# BFF1113
# Engineering Materials

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# Course Guidelines:

1. Introduction to Engineering Materials
2. Bonding and Properties
3. Crystal Structures & Properties
4. Imperfection in Solids
5. Mechanical Properties of Materials
6. Physical Properties of Materials
7. Failure & Fundamental of Fracture
8. Metal Alloys
9. Phase Diagram
10. Phase Transformation – Heat Treatment
11. Processing and Application of Metals
12. Ceramic Materials
13. Polymer Materials
14. Composite Materials
15. Corrosion & Degradation of Materials
16. Environment and Sustainability

# PHYSICAL PROPERTIES OF MATERIALS

1. Density
2. Melting Point
3. Thermal properties
4. Electrical Properties
5. Magnetic properties
6. Optical Properties

# Introduction

- Important criterion in material selection is consideration of **physical properties,** including**:**

  1. Density
  2. Melting point
  3. Thermal properties
  4. Electrical properties
  5. Magnetic properties
  6. Optical properties

# 1.0: Density

- **Density** of a material is its mass per unit volume
- **Specific gravity** is expresses as a material's density in relation to that of water (1 g/$cm^3$) We would need to have **strength-to-weight ratio** (**specific strength**) and **stiffness-to-weight ratio** (**specific stiffness**) of materials and structures
- Weight saving is important to aircraft and aerospace structures

VIDEO - DENSITY

# Density

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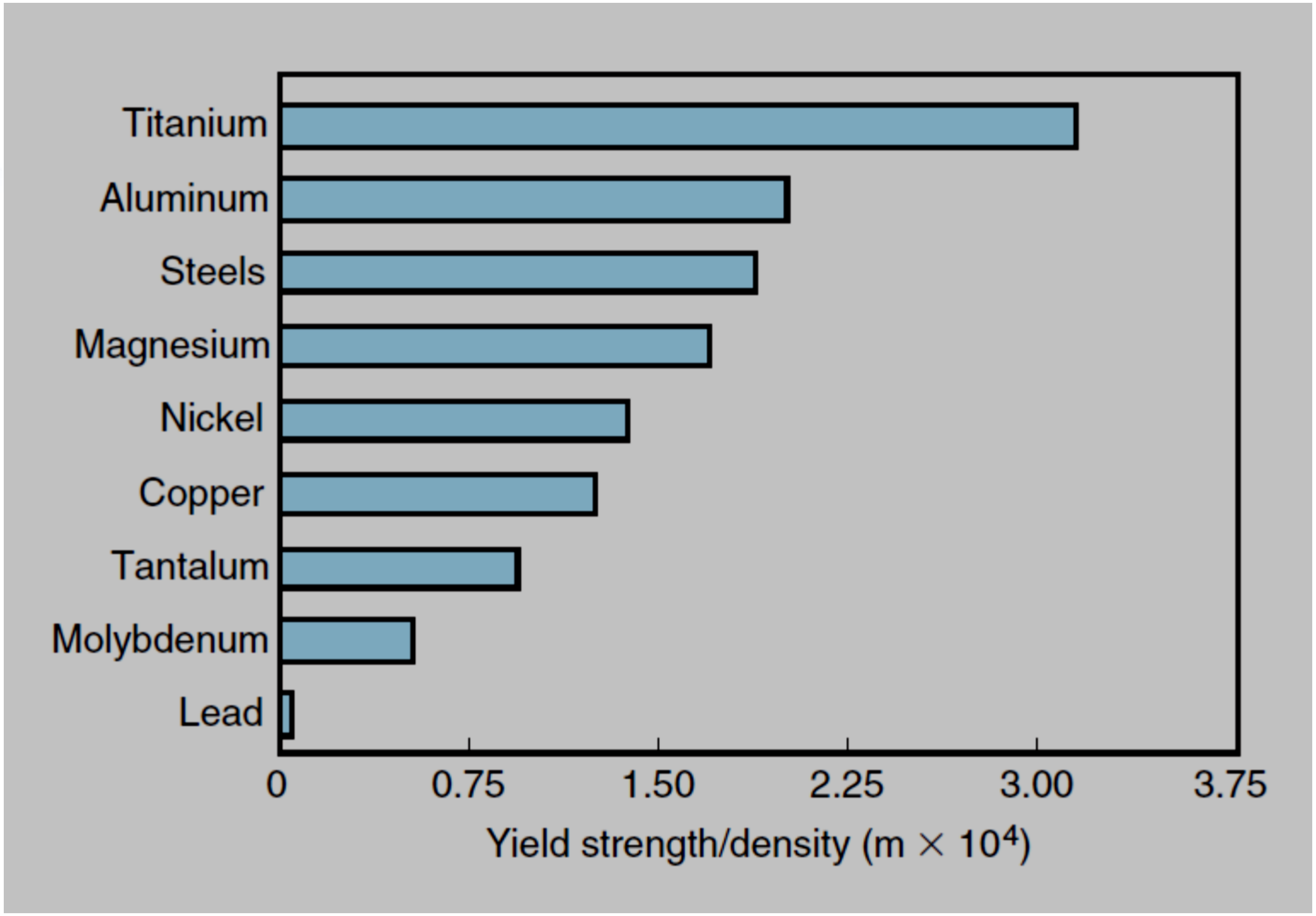
**Physical Properties of Selected Materials at Room Temperature**

| | Density ($kg/m^3$) | Melting point (°C) | Specific heat (J/kg K) | Thermal conductivity (W/m K) | Coefficient of thermal expansion ($\mu$m/m-°C) | Electrical resistivity (Ω-m) |
|---|---|---|---|---|---|---|
| **Metallic** | | | | | | |
| Aluminum | 2700 | 660 | 900 | 222 | 23.6 | $2.8 \times 10^{-8}$ |
| Aluminum alloys | 2630–2820 | 476–654 | 880–920 | 121–239 | 23.0–23.6 | $2.8-4.0 \times 10^{-8}$ |
| Beryllium | 1854 | 1278 | 1884 | 146 | 8.5 | $4.0 \times 10^{-8}$ |
| Columbium (niobium) | 8580 | 2468 | 272 | 52 | 7.1 | $15 \times 10^{-8}$ |
| Copper | 8970 | 1082 | 385 | 393 | 16.5 | $1.7 \times 10^{-8}$ |
| Copper alloys | 7470–8940 | 885–1260 | 377–435 | 29–234 | 16.5–20 | $1.7-5.9 \times 10^{-8}$ |
| Gold | 19,300 | 1063 | 129 | 317 | 19.3 | $2.4 \times 10^{-8}$ |
| Iron | 7860 | 1537 | 460 | 74 | 11.5 | $9.5 \times 10^{-8}$ |
| Steels | 6920–9130 | 1371–1532 | 448–502 | 15–52 | 11.7–17.3 | $17.0 \times 10^{-8}$ |
| Lead | 11,350 | 327 | 130 | 35 | 29.4 | $20.6 \times 10^{-8}$ |
| Lead alloys | 8850–11,350 | 182–326 | 126–188 | 24–46 | 27.1–31.1 | $20.6-24 \times 10^{-8}$ |
| Magnesium | 1745 | 650 | 1025 | 154 | 26.0 | $4.5 \times 10^{-8}$ |
| Magnesium alloys | 1770–1780 | 610–621 | 1046 | 75–138 | 26.0 | $4.5-15.9 \times 10^{-8}$ |
| Molybdenum alloys | 10,210 | 2610 | 276 | 142 | 5.1 | $5.3 \times 10^{-8}$ |
| Nickel | 8910 | 1453 | 440 | 92 | 13.3 | $6.2 \times 10^{-8}$ |
| Nickel alloys | 7750–8850 | 1110–1454 | 381–544 | 12–63 | 12.7–18.4 | $6.2-110 \times 10^{-8}$ |
| Silicon | 2330 | 1423 | 712 | 148 | 7.63 | $1.0 \times 10^{-3}$ |
| Silver | 10,500 | 961 | 235 | 429 | 19.3 | $1.6 \times 10^{-8}$ |
| Tantalum alloys | 16,600 | 2996 | 142 | 54 | 6.5 | $13.5 \times 10^{-8}$ |
| Titanium | 4510 | 1668 | 519 | 17 | 8.35 | $42 \times 10^{-8}$ |
| Titanium alloys | 4430–4700 | 1549–1649 | 502–544 | 8–12 | 8.1–9.5 | $40-171 \times 10^{-8}$ |
| Tungsten | 19,290 | 3410 | 138 | 166 | 4.5 | $5 \times 10^{-8}$ |
| Zinc | 7140 | 419 | 385 | 113 | 32.5 | $5.45 \times 10^{-8}$ |
| Zinc alloys | 6640–7200 | 386–525 | 402 | 105–113 | 32.5–35 | $6.06-6.89 \times 10^{-8}$ |
| **Nonmetallic** | | | | | | |
| Ceramics | 2300–5500 | — | 750–950 | 10–17 | 5.5–13.5 | — |
| Glasses | 2400–2700 | 580–1540 | 500–850 | 0.6–1.7 | 4.6–70 | — |
| Graphite | 1900–2200 | — | 840 | 5–10 | 7.86 | — |
| Plastics | 900–2000 | 110–330 | 1000–2000 | 0.1–0.4 | 72–200 | — |
| Wood | 400–700 | — | 2400–2800 | 0.1–0.4 | 2–60 | — |

# Density


Titanium
Aluminum
Steels
Magnesium
Nickel
Copper
Tantalum
Molybdenum
Lead
0
0.75
1.50
2.25
3.00
3.75
Yield strength/density (m × 10⁴)

# 2.0: Melting Point

- **Melting point** of a material depends on the energy required to separate its atoms
- Annealing, heat treating and hot-working require a knowledge of the melting points of the materials involved
- Higher the melting point of the material, the more difficult the operation becomes

VIDEO – MELTING POINT

# 3.0: Thermal properties

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- **Thermal conductivity** is the rate at which heat flows within and through a material

- **Thermal expansion** is the tendency of matter to change in volume in response to a change in temperature, through heat transfer.
  - Solid materials expand when heated and contract when cooled.
  - The fractional change in length, area or volume is proportional to the temperature change, the constant of proportionality being the coefficient of thermal expansion.
  - The coefficient of thermal expansion describes how the size of an object changes with a change in temperature. The larger the interatomic bonding energy, the lower the coefficient of thermal expansion.
- Thermal expansion can cause **thermal stresses** due to *temperature gradients*
- To reduce thermal stresses, a combination of high thermal conductivity and low thermal expansion is desirable

- **Specific heat capacity** of a material is the amount of heat required to change a unit mass (or unit quantity, such as mole) of a substance by one degree in temperature.

## Equation Summary

| Equation Number | Equation | Solving for | Page Number |
|---|---|---|---|
| 19.1 | $C = \frac{dQ}{dT}$ | Definition of heat capacity | 782 |
| 19.3a<br>19.3b | $\frac{l_f - l_0}{l_0} = \alpha_l(T_f - T_0)$<br>$\frac{\Delta l}{l_0} = \alpha_l \Delta T$ | Definition of linear coefficient of thermal expansion | 785 |
| 19.4 | $\frac{\Delta V}{V_0} = \alpha_v \Delta T$ | Definition of volume coefficient of thermal expansion | 786 |
| 19.5 | $q = -k\frac{dT}{dx}$ | Definition of thermal conductivity | 789 |
| 19.8 | $\sigma = E\alpha_l(T_0 - T_f) = E\alpha_l \Delta T$ | Thermal stress | 792 |
| 19.9 | $TSR \cong \frac{\sigma_f k}{E\alpha_l}$ | Thermal shock resistance parameter | 794 |

# 4.0: Electrical properties

- **Electrical conductivity** is the measure of a material's ability to accommodate the transport of an **electric** charge.

- **Semiconductivity**
  - The electrical properties of *semiconductors* are extremely sensitive to temperature
  - Properties is controlled by the concentration and type of impurities (**dopants**)

- **Dielectric behaviour**
  - **Dielectric Strength**
  - *Dielectric strength* is defined as the voltage required per unit distance for electrical breakdown
  - Units is V/m
- Application: use as insulator in capacitor

Conductors & insulators  Video

## Piezoelectricity

- The *piezoelectric effect* is exhibited by **smart materials; used in sound detection, high voltage generation; transducer.**
- 2 behaviours are involved:

1. When deformed by an external force, the materials emit a small electric current
2. When subjected to an electric current, materials undergo a reversible change in shape

For example, lead zirconate titanate crystals will generate measurable piezoelectricity when their static structure is deformed by about 0.1% of the original dimension. Conversely, those same crystals will change about 0.1% of their static dimension when an external electric field is applied to the material

# 5.0: Magnetic Properties

What is magnet ?

- Materials may be classified by their response to externally applied magnetic fields as **diamagnetic, paramagnetic, or ferromagnetic**.
- These magnetic responses differ greatly in strength.
  - Diamagnetism is a very weak form of magnetism that is NONpermanent and persist only while an external field is being applied.
  - Paramagnetism, when present, is stronger than diamagnetism and produces magnetization in the direction of the applied field, and proportional to the applied field.
  - Ferromagnetic materials possess a permanent magnetism moment in the absence of an external field, and manifest very large and permanent magnetizations. Ex. Cobalt, Nickel etc.

VIDEO - Paramagnetism & diamagnetism

# 6.0: Optical Properties

- Optical properties refer to a material's response to exposure to electromagnetic radiation, in particular to visible light.

- Basic principles involve the nature of electromagnetic radiation and its interactions with solid materials (light interactions; refraction, absorption etc.)

- Example: Colour, Opacity.

## Physical Properties of Materials, in Descending Order

| Density | Melting point | Specific heat | Thermal conductivity | Thermal expansion | Electrical conductivity |
|---|---|---|---|---|---|
| Platinum | Tungsten | Wood | Silver | Plastics | Silver |
| Gold | Tantalum | Beryllium | Copper | Lead | Copper |
| Tungsten | Molybdenum | Porcelain | Gold | Tin | Gold |
| Tantalum | Columbium | Aluminum | Aluminum | Magnesium | Aluminum |
| Lead | Titanium | Graphite | Magnesium | Aluminum | Magnesium |
| Silver | Iron | Glass | Graphite | Copper | Tungsten |
| Molybdenum | Beryllium | Titanium | Tungsten | Steel | Beryllium |
| Copper | Copper | Iron | Beryllium | Gold | Steel |
| Steel | Gold | Copper | Zinc | Ceramics | Tin |
| Titanium | Silver | Molybdenum | Steel | Glass | Graphite |
| Aluminum | Aluminum | Tungsten | Tantalum | Tungsten | Ceramics |
| Beryllium | Magnesium | Lead | Ceramics | | Glass |
| Glass | Lead | | Titanium | | Plastics |
| Magnesium | Tin | | Glass | | Quartz |
| Plastics | Plastics | | Plastics | | |