ETME 3210 Maintenance of Mechatronics Systems

Introduction to Materials in Maintenance and Destructive Testing of Materials

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Types of Materials

- There are four main types of materials:
  - **Metals:** have a crystalline structure, can be pure or in alloy form, can be ferrous or non-ferrous.
  - **Polymers:** long chains or networks of molecules usually non-crystalline, usually have organic content. Examples: plastics and elastomers
  - **Ceramics:** inorganic, chemically bonded metals and nonmetals. Usually brittle, high strength with and light weight. Examples: alumina, silicon carbide, and silicon nitride
  - **Composites:** the integration of two or more materials together (not mixed), one material is a filler (reinforcement), the other is a matrix (resin) material. Can have very high strengths with very low densities. Example: carbon fibers in epoxy matrix.

Why study material properties?

Heydar Aliyev Cultural Center in Azerbaijan,

Source: www.architectmagazine.com

Gateway Arch in St. Louis

Source: Wimimedia Commons

Beluga aircraft

Source:

Wikimedia Commons

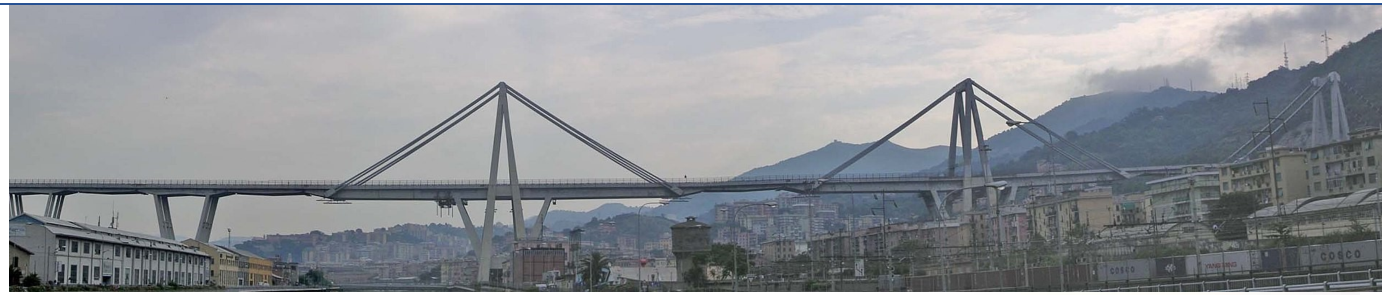
Burj Khalifa, Dubai, UAE

Source: Wimimedia Commons

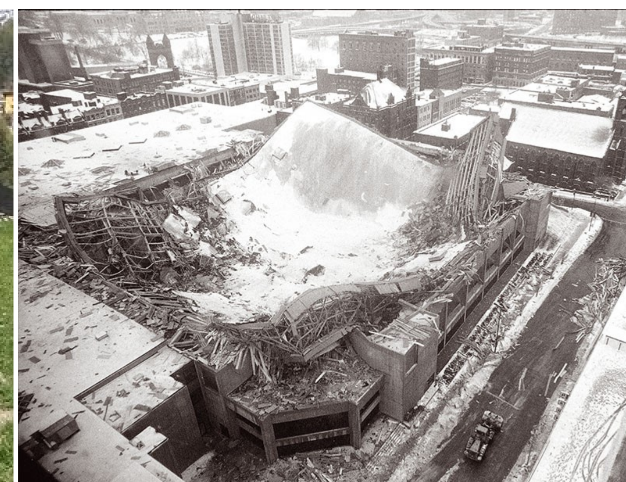
Examples of Structural Failures

Collapse of Ponte Morandi in 08/2018 due to corrosion in steel cables.

Source: www.ilfattoquotidiano.it



Source: Daily Mail, published April 24, 2014



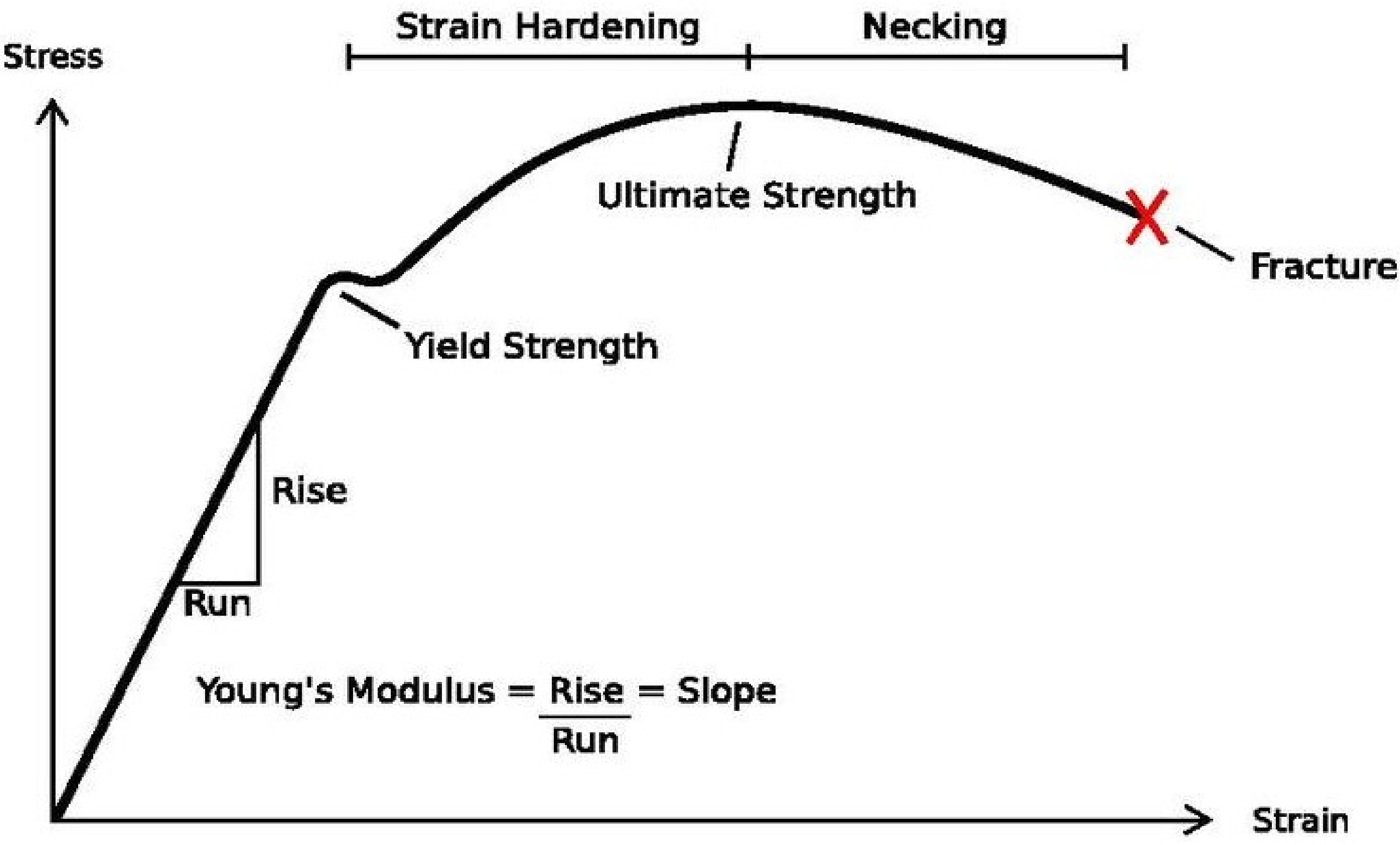
Hartford stadium collapse, 1971

Source: The Structural Engineer, Aug 2015.

Stress versus Strain

- **Stress:** the force applied over a unit area.
- When materials are subjected to a stress, say a tensile stress, they exhibit a linear elongation up to a certain point.
- The linear elongation is accompanied by thinning of the cross section.
- **Strain:** a measure of the elongation of a material
- **Ultimate strength:** the peak of the stress-strain curve, after which the cross section becomes very thin, and fracture occurs afterwards.

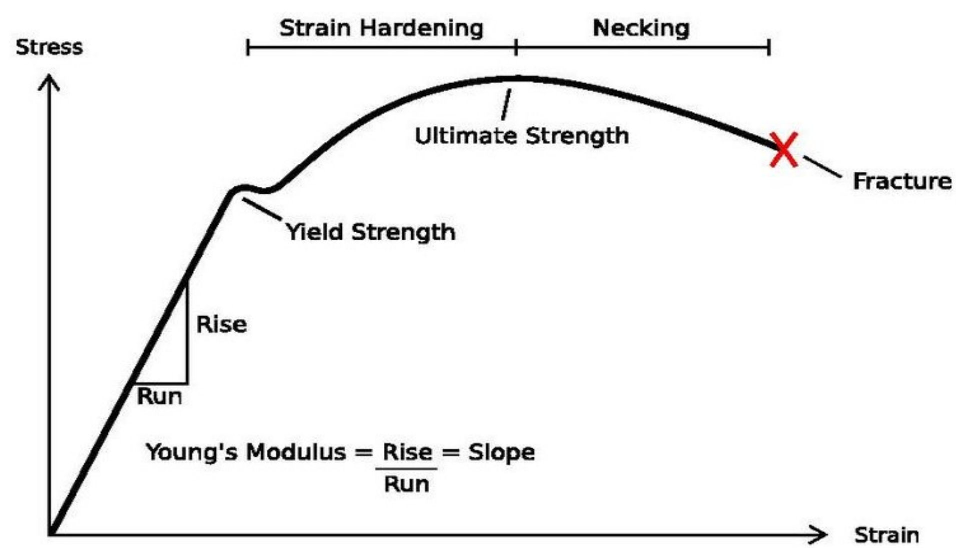
Stress versus Strain



Stress versus Strain

- **Elastic Limit:** the point below which the material elongation is considered elastic, i.e. the material retains its original shape after stress is gone.
- **Tensile Modulus of elasticity (E):** the slope of the line in the elastic region. When the stress is tensile, the modulus of elasticity is called "Young's modulus".

$$E = \frac{Stress}{Strain} = \frac{\sigma}{\epsilon}$$



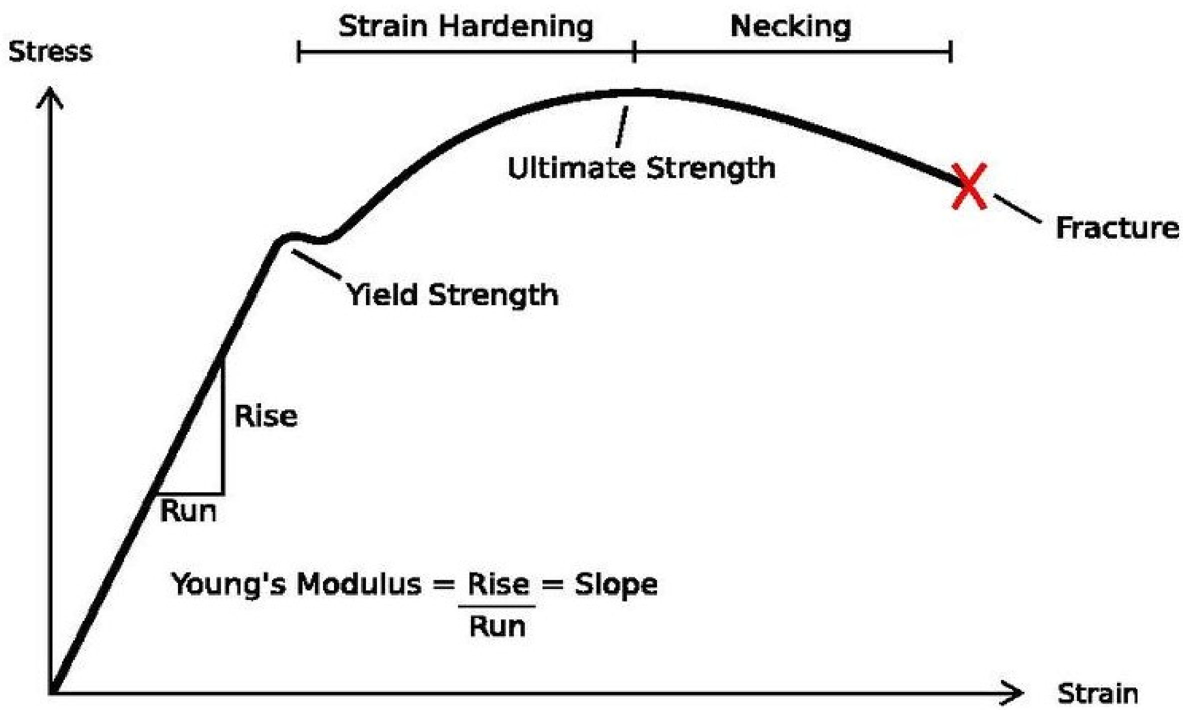
Tensile stress vs. strain test:

https://www.youtube.com/watch?v=67fSwIjYJ-E

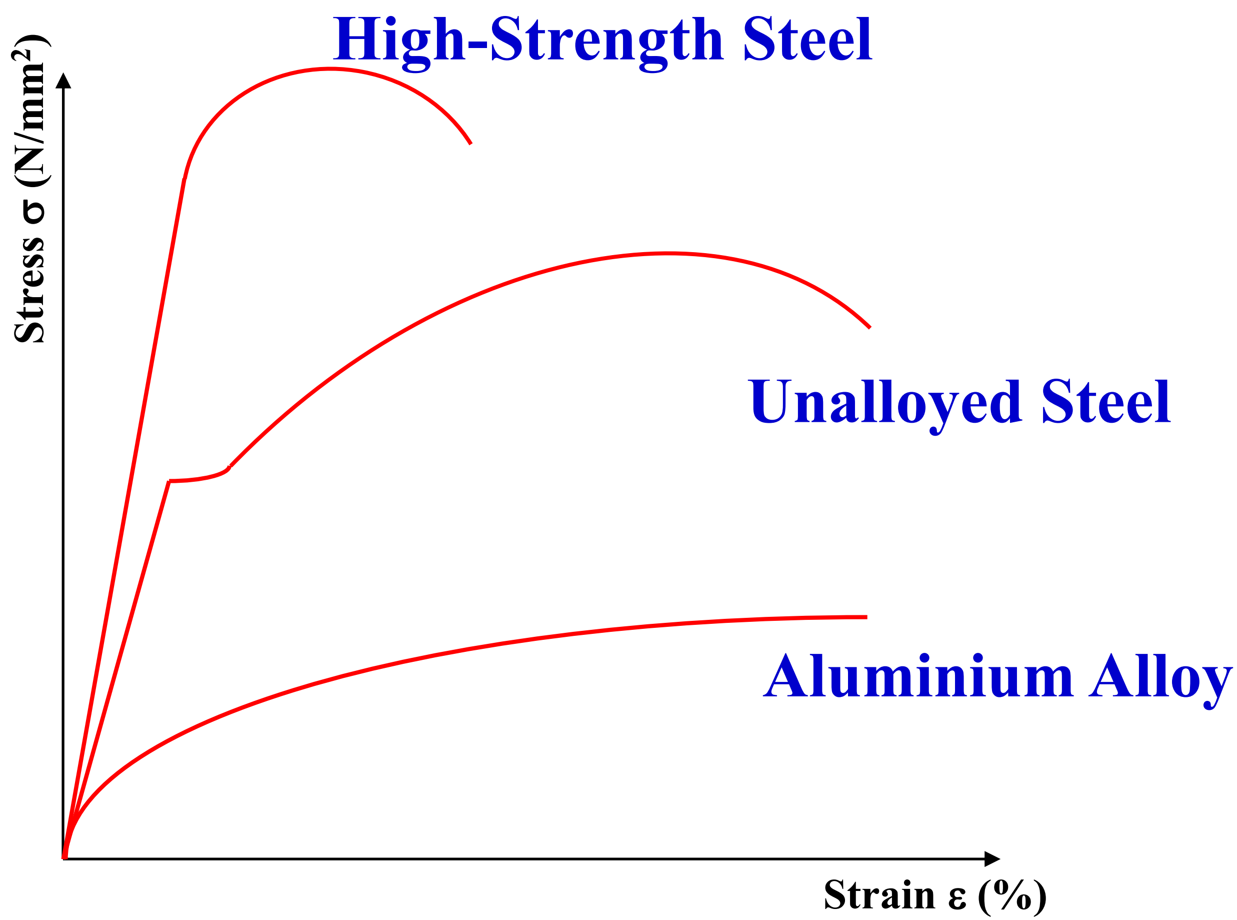
Stress versus Strain

- **Shear Modulus of Elasticity (G):** this is the modulus when the material is subjected to a shear stress.
- **Poisson's Ratio :** the ratio between the shortening strain and the tensile strain.

$$G = \frac{E}{2(1+\nu)}$$



Stress Vs Strain for Steel

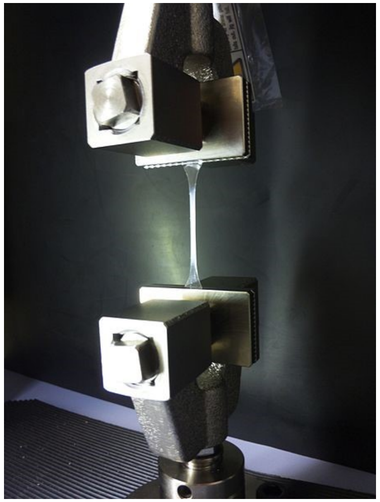


Tensile Tests

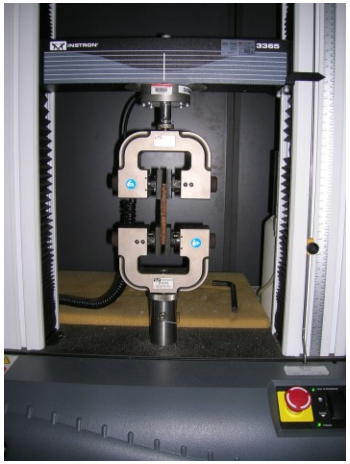
- https://www.youtube.com/watch?v=67fSwIjYJ-E

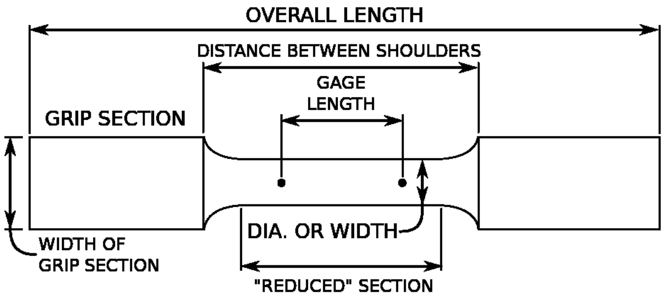
Cast Iron tensile test

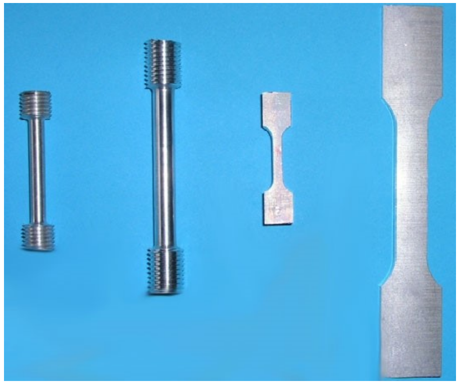
Aluminum tensile test



Polymer tensile test





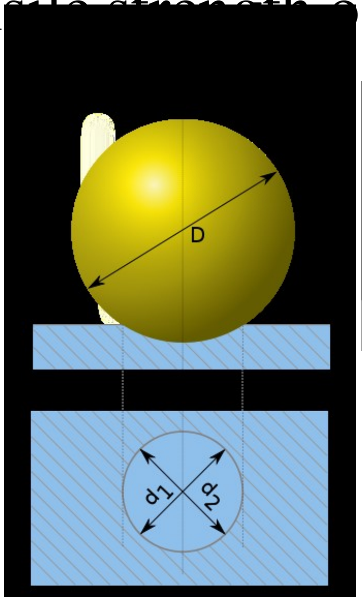


Material	Yield strength (MPa)	Ultimate tensile strength (MPa)	Density (g/cm^3)
Steel, structural ASTM A36 steel	250	400-550	7.8
Steel, 1090 mild	247	841	7.58
Human skin	15	20	2
Aluminium alloy 6061-T6	241	300	2.7
Copper	70	220	8.92
Brass	200 +	550	8.73
Tungsten	941	1510	19.25
Glass		33	2.53

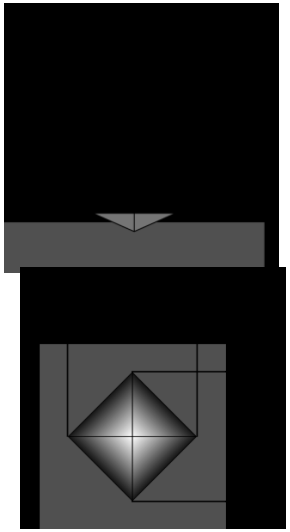
Hardness of a Material

- **Hardness:** Resistance of a material to indentation by a penetrating object.
- **Common hardness tests:**
  - **Brinnell Hardness Test**
  - **Rockwell Hardness Test**
  - **Vickers Hardness Test**
- Hardness numbers are proportional to the tensile strength of the material.

https://www.youtube.com/watch?v=RJXJpeH78iU



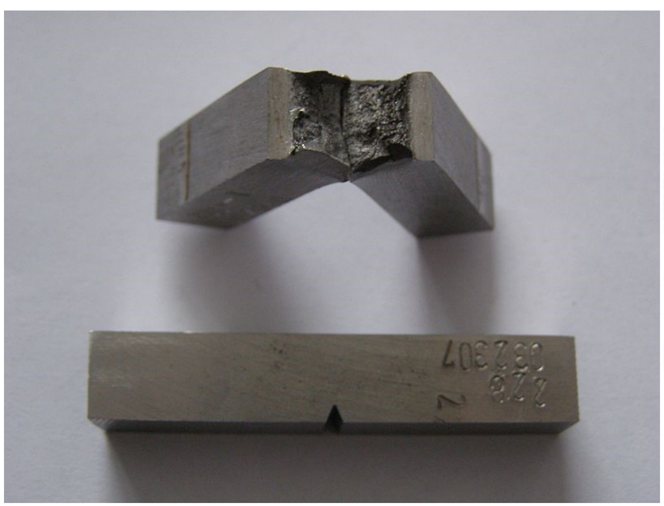
Brinell Test

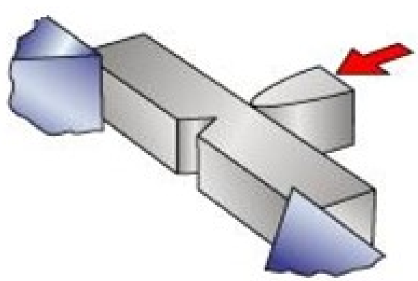


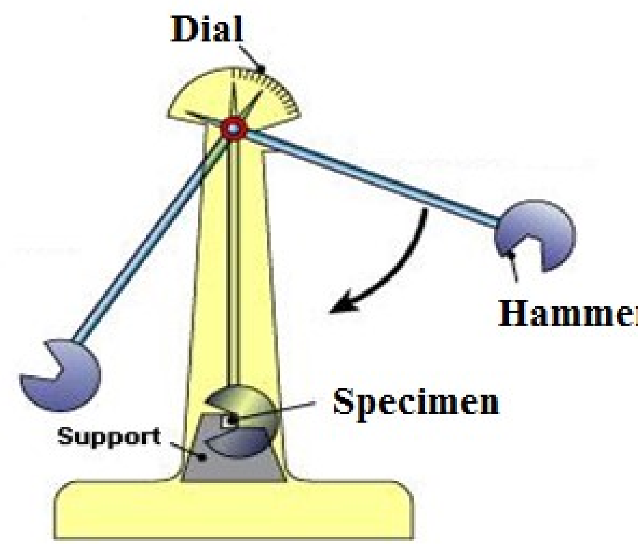
Vickers Test

Toughness and Impact Loads

- **Impact Load**: an external load that is applied to a structure for a time duration that does not exceed one third of the structure's natural time period. Otherwise, it is called a **static load.**
- **Toughness of Materials:** ability of the material to absorb energy before fracture.
- One test that is used to measure impact strength is the **Charpy Test.**
- This test can be used to indicate the brittleness of materials
- https://www.youtube.com/watch?v=tpGhqQvftAo
- Vehicle bodies are made to be tough but not very strong to protect lives: https://www.youtube.com/watch?v=xtxd27jlZ_g







Creep in Materials

- The progressive elongation that results due to a constant high load for a long period of time.
- The load does not have to exceed the yield strength at the normal operating temperature of the material for creep to happen.
- Creep should be considered for loads operating at high temperatures. The yield strength of materials drops as temperature increases.
- Creep experiment:
- https://www.youtube.com/watch?v=kcEej2oj6sA

Fatigue

- Fatigue: a cyclic load that changes with time.
- The fatigue load can be higher than the yield impact energy
- Fatigue strength or endurance strength.
- Fatigue Tests:
- https://www.youtube.com/watch?v=LhUclxBUV_E

Fatigue fracture surface
Source: Wikimedia Commons

Fatigue fracture
Source: Wikimedia Commons

Summary of Mechanical Properties of Materials

- Young's modulus of elasticity (Stiffness)
- Poisson's ratio of the material
- Yield strength
- Ultimate tensile strength
- Elasticity and Plasticity
- Toughness
- Ductility and brittleness
- Hardness
- Creep
- Fatigue strength

Physical Properties of Materials

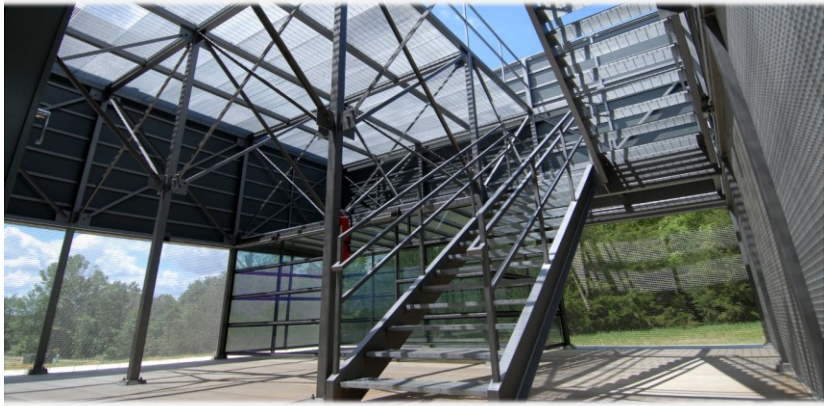
- Physical properties
  - Density: mass/volume
  - Coefficient of thermal expansion: the ratio of the change in length to the change in temperature.
  - Thermal conductivity
  - Electrical resistivity

Summary of Destructive Tests

- All the material property tests that were shown in these slides result in the destruction of the integrity of the structure of the specimen being tested. In summary we saw:
  - Tensile Stress-Strain test
  - Hardness tests: (Brinnel, Rockwell, and Vickers tests)
  - Impact test (Charpy test)
  - Crash tests
  - Creep test
  - Fatigue test

Metals and Alloys

- Metals for Commercially Available Shapes
  - I-beam shapes
  - Hollow tubing: round, pipe, square, rectangular



Metals in Manufacturing

- Some of the most commonly used metals include:
- Steel
- Aluminum
- Copper and Copper alloys:
  - Copper: very good conductor, used in wires, rarely used in manufacturing. Why?
  - Brass: An alloy of copper and zinc, has excellent corrosion resistance.
  - Bronze: good strength and excellent corrosion resistance.

Carbon and Alloy Steel

- Steel
  - Used for machine elements; high strength, high stiffness, durability, relative ease of fabrication
  - Alloy of iron, carbon, manganese, one or more significant elements
  - Designation systems for steels managed by SAE International or ASTM International

TABLE 2–8 Alloy Groups in the SAE Numbering System

10xx	Plain carbon steel: No significant alloying element except carbon and manganese; less than 1.0% manganese. Also called *nonresulfurized.*
11xx	Free-cutting steel: Resulfurized. Sulfur content (typically 0.10%) improves machinability.
12xx	Free-cutting steel: Resulfurized and rephosphorized. Presence of increased sulfur and phosphorus improves machinability and surface finish.
12Lxx	Free-cutting steel: Lead added to 12xx steel further improves machinability.
13xx	Manganese steel: Nonresulfurized. Presence of approximately 1.75% manganese increases hardenability.
15xx	Carbon steel: Nonresulfurized; greater than 1.0% manganese.
23xx	Nickel steel: Nominally 3.5% nickel.
25xx	Nickel steel: Nominally 5.0% nickel.
31xx	Nickel-chromium steel: Nominally 1.25% Ni; 0.65% Cr.
33xx	Nickel-chromium steel: Nominally 3.5% Ni; 1.5% Cr.
40xx	Molybdenum steel: 0.25% Mo.
41xx	Chromium-molybdenum steel: 0.95% Cr; 0.2% Mo.
43xx	Nickel-chromium-molybdenum steel: 1.8% Ni; 0.5% or 0.8% Cr; 0.25% Mo.
44xx	Molybdenum steel: 0.5% Mo.
46xx	Nickel-molybdenum steel: 1.8% Ni; 0.25% Mo.
48xx	Nickel-molybdenum steel: 3.5% Ni; 0.25% Mo.
5xxx	Chromium steel: 0.4% Cr.
51xx	Chromium steel: Nominally 0.8% Cr.
51100	Chromium steel: Nominally 1.0% Cr; bearing steel, 1.0% C.
52100	Chromium steel: Nominally 1.45% Cr; bearing steel, 1.0% C.
61xx	Chromium-vanadium steel: 0.50–1.10% Cr; 0.15% V.
86xx	Nickel-chromium-molybdenum steel: 0.55% Ni; 0.5% Cr; 0.20% Mo.
87xx	Nickel-chromium-molybdenum steel: 0.55% Ni; 0.5% Cr; 0.25% Mo.
92xx	Silicon steel: 2.0% silicon.
93xx	Nickel-chromium-molybdenum steel: 3.25% Ni; 1.2% Cr; 0.12% Mo.

Carbon and Alloy Steel

- Steel Classes
  - Low carbon steel: Carbon <0.30%
  - Medium carbon steel: Carbon ~ 0.30-0.50%
  - High carbon steel: 0.50 – 0.95%
  - Bearing steel: Carbon > 1.0 %
- Alloy Groups:
  - Sulfur, phosphorus: improve machinability.
  - Nickel: improves ductility and corrosion resistance.
  - Chromium: improves hardenability, wear abrasion resistance.

SAE Designations for Steel

- SAE XXXX

Carbon content in hundredths of a percentage point

Alloy group and Major alloying element

Conditions for Steels and Heat Treatment

- Heat Treating
  - Annealing
  - Normalizing
  - Through-hardening and quenching and tempering
  - Case hardening

Types of Steels

- **Stainless Steel**
  - High level of corrosion resistance; alloy chromium content of at least 10%
  - The stainless steel series’ are 100 to 600
  - The 304 and 316 families are the most common, non (or mildly)-magnetic, highly resistant to corrosion.
  - The 300 series has austenitic structure high content of chrome and nickel
  - The 400 series is magnetic and have ferritic and martensitic structure.




Question

- **How to distinguish between galvanized steel, stainless steel, and aluminum?**
  - **The magnet test:** if the magnet sticks to the metal then it is certainly not aluminum. (but it can be steel or of some grades of stainless steel)
  - **The density test:** steel is three times as dense as aluminum. If the object feels light, it is aluminum.
  - **The rust test:** Rust can develop on stainless steel at edges and corners, but rust never develops on aluminum.
  - **The scratch test:** Aluminum is not as hard as steel. It is a lot easier to scratch aluminum and the zinc coating layer than to scratch stainless steel. (this test is not recommended)

Types of Steels

- Structural Steel
  - Low-carbon, hot-rolled steel, very ductile to absorb energy and stand earthquackes.
- Tool Steels
  - Used for cutting tools, punches, dies, shearing blades, chisels, similar uses
- Cast Iron
  - High strength in compression, generally brittle. Large gears, machine structures, brackets, linkage parts, important machine parts.

Aluminum

- Aluminum
  - Light weight, good corrosion resistance, relative ease of forming and machining, pleasing appearance

Polymers

- Polymers are macromolecules that consist of a large number of molecules bonded together (poly molecules).
- Examples include:
  - Wood
  - Plastic
  - Waxes

Ceramics

- Inorganic, chemically bonded metals and nonmetals. Ceramics are known for their brittleness and light weight.
- Examples:
  - Porcelain
  - Glasses
  - Clay

Composite Materials

- Composites
  - Materials having two or more constituents blended in such a way that results in bonding between the materials
  - Examples: Reinforced concrete, carbon fibers, and plywood.

TABLE 2–16 Examples of Composite Materials and their Uses

Type of composite	Typical applications
Glass/epoxy	Automotive and aircraft parts, tanks, sporting goods, printed wiring boards
Boron/epoxy	Aircraft structures and stabilizers, sporting goods
Graphite/epoxy	Aircraft and spacecraft structures, sporting goods, agricultural equipment, material handling devices, medical devices
Aramid/epoxy	Filament-wound pressure vessels, aerospace structures and equipment, protective clothing, automotive components
Glass/polyester	Sheet-molding compound (SMC), body panels for trucks and cars, large housings

Composite Materials

- Composites
  - Polymer Matrix Composites (PMC)
  - Metal Matrix Composites (MMC)
  - Ceramic Matrix Composites (CMC)