To assure performance, safety, and durability, it's necessary to avoid excess deformation — bending, twisting, stretching — of the components/parts of a structure
→ cracking in components must be avoided entirely (or strictly limited) so that it does not progress to the point of complete fracture

Mechanical Behavior of Materials
the study of deformation and fracture in materials

Most basic concern in design to avoid structural failure is that the stress in a component must not exceed the strength of a material (strength is the stress that causes a deformation or fracture failure)

Additional complexities/particular causes of failure:
- stresses can act in more than one direction; state of stress is bi- or tri-axial
- real components may contain flaws or even cracks that must be specifically considered
- stresses may be applied for long periods of time
- stresses may be repeatedly applied and removed, or the direction of stress repeatedly reversed

TYPES OF MATERIAL FAILURE
* deformation failure is a change in the physical dimensions or shape of a component that is sufficient for its function to be lost or impaired
* fracture is cracking to the extent that a component is separated into two or more pieces

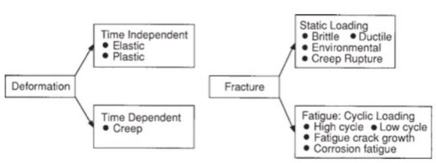
corrosion is the loss of material due to chemical action

wear is surface removal due to abrasion or sticking between solid surfaces that touch

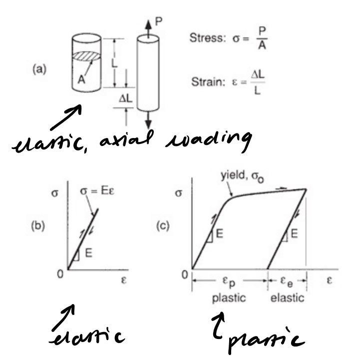
→ if wear is caused by a fluid (gas/liquid) it's called erosion, which is especially likely if the fluid contains hard particles

* focus on these two

Basic Types of Deformation and Fracture



ELASTIC & PLASTIC DEFORMATION
Elastic deformation is recovered immediately upon unloading
→ where this is the only deformation present, stress and strain are usually proportional
→ for axial loading, the constant of proportionality is the elastic modulus, E
→ ex. failure via elastic deformation: tall building that sways in wind but only remote chance of collapse



Plastic deformation is not recovered upon unloading and is therefore permanent
→ once plastic deformation begins, only a small increase in stress usually causes a relatively large additional deformation (called yielding, value of stress where behavior begins called yield strength, σ_o)

Materials capable of sustaining large amounts of plastic deformation are said to behave in a **ductile** manner, and those that fracture without very much plastic deformation behave in a **brittle** manner

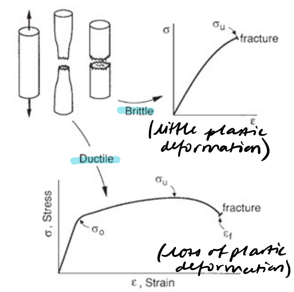
- ductile : metals such as low-strength steels, copper, lead; some plastics like polyethylene
- brittle : glass, stone, acrylic plastic, some metals such as high-strength steels

Tension tests assess strength and ductility of materials

σ_u : ultimate tensile strength (highest stress reached before fracture)

ε_f : strain at fracture (measure of ductility and usually expressed as a percentage, then being called "percent elongation")

→ materials having high values of both σ_u and ε_f are said to be tough (desirable for design)



Large plastic deformations virtually always constitute failure

Buckling is deformation due to compressive stress that causes large changes in alignment of columns or plates, perhaps to the extent of folding/collapse

→ either elastic or plastic or both deformation can dominate behavior

Creep deformation that accumulates w/time

→ deformation may become so large that a component can no longer perform its function

→ virtually any material will creep upon approaching its melting temperature; creep often an important problem where high temp is encountered ex. gas-turbine engines

→ tungsten lightbulb filaments → creep deformation w/sagging of coil

FRACTURE UNDER STATIC & IMPACT LOADING

- rapid fracture can occur under loading that does not vary w/time or that changes only slowly, called **static loading**
  - → if such fracture is accompanied by little plastic deformation, it's called **brittle fracture**
    - normal failure of glass/ceramics/other materials resistant to plastic deform.
- if loading is applied rapidly, called **impact loading**, brittle fracture likely
- if large crack or other sharp flaw present, brittle fracture can occur even in ductile steels or aluminum alloys, or in other materials that are normally capable of deforming plastically by large amounts

Resistance to brittle fracture in the presence of a crack is measured by a material property called the **fracture toughness K_{Ic}**

→ materials w/high strength generally have low fracture toughness, vice versa

Ductile fracture type of fracture accompanied by significant plastic deformation and is sometimes a gradual tearing process

→ important in design of pressure vessels and large welded structures (bridges, ships)

Environmentally assisted cracking (EAC) fracture occurs as a result of a combination of stress and chemical effects ("stress corrosion cracking," SCC also used)

→ low strength steels susceptible in caustic/basic soln such NaOH

Creep rupture creep deformation proceeds to the point that separation into 2 pieces occurs
→ similar to ductile fracture except the process is time-dependent

FATIGUE UNDER CYCLIC LOADING

Fatigue failure due to repeated loading; generally one or more tiny cracks start in the material and these grow until complete failure occurs
- → simple ex: breaking a piece of wire by bending it back and forth a lot
- → important in design of objects subjected to repeated loading/vibration
- → vehicles, trucks over bridges, sailboat rudders

- **high cycle fatigue** when # of repetitions/cycles of load is large (millions)
- **low cycle fatigue** small # of cycles (10s, 100s, 1000s), generally accompanied by significant plastic deformation whereas high cycle fatigue associated w/ small deformations that are primarily elastic

Thermal fatigue repeated heating/cooling causing cyclic stress due to differential thermal expansion and contraction

fatigue crack growth growth of present cracks by fatigue leading to brittle or ductile fracture once the cracks become sufficiently large
→ cracks gradually growing during use of airplane, joining together and forming a large crack that caused a major fracture

COMBINED EFFECTS

Fretting fatigue wear due to small motions between fitted parts combine w/ cyclic loading to produce surface damage followed by cracking
- → can occur where gear is fastened on a shaft by shrink/press fitting
- → can cause failure at surprisingly low stress levels

Corrosion fatigue combination of cyclic loading and corrosion
→ cyclically loaded components of steel that must operate in seawater (oil well)

SAFETY FACTOR

- ratio of the stress that causes failure to the stress expected to occur in actual service

$$X_1 = \frac{\text{stress causing failure}}{\text{stress in service}}$$

→ values of 1.5 to 3.0 are common

- safety factor in stress may need to be supplemented by safety factors in life

$$X_2 = \frac{\text{failure life}}{\text{desired service life}}$$

→ ex. helicopter part to fail in 10 yrs and replaced in 2 yrs then $X_2 = 5$

Load factor design (allowable stress design) the loads (forces, moments, torque, etc) expected in service are multiplied by a <u>load factor</u> Y ... corresponds to failure condition

$$(\text{load in service}) \times Y = \text{load causing failure}$$