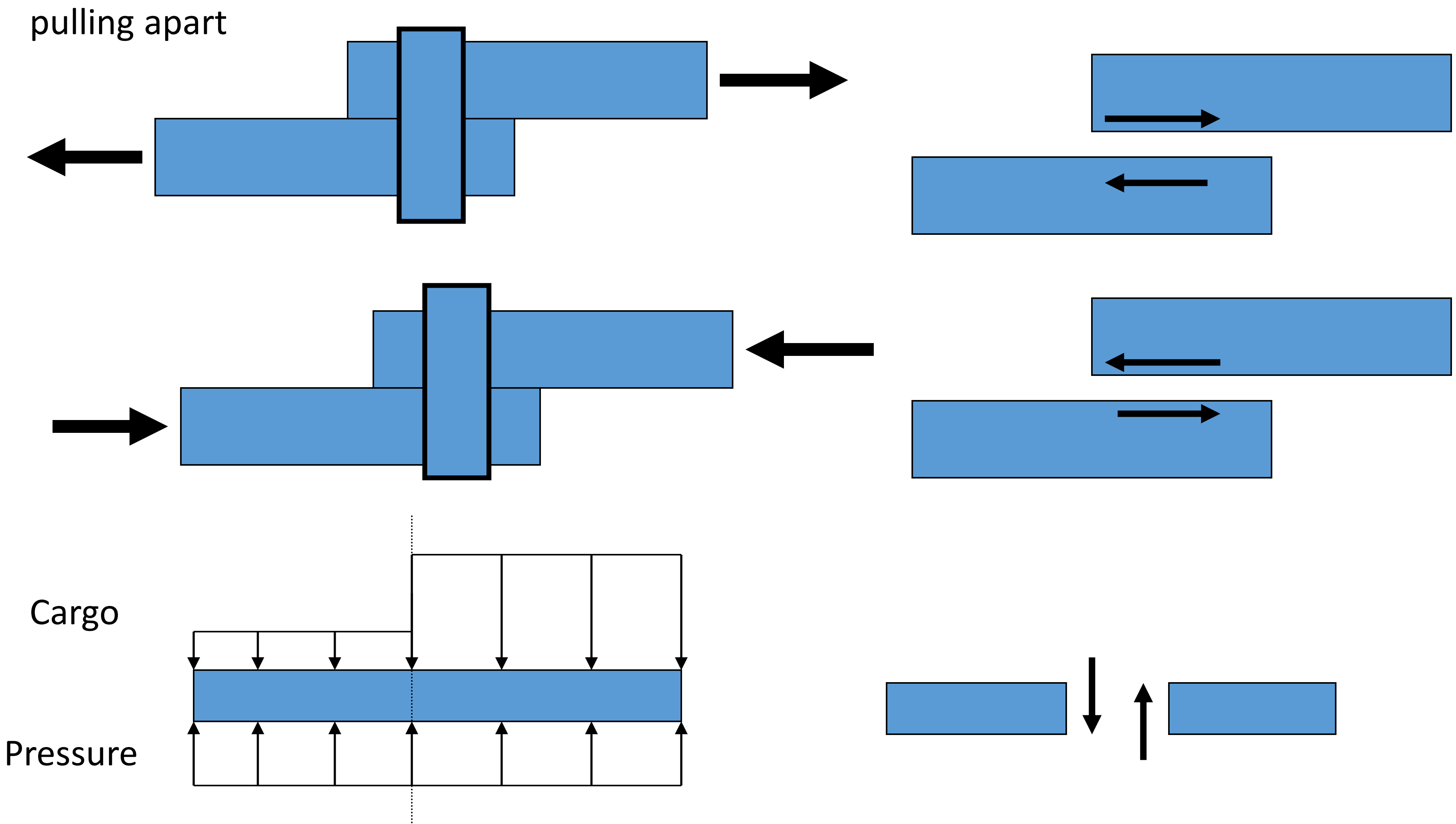
  - Tension Load: As the ends of material are pulled apart to make the material longer, the load is called a tension load.

  - Compression Load: As the ends of material are pushed into make the material smaller, the load is called a compression load.



Classifying Loads on Materials

- **Shear Load : Tangential load**



Classifying Loads on Materials

- **Torsion Loads: Angular distortion on a component, such as a shaft, when a moment is applied. (Twisting)**

- **Thermal Loads: Distortion caused be heating or cooling a material. A normal load is created when the material is constrained in any direction in the plane that is constrained.**

Stress and Strain

In order to compare materials, we must have measures.

- **Stress : load per unit Area**

$$\boxed{\sigma = \frac{F}{A}}$$

F : load applied in Newton(s)

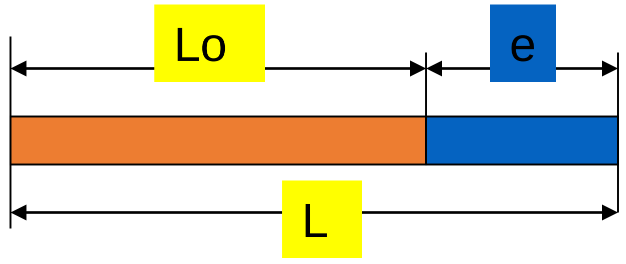
A : cross sectional area in mm²

σ : stress in N/mm²

Stress and Strain

- **Strain:**
  - Ratio of elongation of a material to the original length
  - unit deformation

$$\boxed{\varepsilon = \frac{e}{L_o}}$$



e : elongation (mm)

Lo : unloaded(original) length of a material (mm)

ε : strain (mm/mm) - Unitless

Elongation:

$$\boxed{e = L - L_o}$$

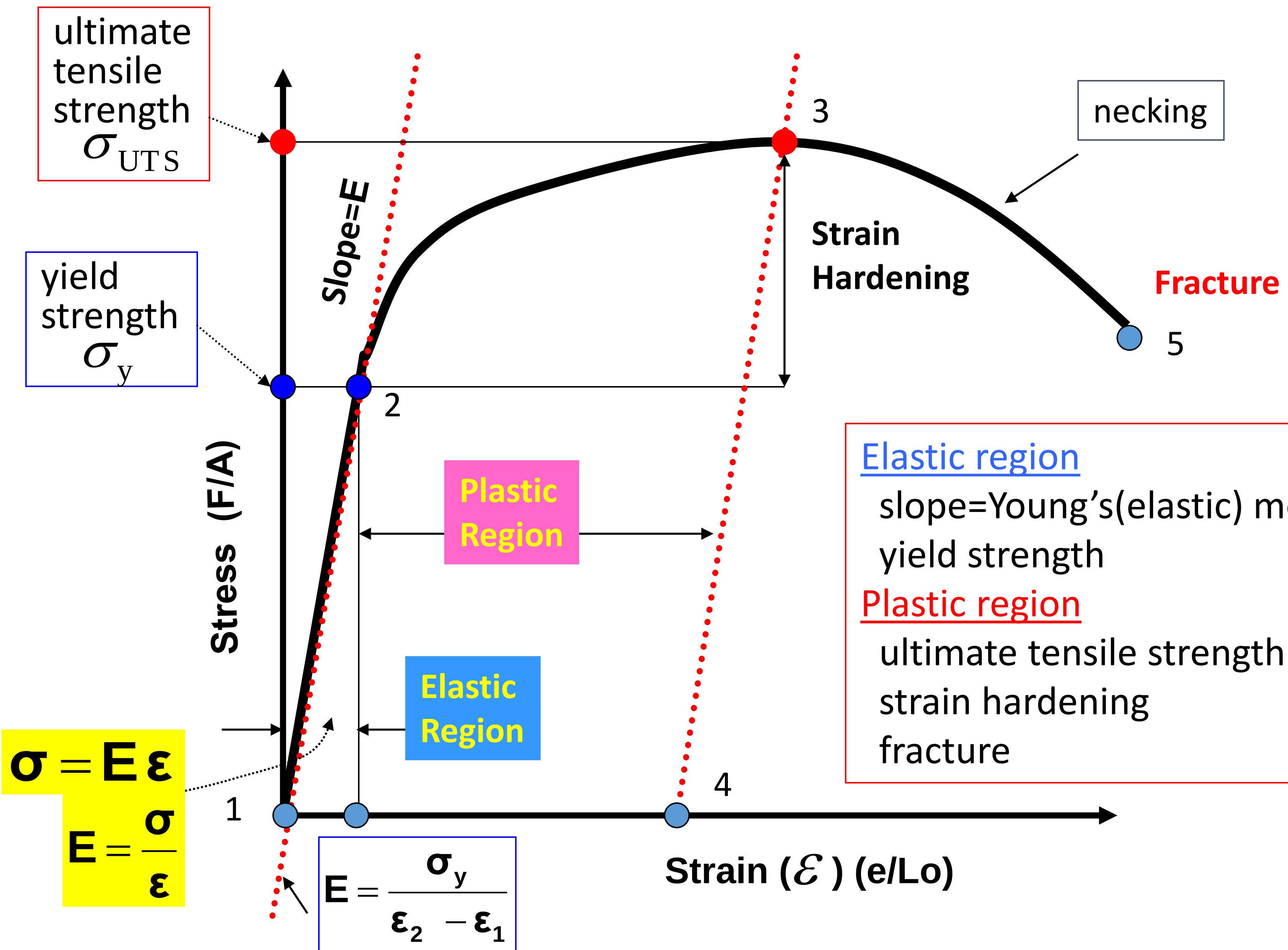
L : loaded length of a material (mm)

Baldwin Hydraulic Machine for Tension & Compression test

Stress-Strain Diagram

- A plot of Strain vs Stress.
- The diagram gives us the behavior of the material and material properties.
- Each material produces a different stress-strain diagram.

Stress-Strain Diagram



Elastic region
- slope=Young's(elastic) modulus
- yield strength

Plastic region
- ultimate tensile strength
- strain hardening
- fracture

Stress-Strain Diagram

- **Elastic Region (Point 1 –2)**

  - The material will return to its original shape after the material is unloaded(like a rubber band).

  - The stress is linearly proportional to the strain in this region.

$$\boxed{\sigma = E\varepsilon} \quad \text{or} \quad \boxed{E = \frac{\sigma}{\varepsilon}}$$

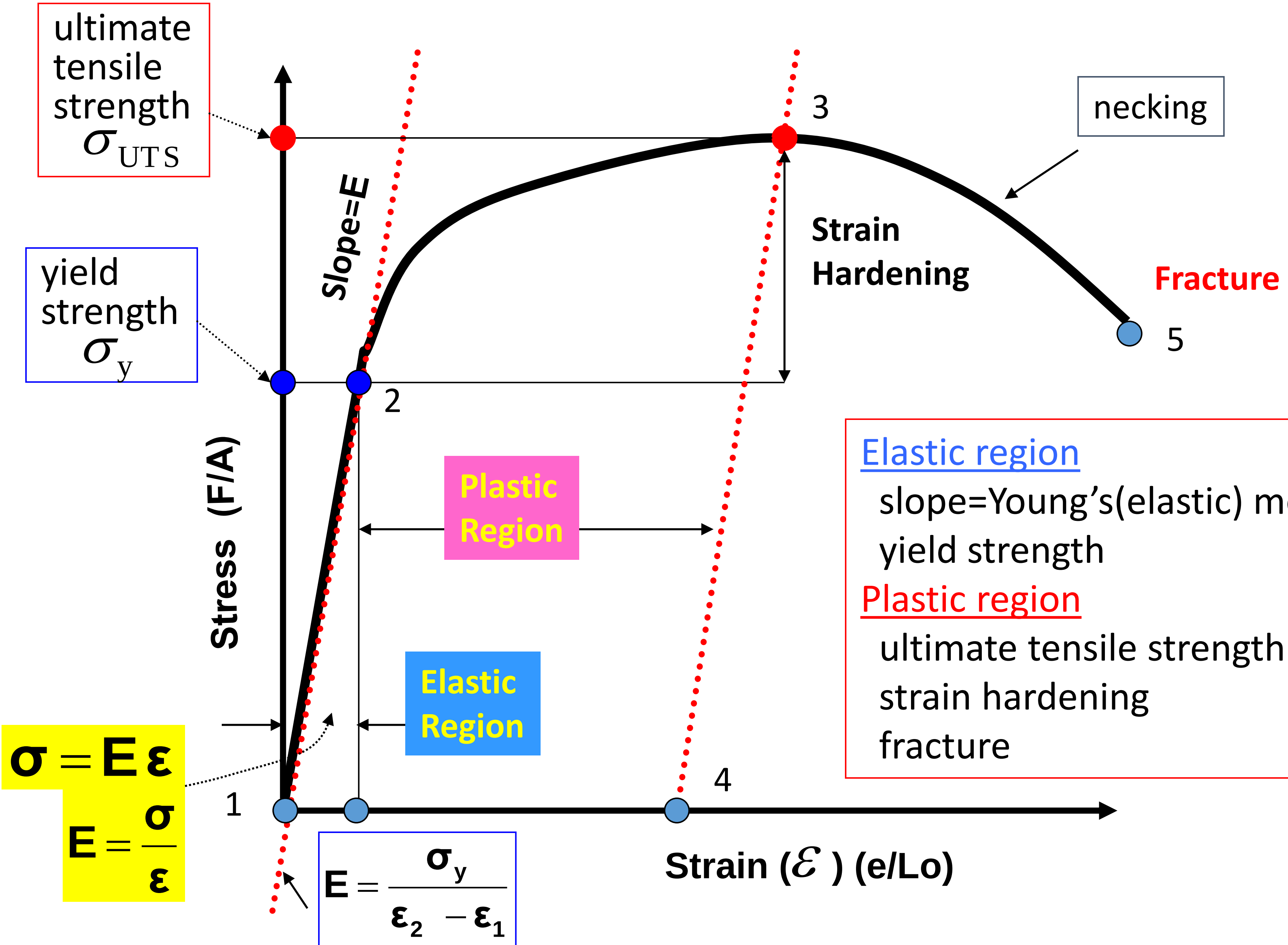
σ : Stress (N/mm^2)

E : Elastic modulus (Young's Modulus) (N/mm^2)

ε : Strain

- Point 2 : <u>Yield Strength</u> : a point at which permanent deformation occurs. (If it is passed, the material will no longer return to its original length.)

Stress-Strain Diagram



Elastic region
- slope=Young's(elastic) modulus
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Stress-Strain Diagram

<u>The ELASTIC Range Means</u>:

- The strain, or elongation over a unit length, will behave linearly (as in y=mx +b) and thus predictable.

-The material will return to its original shape (Point 1) once an applied load is removed.

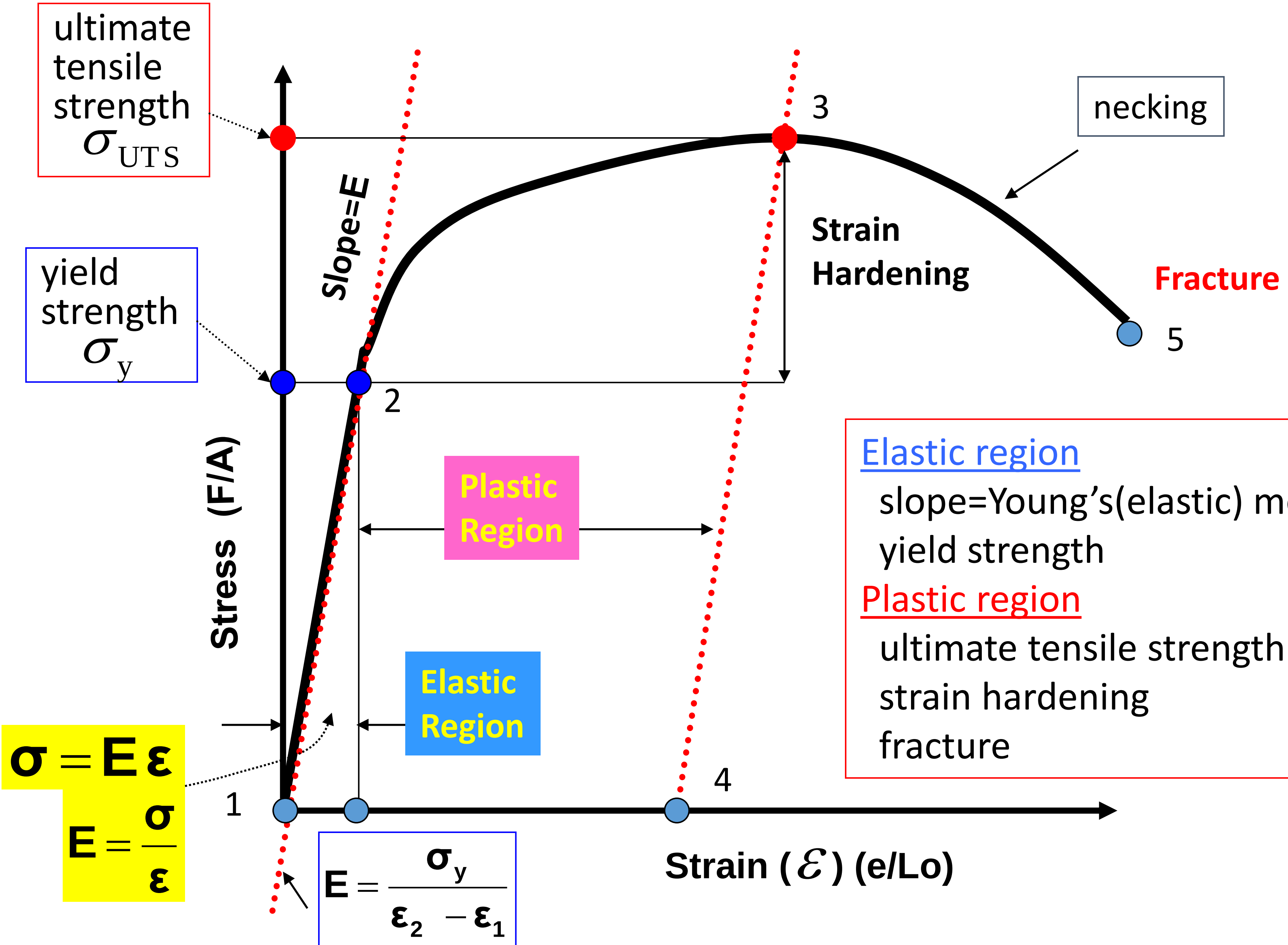
- The stress within the material is less than what is required to create a plastic behavior (deform or stretch significantly without increasing stress).

Stress-Strain Diagram

Plastic Region (Point 2 –3)

- If the material is loaded beyond the yield strength, the material will not return to its original shape after unloading.
- It will have some permanent deformation.
- If the material is unloaded at Point 3, the curve will proceed from Point 3 to Point 4. The slope will be the as the slope between Point 1 and 2.
- The distance between Point 1 and 4 indicates the amount of permanent deformation.

Stress-Strain Diagram



Elastic region
- slope=Young's(elastic) modulus
- yield strength

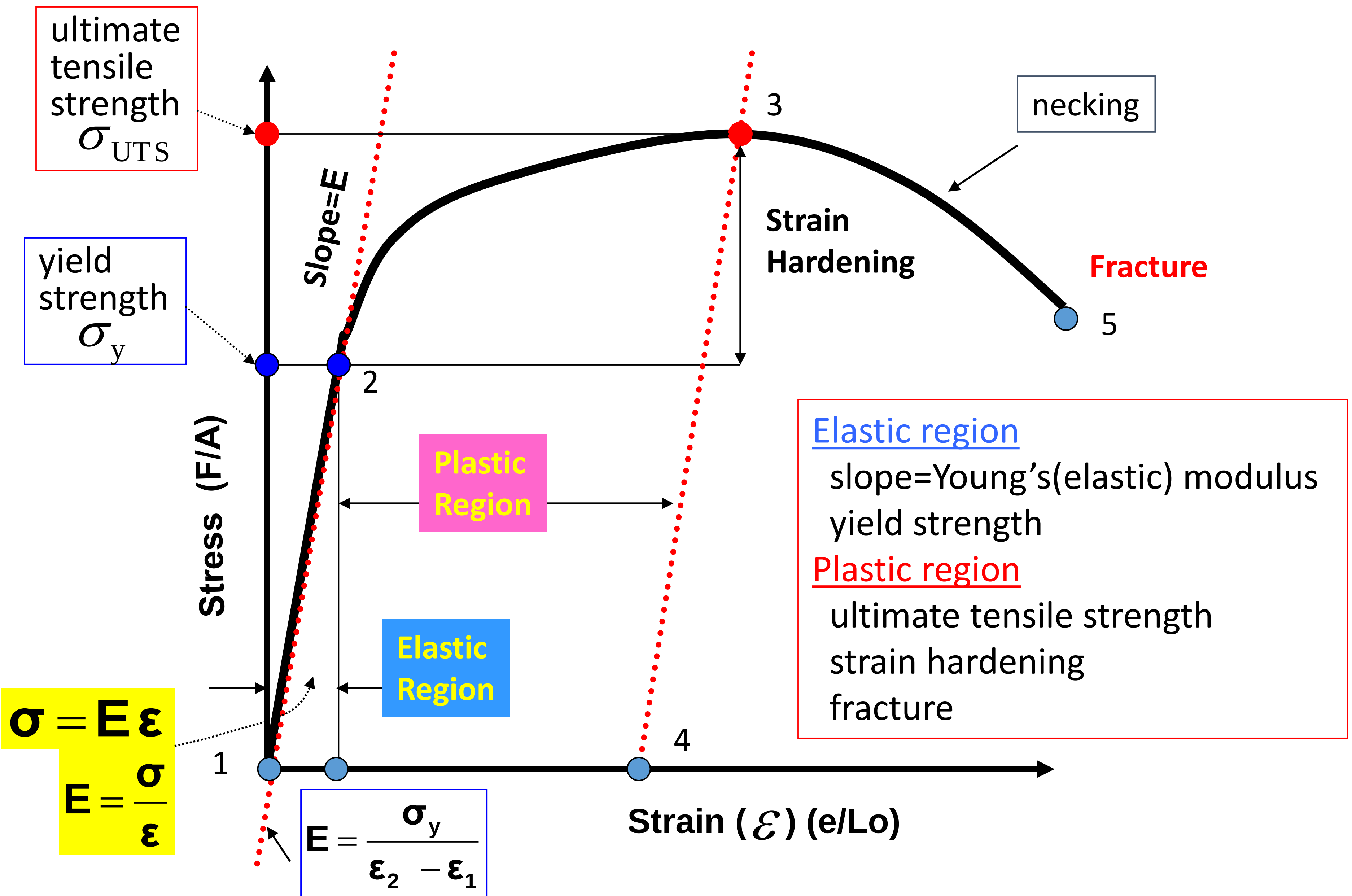
Plastic region
- ultimate tensile strength
- strain hardening
- fracture

Stress-Strain Diagram

Strain Hardening

- If the material is loaded again from Point 4, the curve will follow back to Point 3 with the same Elastic Modulus(slope).
- The material now has a higher yield strength of Point 4.
- Raising the yield strength by permanently straining the material is called Strain Hardening.

Stress-Strain Diagram



Stress-Strain Diagram

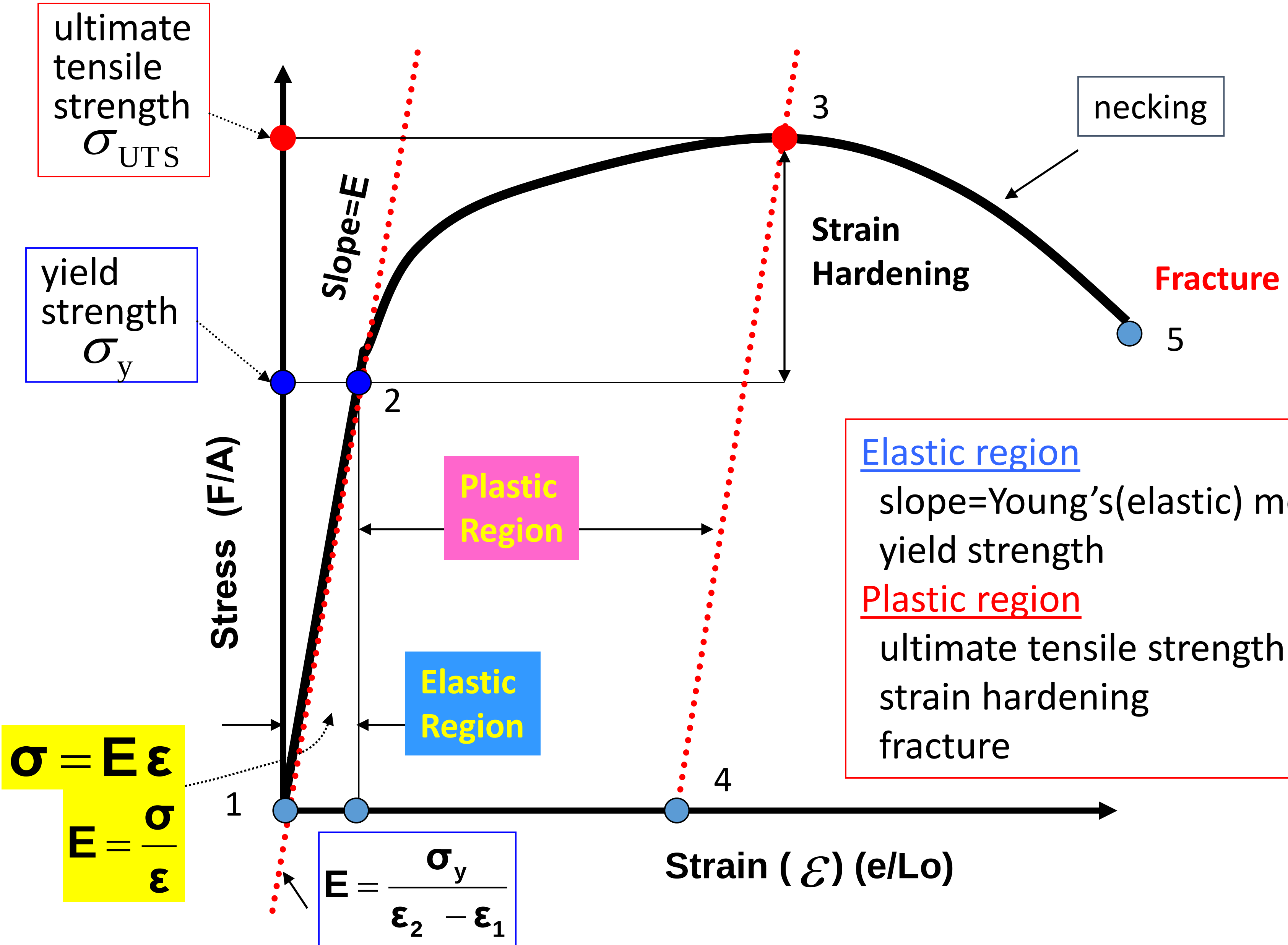
Tensile Strength (Point 3)

- The largest value of stress on the diagram is called Tensile Strength(TS) or Ultimate Tensile Strength (UTS)
- It is the maximum stress which the material can support without breaking.

Fracture (Point 5)

- If the material is stretched beyond Point 3, the stress decreases as necking and non-uniform deformation occur.
- Fracture will finally occur at Point 5.

Stress-Strain Diagram



Elastic region

slope=Young's(elastic) modulus

yield strength

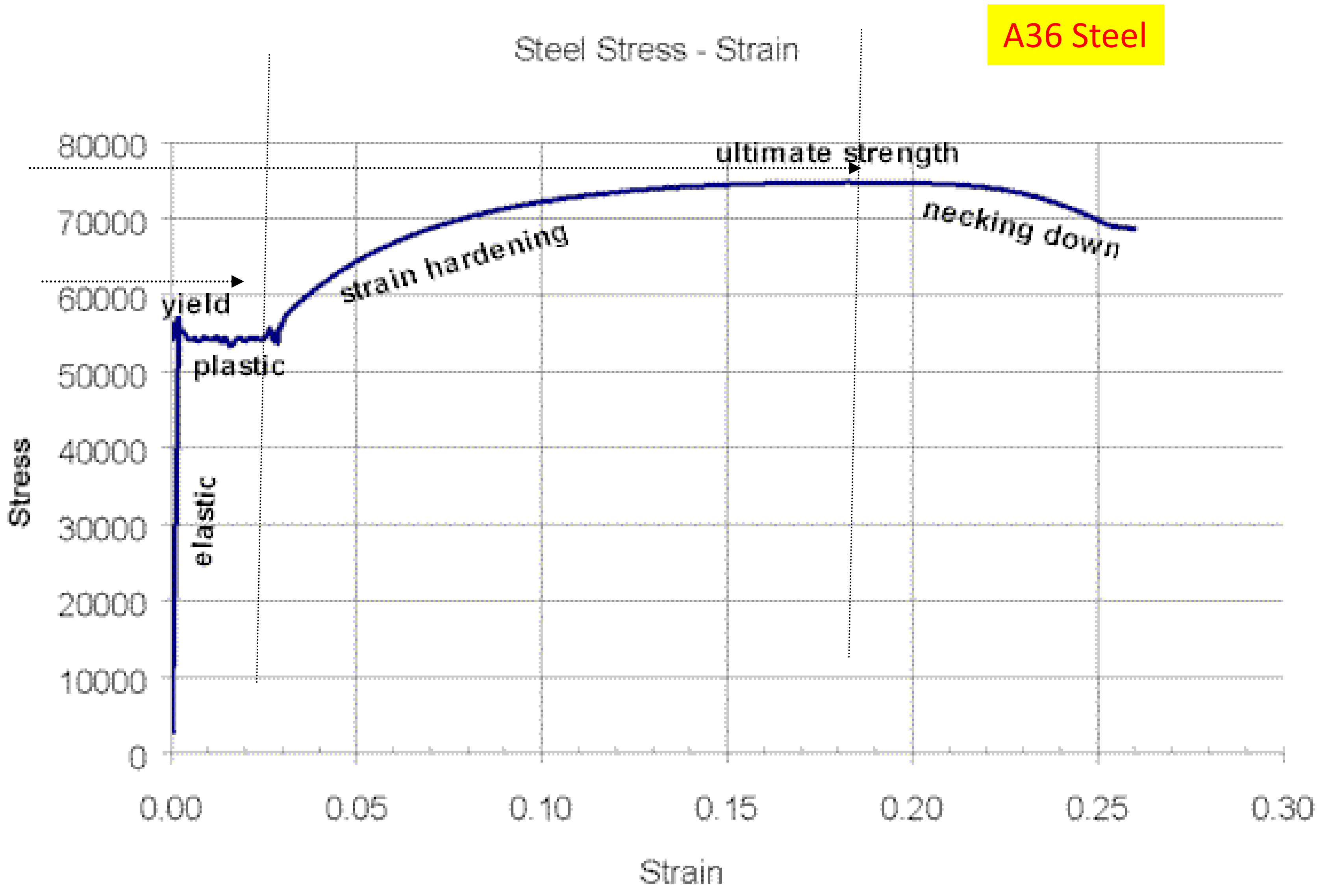
Plastic region

ultimate tensile strength

strain hardening

fracture

Stress-Strain Diagram



Material Properties

Characteristics of Material are described as

- **Strength**
- **Hardness**
- **Ductility**
- **Brittleness**
- **Toughness**

Material Properties

Strength:

- Measure of the material property to resist deformation and to maintain its shape
- It is quantified in terms of yield stress σ_y or ultimate tensile strength σ_{ult}.
- High carbon steels and metal alloys have higher strength than pure metals.
- Ceramic also exhibit high strength characteristics.

Material Properties

Hardness:

- Measure of the material property to resist indentation, abrasion and wear.
- It is quantified by hardness scale such as Rockwell and Brinell hardness scale that measure indentation / penetration under a load.
- Hardness and Strength correlate well because both properties are related to inter-molecular bonding. A high-strength material is typically resistant to wear and abrasion.

A comparison of hardness of some typical materials:

Material	Brinell Hardness
Pure Aluminum	15
Pure Copper	35
Mild Steel	120
304 Stainless Steel	250
Hardened Tool Steel	650/700
Hard Chromium Plate	1000
Chromium Carbide	1200
Tungsten Carbide	1400
Titanium Carbide	2400
Diamond	8000
Sand	1000

Material Properties

Ductility:

- Measure of the material property to deform before failure.

- It is quantified by reading the value of strain at the fracture point on the stress strain curve.

- Ductile materials can be pulled or drawn into pipes, wire, and other structural shapes

- Examples of ductile material :

  low carbon steel

  aluminum

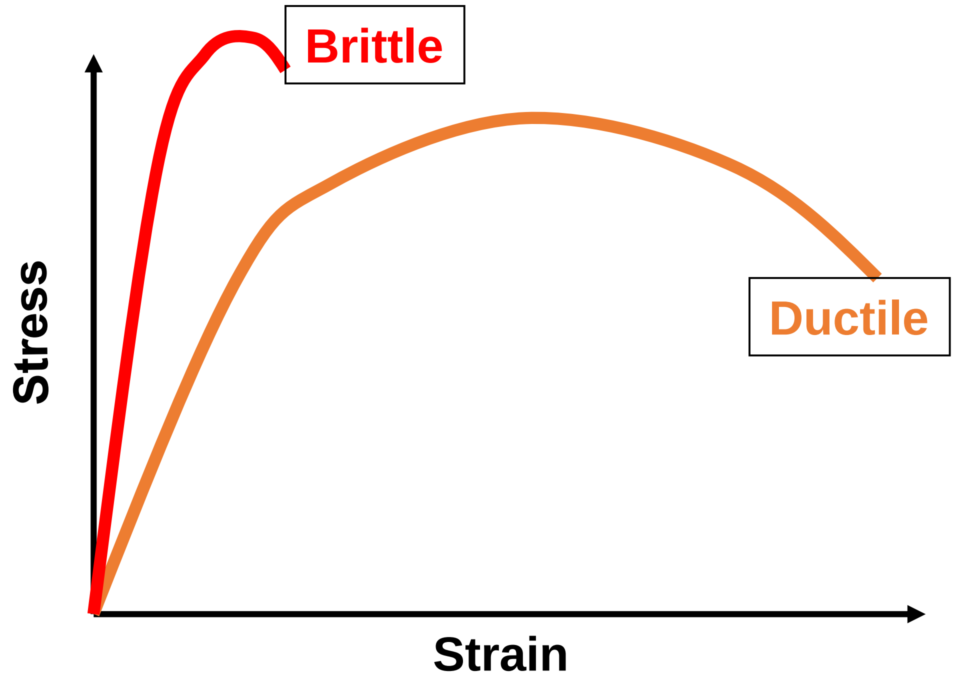
  copper

  brass

Material Properties

Brittleness:

- Measure of the material’s inability to deform before failure.
- The opposite of ductility.
- Example of ductile material : glass, high carbon steel, ceramics



Material Properties

Toughness:

- Measure of the material ability to absorb energy.
- It is measured by two methods.

a) Integration of stress strain curve

- Slow absorption of energy
- Absorbed energy per unit volume

unit : $(lb/in^2) * (in/in) = lb \cdot in/in^3$

b) Charpy test

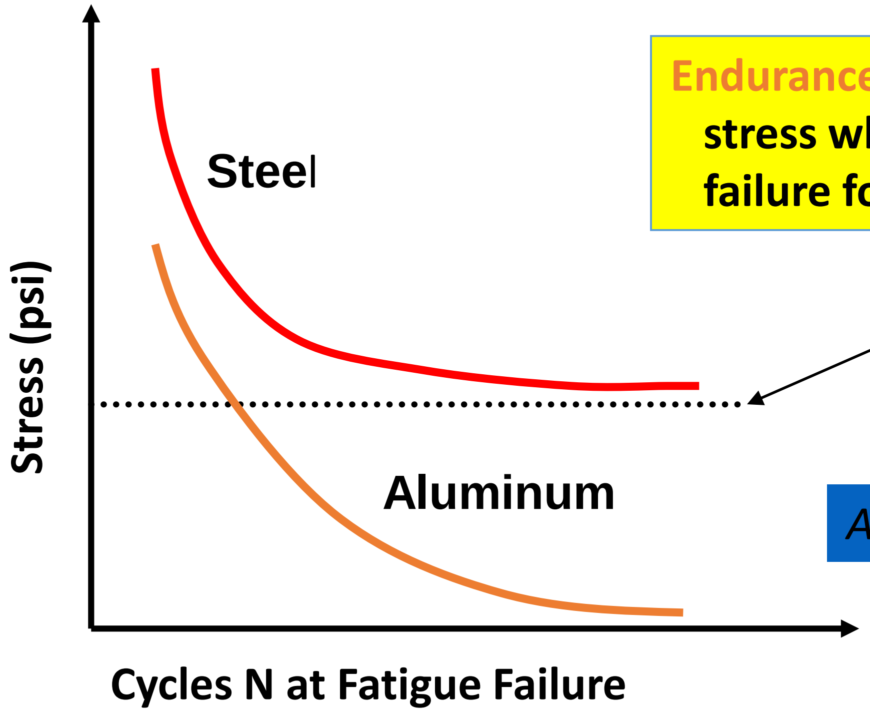
- Ability to absorb energy of an impact without fracturing.
- Impact toughness can be measured.

Material Properties

Fatigue:

- **The repeated application of stress typically produced by an oscillating load such as vibration.**
- **Sources of ship vibration are engine, propeller and waves.**

MAXIMUM stress decreases as the number of loading cycles increases.



Endurance Limit : A certain threshold stress which will not cause the fatigue failure for the number of cycles.

Aluminum has no endurance limit

Factors effecting Material Properties

Temperature :

Increasing temperature will:

- **Decrease Modulus of Elasticity (As Long as Structure Does Not Change)**
- **Decrease Yield Strength**
- **Decrease Ultimate Tensile Strength**
- **Decrease Hardness**
- **Increase Ductility**
- **Decrease Brittleness**

Environment:

- **Sulfites, Chlorine, Oxygen in water, Radiation, Pressure**

Ways to Effect / Alter Material Properties

Alloying (Adding other elements to alter the molecular properties):

- Steel: Carbon, chromium, molybdenum, nickel, tungsten, manganese
- Aluminum: Copper, manganese, silicon, zinc, magnesium

Thermal Treatments (Application of heat over varying time):

Annealing:

- Heating higher than its critical temperature then cooling slowly.
- Improves hardness, strength, and ductility.
- Ship's hulls are annealed.

Hardening:

- Heating higher than its critical temperature then cooling rapidly.
- Improves hardness.
- Increases internal stresses, may cause cracking.

Ways to Effect / Alter Material Properties

Thermal Treatments:

Tempering:

- Steel is heated below the critical temperature and cooled slowly.
- Used with hardening to reduce the internal stresses.

Hot-Working:

- Forming of shapes while material is hot.
- Less internal stresses due to annealing (change in the molecular structure).

Cold-Working:

- Forming shapes while material is cold.
- Causes internal stresses, resulting in a stronger shape.