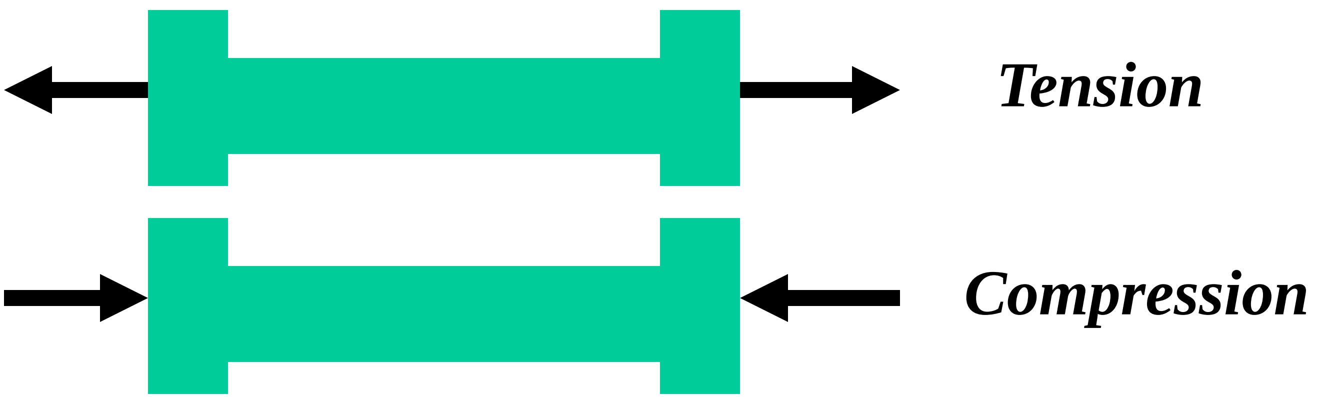
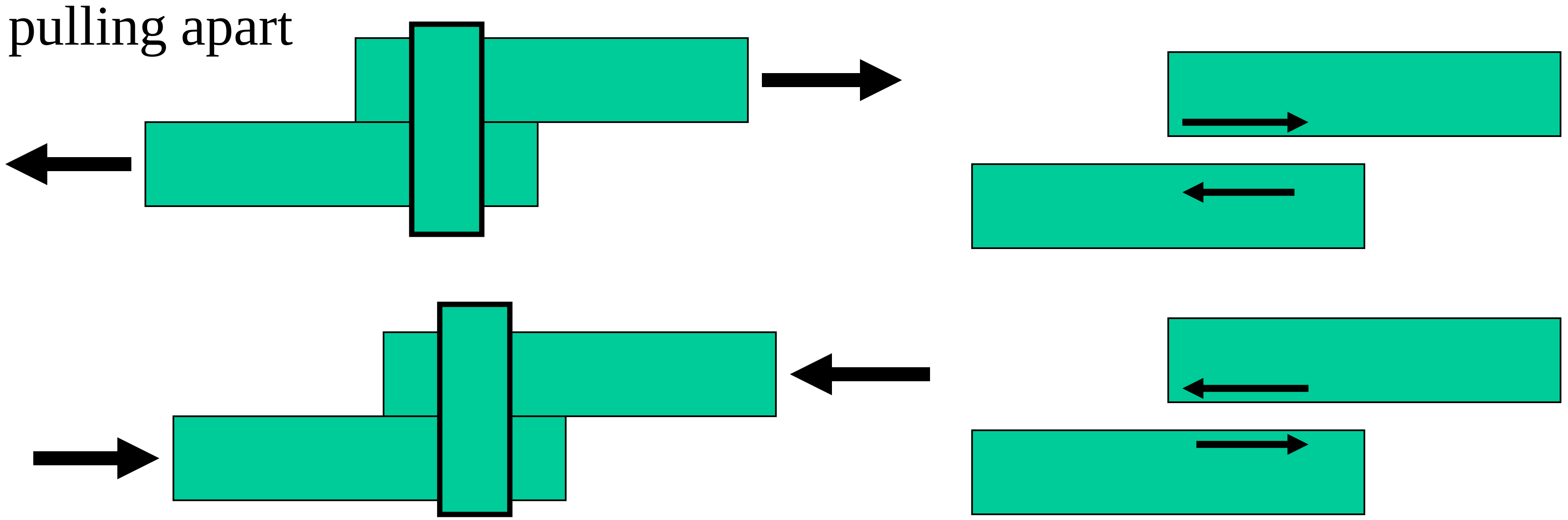
Classifying Loads on Materials

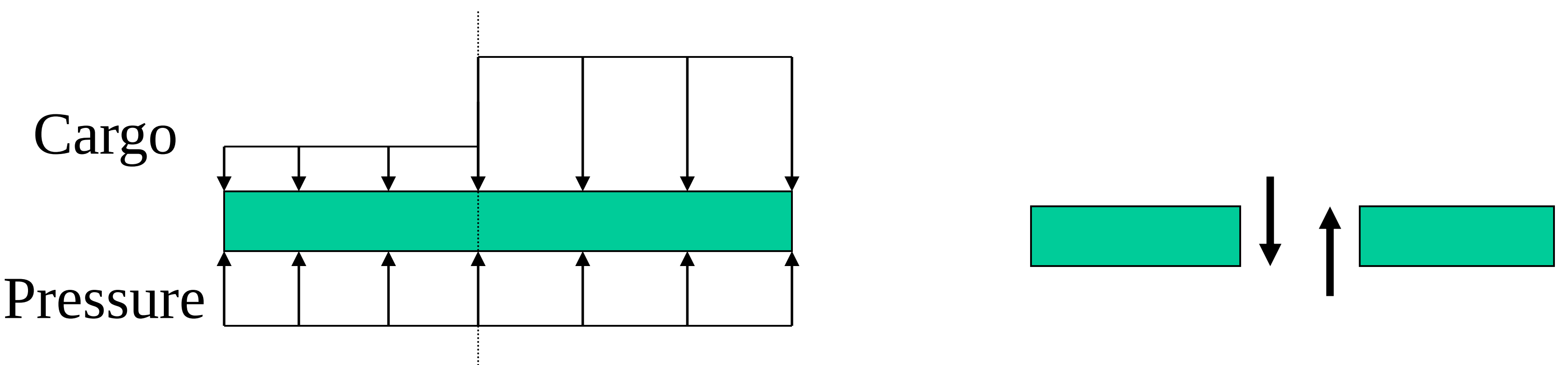
- **Normal Load (Axial load): Load is perpendicular to the supporting material.**
  - Tension Load: As the ends of material are pulled apart to make the material longer, the load is called a tension load.
  - Compression Load: As the ends of material are pushed in to make the material smaller, the load 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 pounds

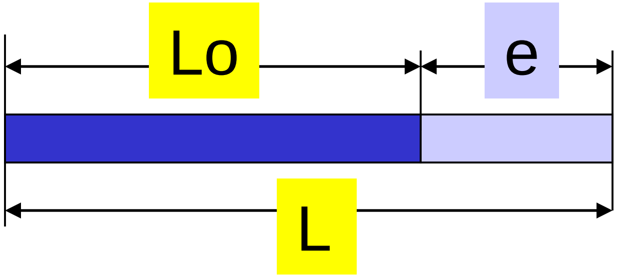
A : cross sectional area in in^2

σ : stress in psi

Stress and Strain

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

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



e : elongation (ft)

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

ε : strain (ft/ft) or (in/in)

Elongation:

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

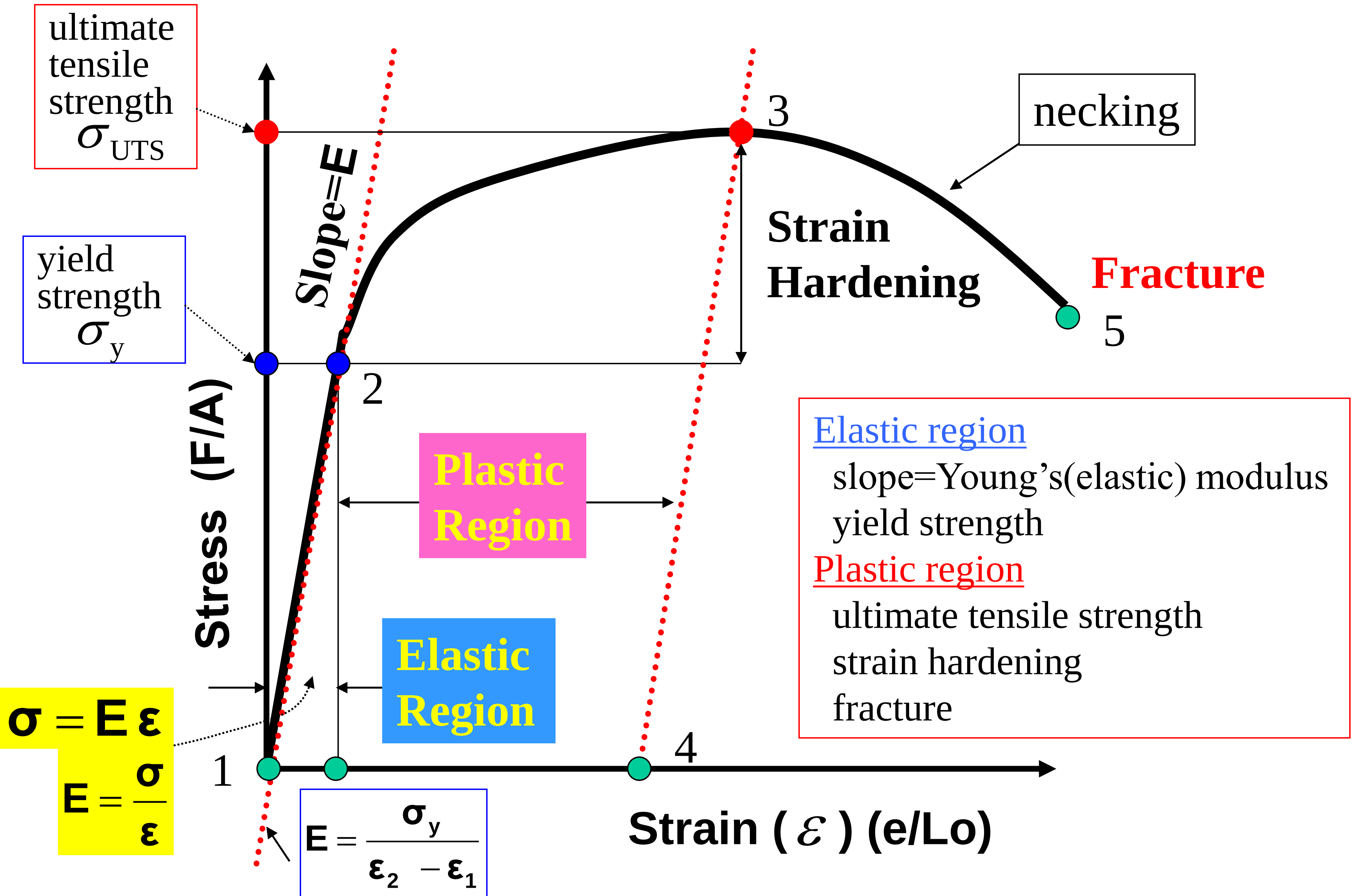
L : loaded length of a material (ft)

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



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.

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

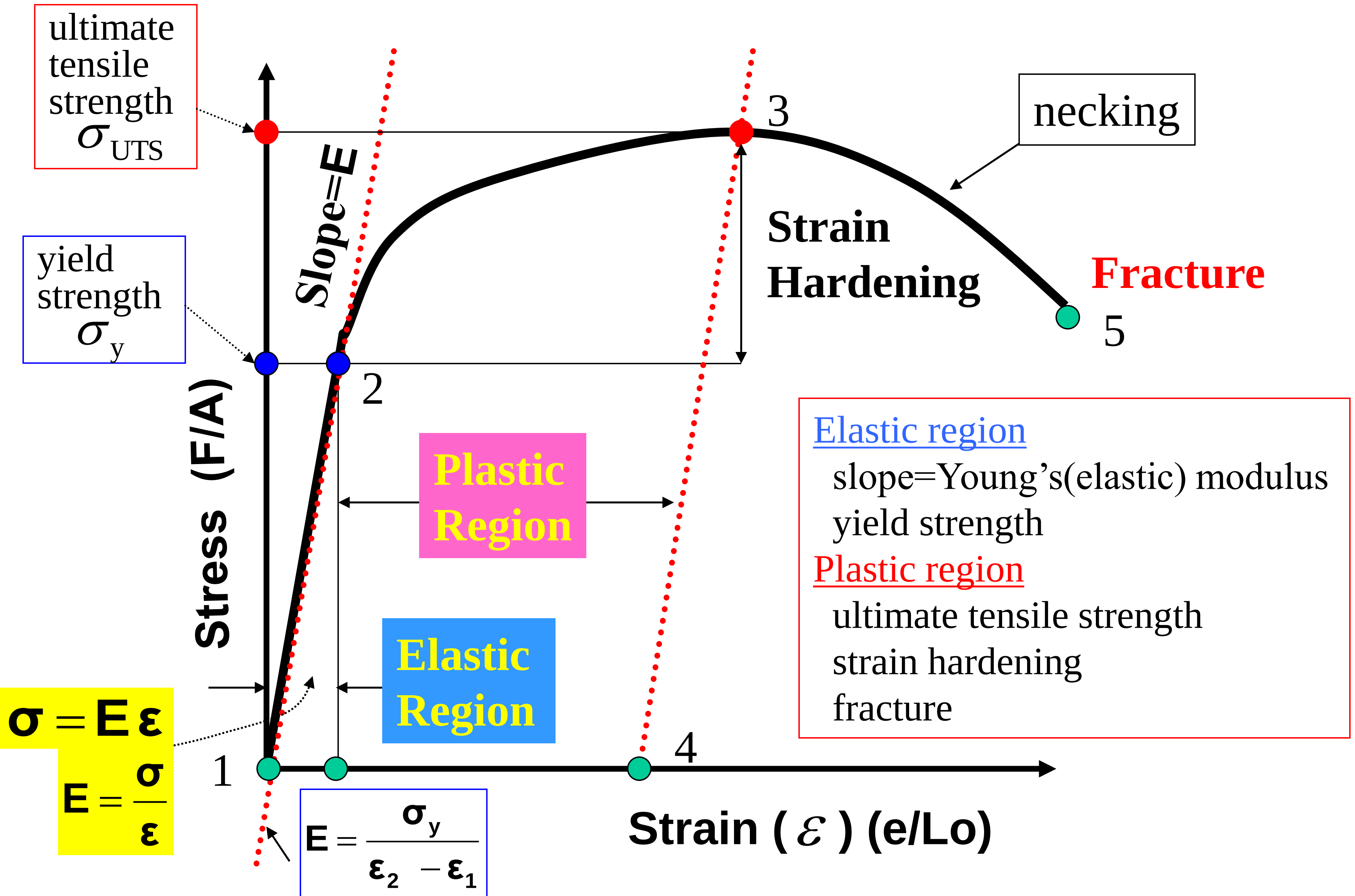
σ **: Stress (psi)**

E **: Elastic modulus (Young's Modulus) (psi)**

ε **: Strain (in/in)**

- **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



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.

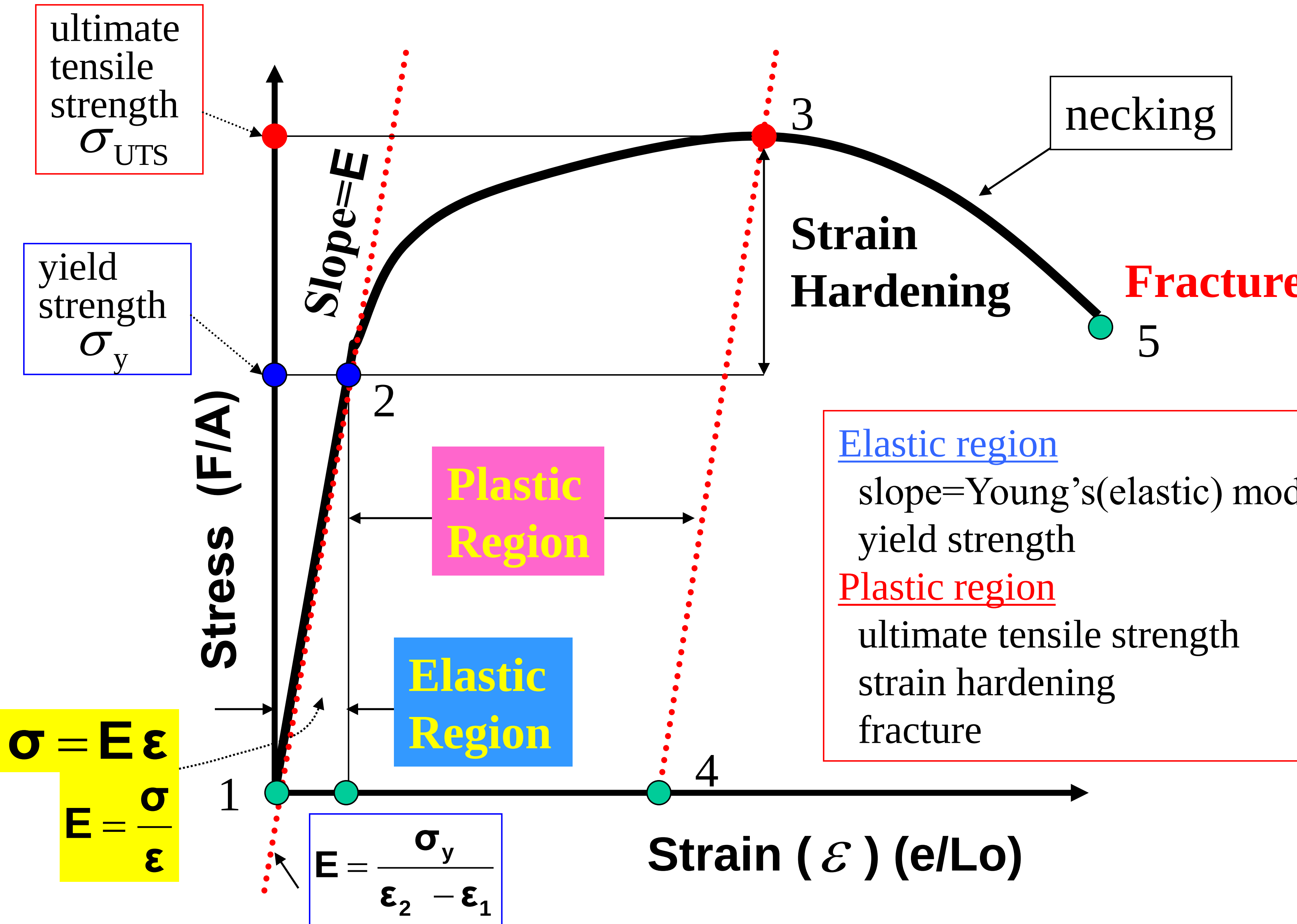
- The stress within the material is less than what is required to create a plastic behavior (deform or stretch significantly without increasing stress).

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

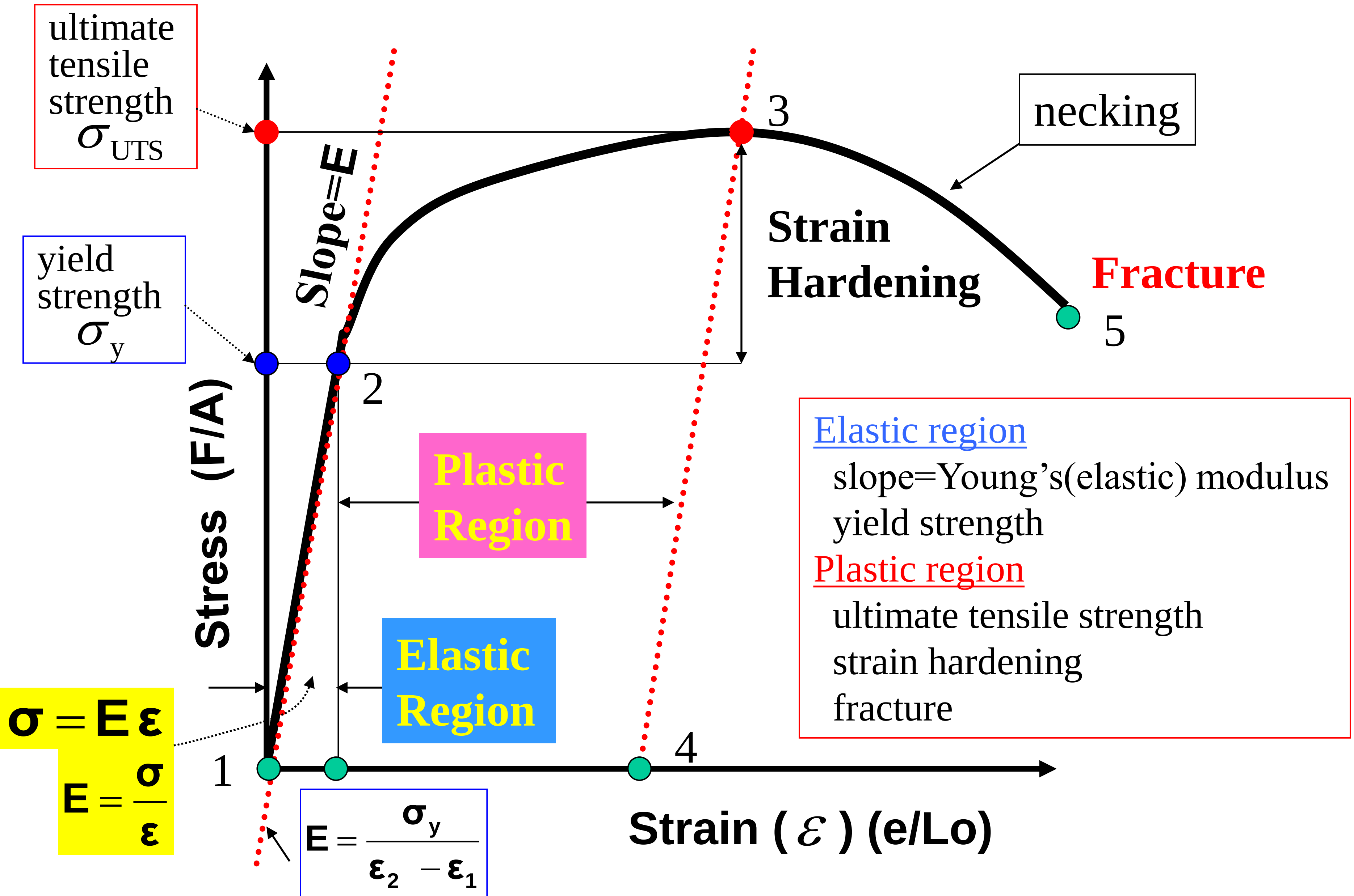
fracture

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

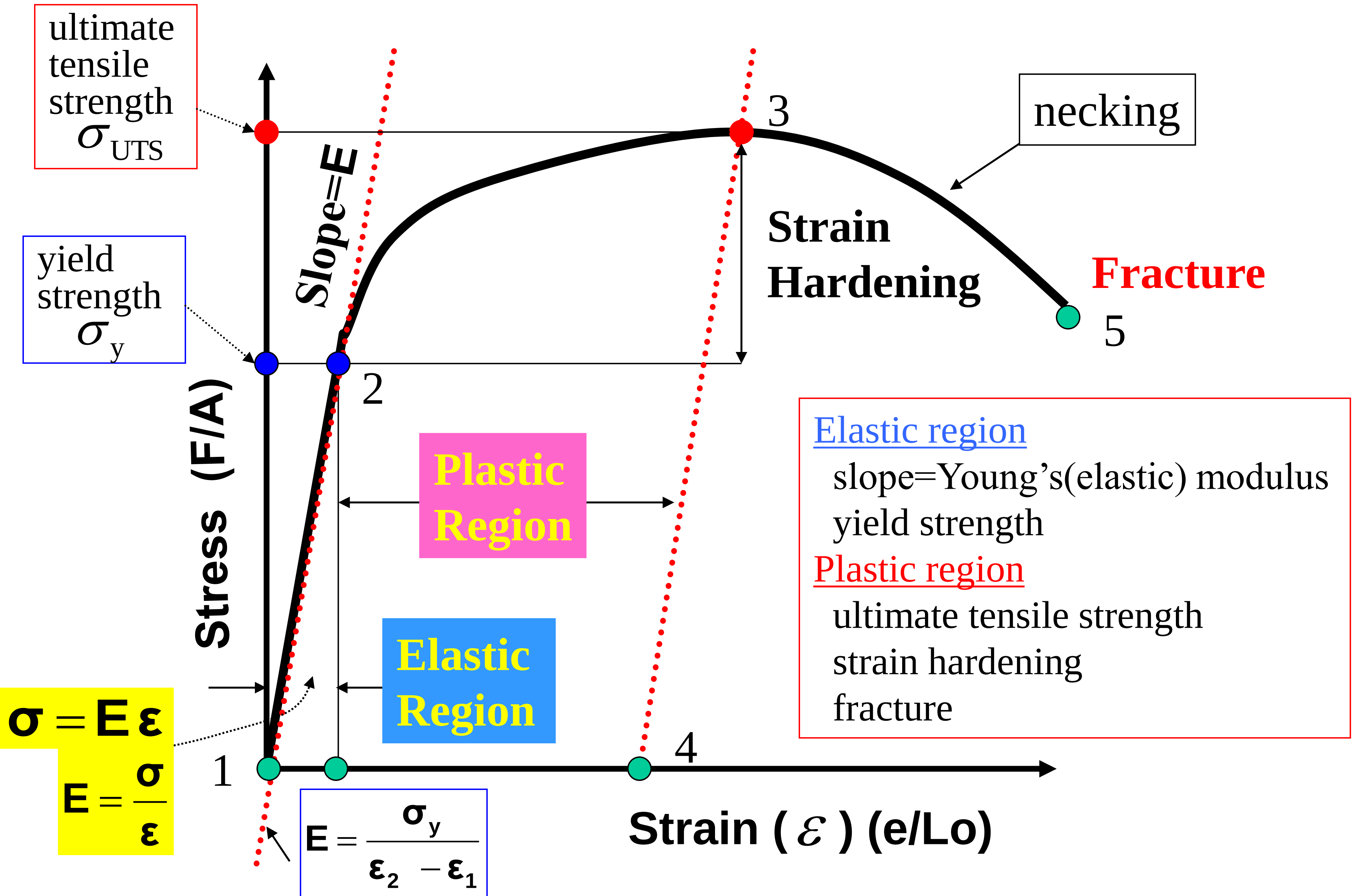
Tensile Strength (Point 3)

- **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.**

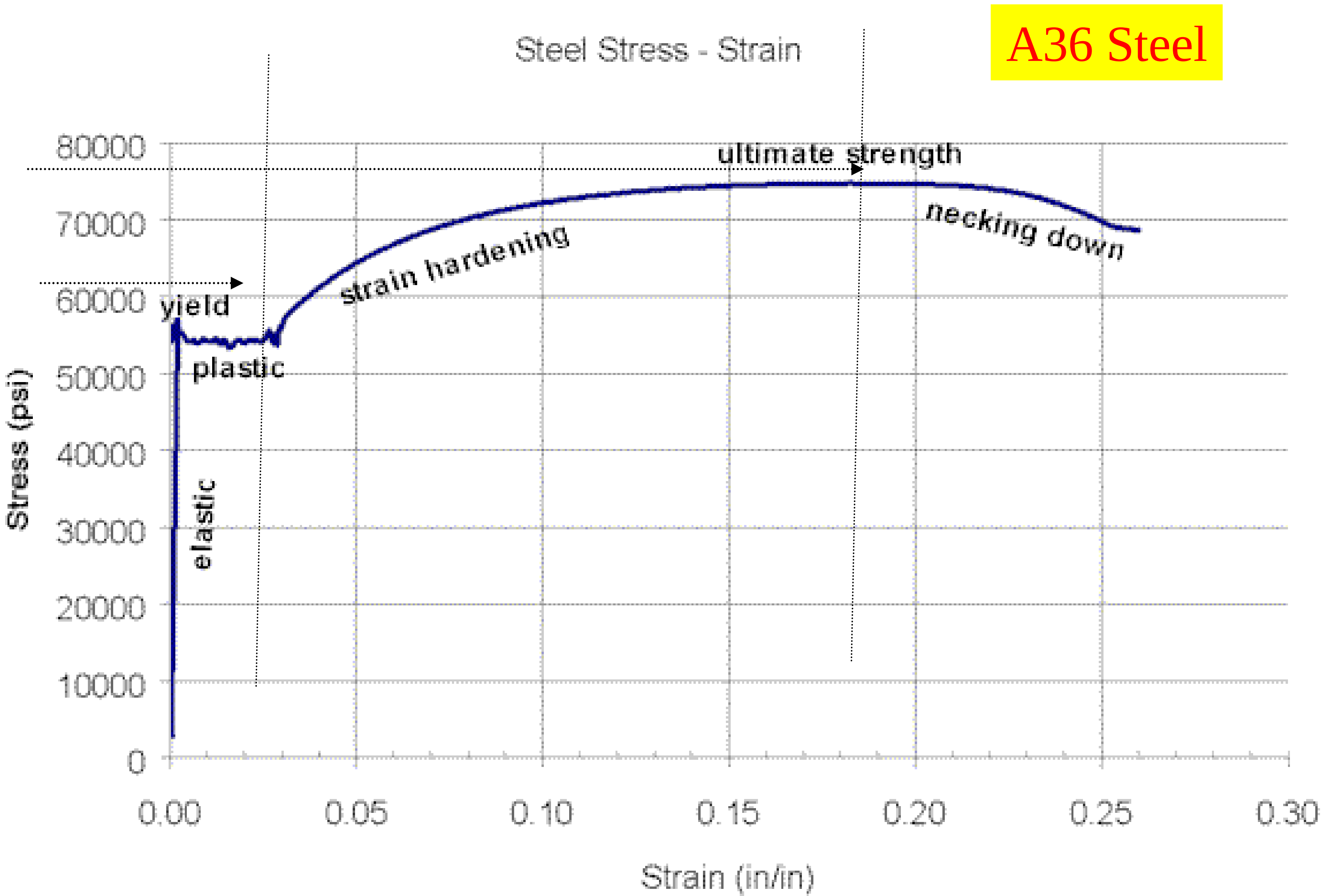
Fracture (Point 5)

- **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



Stress-Strain Diagram



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

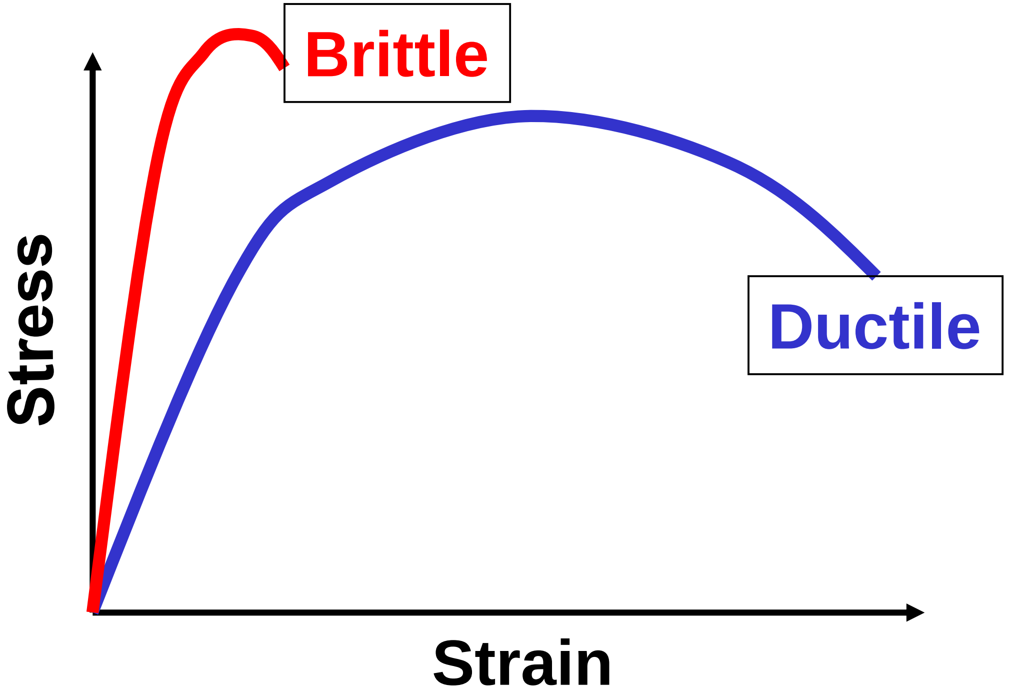
  copper

  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**

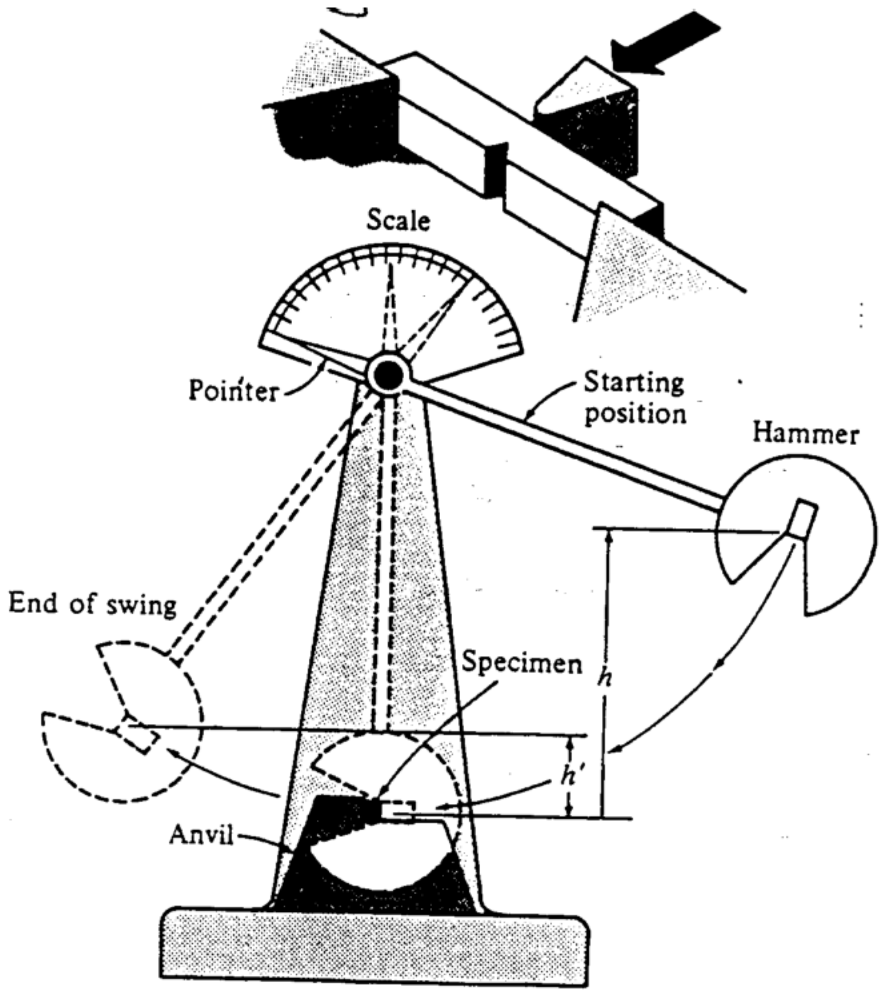
unit : $(lb/in^2) * (in/in) = lb \cdot in/in^3$

b) Charpy test

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

Material Properties

Charpy V-Notch Test:



Material Properties

Charpy V-Notch Test:

- **Charpy test is an impact toughness measurement test because the energy is absorbed by the specimen very rapidly.**

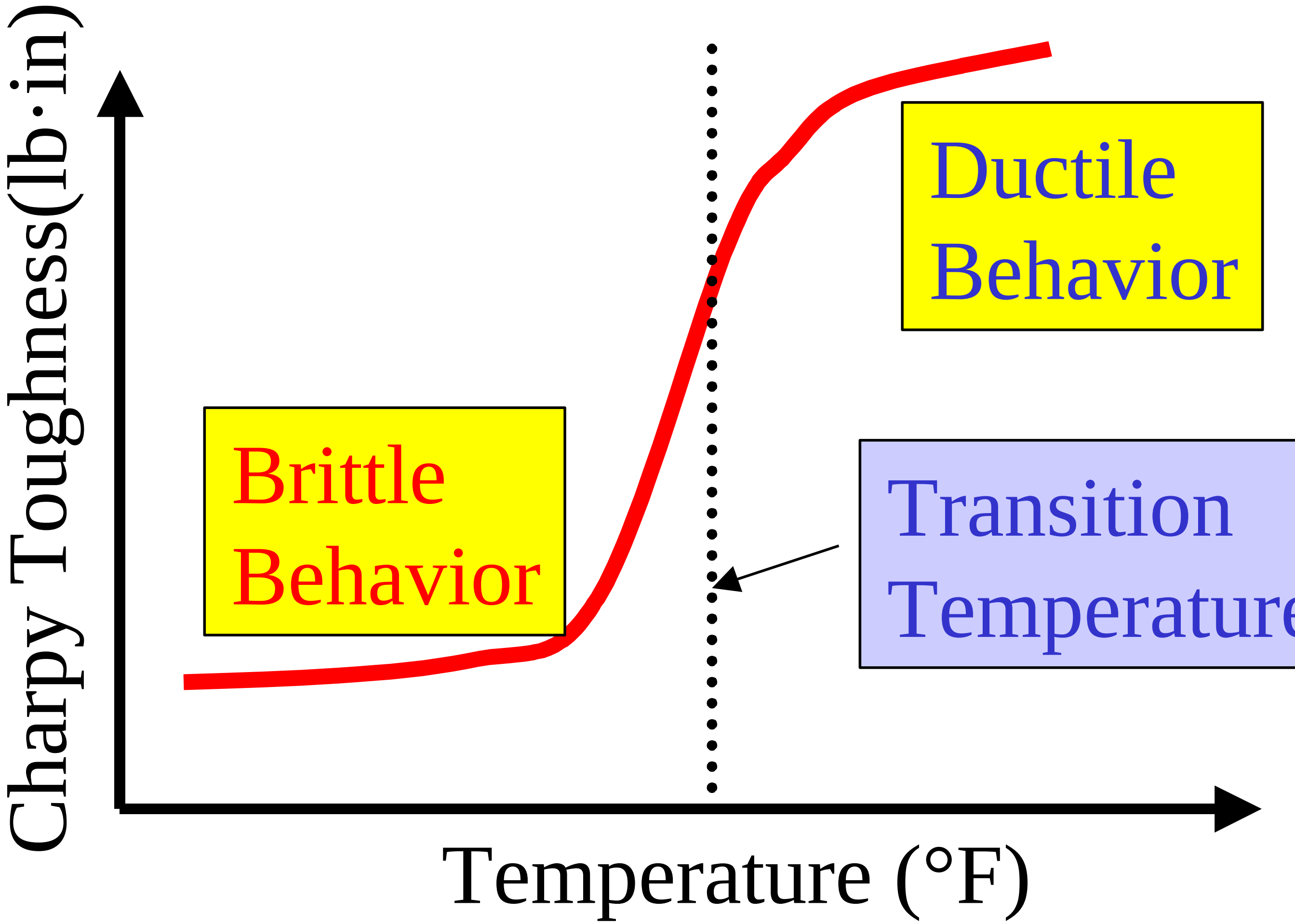
- **The potential energy of the pendulum before and after impact can be calculated form the initial and final location of the pendulum.**

- **The potential energy difference is the energy it took to break the material absorbed during the impact.**

- **Purpose is to evaluate the impact toughness as a function of temperature**

Material Properties

Charpy V-Notch Test:



Material Properties

Charpy V-Notch Test:

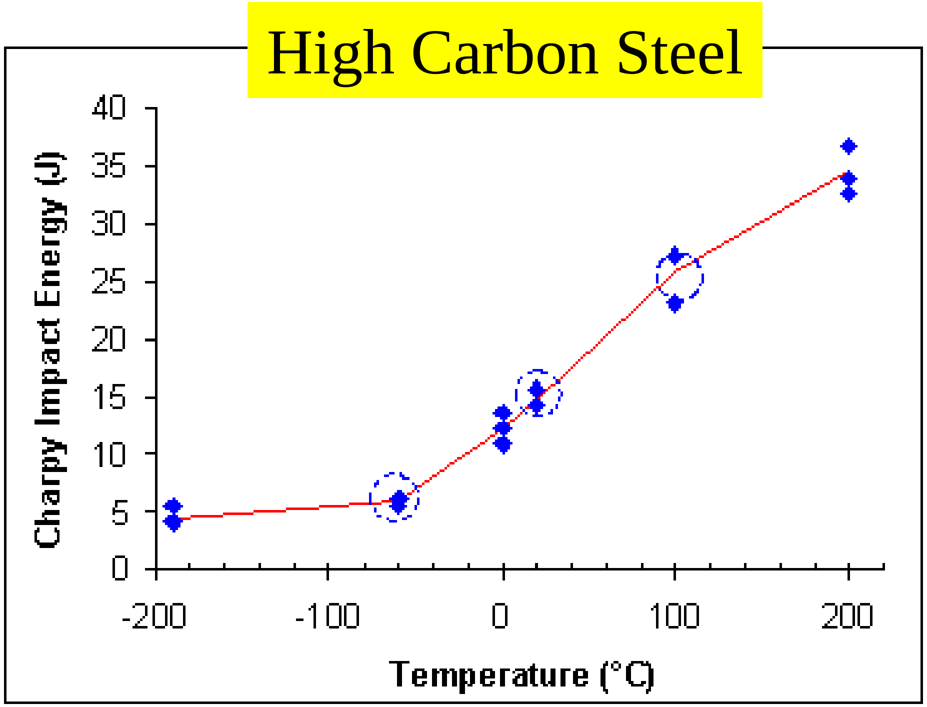
- At low temperature, where the material is brittle and not strong, little energy is required to fracture the material.

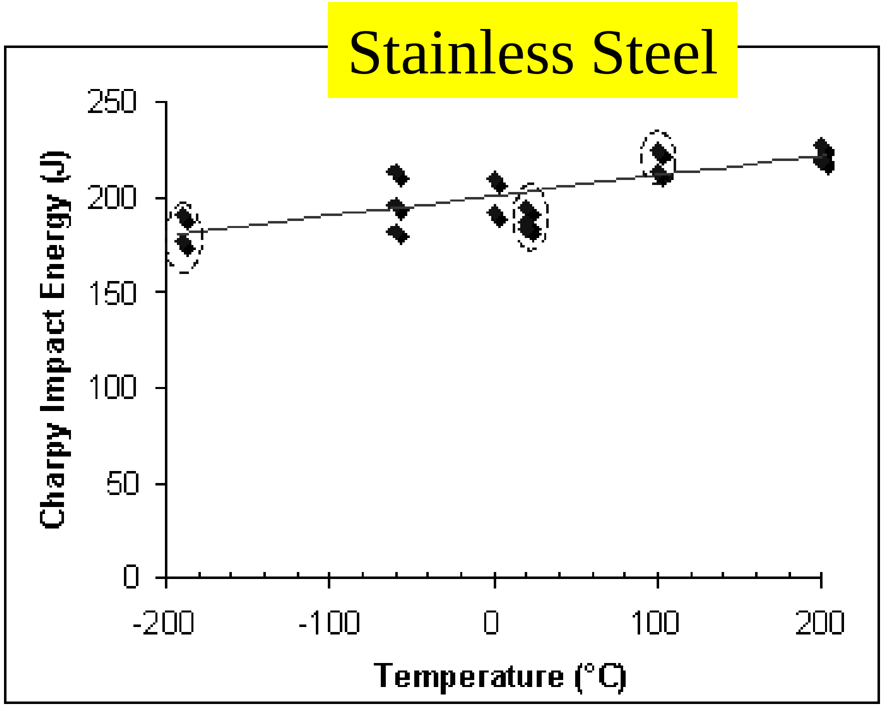
- At high temperature, where the material is more ductile and stronger, greater energy is required to fracture the material

-The transition temperature is the boundary between brittle and ductile behavior.

The transition temperature is an extremely important parameter in selection of construction material.

Charpy V-Notch Test:





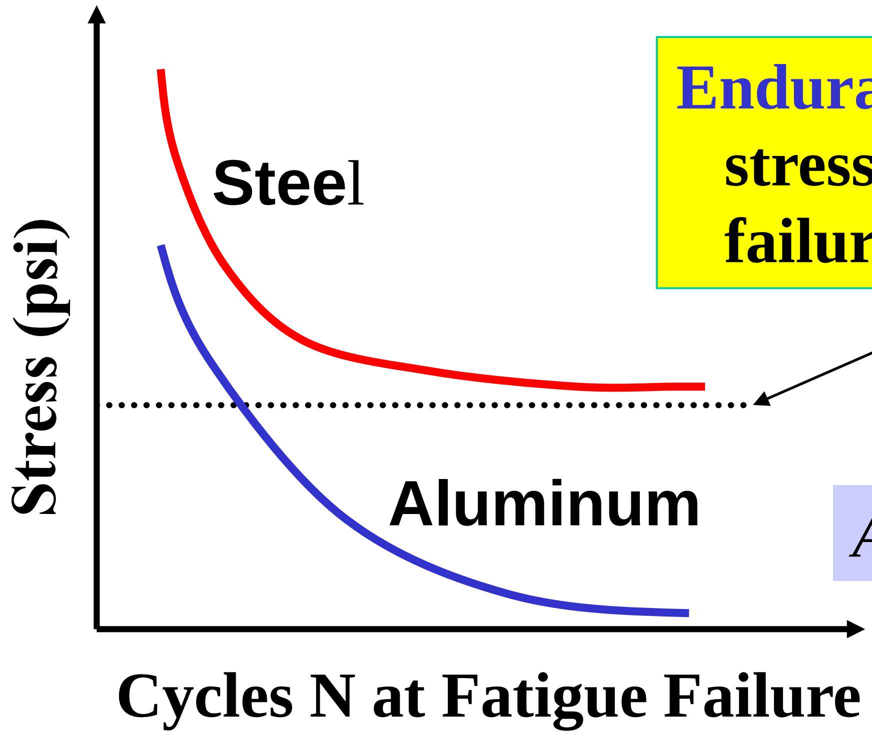
Material Properties

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.

Corrosion & Corrosion Protection

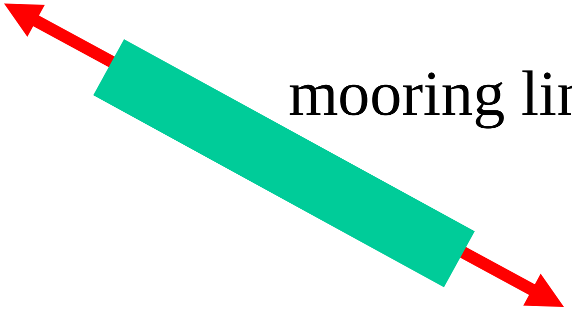
Corrosion is the destruction of metals due to oxidation or other chemical reactions.

Corrosion Protection:

- Design to eliminate conditions favorable to corrosion
- You, a wire brush, and paint
- Cathodic Protection
    - Charging the metal to slow/ stop reaction with other elements
    - Providing a sacrificial metal to give up ions instead of the structure giving up ions (and corroding)

Example:

Mooring line length =100 ft
diameter=1.0 in
Axial loading applied=25,000 lb
Elongation due to loading=1.0 in



1) Find the normal stress.

$$\sigma = \frac{F}{A} = \frac{25{,}000\ \ lb}{0.785\ \ in^2} = 31{,}800\ \ \ psi$$

$$\mathrm{A} = \pi\ \ \mathrm{r}^2 = \pi\,(0.5in)^2 = 0.785\ \ in^2$$

2) Find the strain.

$$\varepsilon = \frac{e}{L_o} = \frac{1in}{100\,ft \times \dfrac{12in}{1\,ft}} = 0.00083\ \ (in/in)$$

Example:

- Salvage crane is lifting an object of 20,000 lb.
- Characteristics of the cable

  diameter=1.0 in, length prior to lifting =50 ft

$\sigma_y = 60{,}000$ psi

$\sigma_{UT} = 70{,}000$ psi

$E = 35 \times 10^6$ psi

1) Find the normal stress in the cable.

$$\sigma = \frac{F}{A} = \frac{20{,}000\ lb}{0.785\ in^2} = 25{,}478\ psi$$

$$(\mathrm{A} = \pi\ \mathrm{r}^2 = \pi (0.5\ in)^2 = 0.785\ in^2)$$

2) Find the strain.

$$\varepsilon = \frac{\sigma}{E} = \frac{25{,}478\ psi}{35 \times 10^6\ psi} = 0.000728\ (in/in)$$

3) Determine the cable stretch in inches.

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

$$e = \varepsilon \times L_o = (0.000728\ in/in) \times (50\ ft \times \frac{12in}{1\,ft}) = 0.44\ in$$