# UNIT 21: MATERIALS ENGINEERING

**Unit code: F/601/1626**

**QCF level: 4**

**Credit value: 15**

---

# LEARNING OUTCOME 1

# TUTORIAL 2

**On successful completion of this unit a learner will:**

---

1 **Be able to determine the properties and selection criteria of materials from tests and data sources**

***Criteria for material selection***: definitions of material properties and character appropriate to the learner's programme of study e.g. mechanical, physical, chemical, process character and costs for range of materials (metals, ceramics, polymers, and composites)

*Categorise materials*: an appreciation of the properties of metals: ceramics, polymers and composites; recognition of micro structural characteristics of the more commonly used engineering materials

*Materials testing*: tests to determine the properties of commonly used engineering materials e.g. metals, ceramics, polymers and composites (such as electrical conductivity/resistivity, magnetic susceptibility, mechanical strength, hardness, toughness, fatigue and creep resistance, corrosion and reactivity, wear resistance, optical and thermal properties, formability); appropriate statistical methods and the processing of test data

*Data sources*: published data e.g. British Standards, ISO, product data sheets, IT sources, standard published data sources, manufacturers' literature, job-specific information such as specifications, test data and engineering drawings; assessment of data reliability

## CONTENTS

The syllabus states that you should be able to determine material properties and character appropriate to your programme of study so you should not study properties that do not apply to your course (e.g. electrical properties if you are studying mechanical/manufacturing). The properties are determined by testing and the tests are covered in a later tutorial. This tutorial applies to all the materials: metals, polymers, ceramics and composites.

## 1. INTRODUCTION

PRE-REQUISITE KNOWLEDGE

The student should already be familiar with the terms in this tutorial and the basic properties of materials so you may find that you can skip some of it.

**The physical properties of materials govern the application, the method of manufacture and the cost. These properties are mainly MECHANICAL, CHEMICAL and ELECTRICAL.**

The properties we look for in materials are many. The following explains the important properties. You will find a list of material properties on the web site www.freestudy.co.uk and you should use it to answer the questions. The physical properties of materials not only govern the method of manufacture but very often they are changed by the method of manufacture and may undergo treatment (e.g. heat treatment) to change them in the final stage.

Once you are familiar with material properties relevant to your studies you may enter values into various search engines connected to data bases to find materials with the property values required. In arriving at these values you will go through other processes and the following is about these processes.

Something not mentioned in the syllabus that has become a major consideration is the recycling of the materials at the end of the life span and perhaps recyclability will one day be a property.

## 2. MECHANICAL PROPERTIES

The mechanical properties of materials are numerous and only the main ones are described in detail here. The complete list of properties that you might use to determine the best material for an application is given below.

Density

Ductility
- % elongation
- % reduction

Strength
- Tensile
- Compressive strength
- Shear strength

Modulus
- Elastic (E)
- Shear(G)
- Bulk (K)

Poisson's ratio

Hardness
- Brinell
- Rockwell
- Vickers

Malleability

Impact strength:-
- Brittleness - Izod, Charpy
- Toughness - Izod, Charpy
- Notch sensitivity - Izod, Charpy

Fatigue properties

Creep properties

Porosity

Coefficient of friction

## DENSITY

Density is a very important concept. It is a figure that tells us how many kg of a uniform substance is contained in a volume of 1 $m^3$. The value for pure water is one of the best-known figures since from the old definition that 1 kg was the mass of 1 $dm^3$ of water then since there are 1000 $dm^3$ in a $m^3$ the density must be 1000 kg per $m^3$. This is written in engineering as 1000 kg/$m^3$. In general density is defined as the ratio of mass to volume and is given the symbol ρ (Greek letter rho). **$\rho = M/V$**

## RELATIVE DENSITY

Often the density of substances is compared to that of water and this is the relative density. For example Lead has a mass 11.34 larger than the mass of the same volume of water so the relative density is 11.34. The symbol used is d.

Relative density = d = Mass of a substance ÷ Mass of the same volume of water

If we take 1 $m^3$ as our volume then d = Mass of 1 $m^3$ of the substance ÷ 1000

d = Density of the substance ÷1000

### SELF ASSESSMENT EXERCISE No.1

1. Lead has a density of 11340 kg/$m^3$. Calculate the volume of 12 kg. What is the melting point?
2. Aluminium has a density of 2710 kg/ $m^3$. Calculate the relative density. What is the melting point?
3. Seawater has a relative density of 1.036. Calculate the density of sea water.

## DUCTILITY

This is a tensile property that allows a material to be drawn (stretched) out into wire. Copper can be pulled out into a long thin wire because it has a large degree of ductility. Cast iron cannot be pulled out in this way and has virtually no ductility. This property is largely defined by the % elongation and % area reduction found in the tensile test.

The picture on the left shows a fracture of a non-ductile metal (probably cast iron) when stretched in a tensile test.

The picture on the right shows the fracture of a ductile metal (probably aluminium).

## MALLEABILITY

This is a compressive property that allows a material to be beaten (squashed) or rolled into thin sheet. Lead is especially malleable and opposite to glass that has no malleability at all. Other examples of malleable metals are gold, iron and to copper. Gold can be formed into very thin leaf and used to gild other materials like wood and plaster.

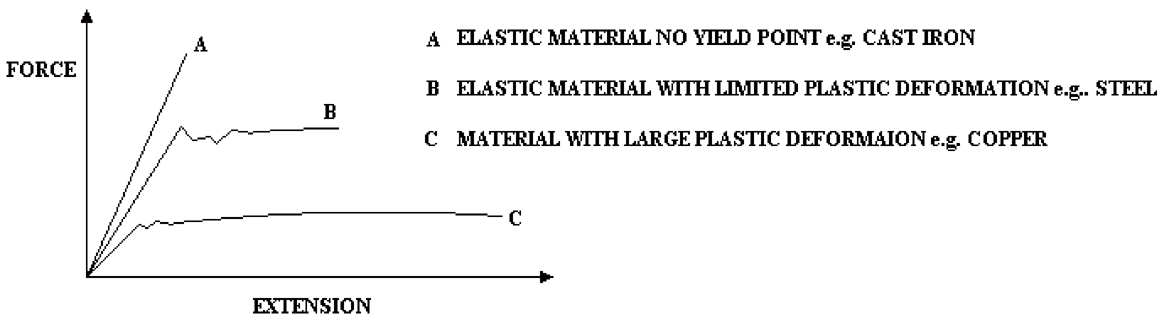
**The ductility and malleability of metals make them suitable for manufacturing by manipulation processes such as ROLLING, SPINNING, FORGING, DRAWING and EXTRUDING.**

## STRENGTH

This is the force at which the material will fail. Strength is normally given as the force per unit area or STRESS. There are various ways that a material may fail.

## TENSILE STRENGTH

A material may fail when it is stretched in which case it is a tensile failure. The stress at which a material fails is found in a ***TENSILE TEST*** covered later. The tensile test is carried out with a standard sized specimen and the force required to stretch it, is plotted against the extension. Typical graphs are shown below.




If the material is ductile, we look for the point at which it starts to stretch like a piece of plasticine. This point is called the yield point and when it stretches in this manner, we call it ***PLASTIC DEFORMATION.***

If the material is not ductile, it will snap without becoming plastic. In this case, we look for the stress at which it snaps and this is called the ***ULTIMATE TENSILE STRENGTH***.

Most materials behave like a spring up to the yield point and this is called ***ELASTIC DEFORMATION*** and it will spring back to the same length when the load is removed.

**COMPRESSIVE STRENGTH**

This is the strength of a material when it is squashed or compressed. Materials are normally very strong in compression because any cracks or faults in the structure will be closed and not pulled apart. Only soft materials like lead will fail easily because they are malleable and will spread out. Materials that are very weak in tension like cast iron and concrete are very strong in compression.

**SHEAR STRENGTH**

This governs how the material resists being cut in a guillotine or scissors and the ultimate shear stress is the stress at which the material is parted.

**TORSIONAL STRENGTH**

This governs the stress at which a material fails when it is twisted and a test similar to the tensile test is carried out, only twisting the specimen instead of stretching it. This is a form of shearing.

**ELASTICITY**

The elasticity of a material governs its ability to spring back to its original shape and size after it has been stretched, compressed, bent or twisted. If too much deformation occurs the material exceeds its ***elastic limit*** and stays deformed. Some materials need more force than others to produce the same deformation and this is governed by its ***modulus***. There are three main moduli.

***Modulus of Elasticity E*** defined as the ratio of tensile stress to strain and determined in a tensile test.
***Modulus of Rigidity G*** defined as the ratio of shear stress and strain and determined in a torsion test.
***Bulk Modulus K*** defined as the ration of pressure and volumetric strain and found with specialised equipment for liquids.
***Poisson's ratio ν*** defined as the ratio of two mutually perpendicular strains and governs how the dimensions of a material change such as reduction in diameter when a bar is stretched.

You should have studies these topics in other modules.

**HARDNESS**

| | |
|---|---|
| 10 | Diamond |
| 9 | Corundum |
| 8 | Topaz |
| 7 | Quartz |
| 6 | Feldspar |
| 5 | Apatite |
| 4 | Fluorite |
| 3 | Calcite |
| 2 | Gypsum |
| 1 | Talc |

This governs how a material resists abrasion and erosion i.e. being scratched and resists being worn away by rubbing. The hardness is found with a hardness tester and there are many of these. The main ones are the Brinell, the Vickers and the Rockwell test that basically consists of measuring how far a ball, cone or pyramid can be pressed into the surface. Hard materials are diamonds and glass. Soft materials are copper and lead.
Hardness is measured by comparing it to the hardness of natural minerals and the list is called the Moh scale. The list runs from 1 to 10 with 1 being the softest ands 10 the hardest.

## TOUGHNESS AND BRITTLENESS

Toughness is about how difficult it is to beak a material. Some materials are very strong but break easily. These are brittle like glass and cast iron. Other materials are not very strong but take a lot of energy and effort to pull it apart. Some polymers (plastics) are like this. Toughness is determined by measuring the energy needed to fracture a specimen. This is done in special test machines that use a swinging hammer to hit the specimen. The test also shows how susceptible the material is to cracking by putting a small notch in the specimen for the crack to start from.
Notched bar tests are covered later.

## MACHENABILITY

This is an index assigned to materials to show how suitable it is for machining or material removal by TURNING, MILLING, DRILLING and so on. There is a table of machinability indexes at
http://www.carbidedepot.com/formulas-machinability.htm

### SELF ASSESSMENT EXERCISE No. 2

1. What is the mechanical property of lead that makes it suitable for use as flashing on roofs?

2. What is the mechanical property of copper that makes it suitable for making into electric wires and water or gas pipes?

3. What is the mechanical property of steel that makes it suitable for structural components such as steel joists?

4. Why is cast iron suitable for making structural columns but not beams?

5. Two metals A and B are formed into identical short lengths of wire.

   Metal A can be stretched until it breaks but can be bent back and forth many times before it breaks.

   Metal B requires much more force to stretch it until it breaks and it does not stretch much. It is easily broken by bending once.

   Which metal is the most ductile?
   Which metal is the most brittle?
   Which metal has the greatest tensile strength?
   Which metal is the toughest?

6. What is the property of industrial diamonds that makes them so suited to make special grinding wheels?

## 3. **THERMAL PROPERTIES**

Again the properties are very many and only the main ones are described in detail. The complete list of properties is given below.

| | |
|---|---|
| Melting point | Brittle transition temperature |
| Solidus | Glass Temperature |
| Latent heat of fusion | Maximum service temperature |
| Thermal conductivity | Melt flow |
| Thermal expansion | Processing Temperature |
| Temperature coefficient of resistance | Vicat softening Temperature |

### MELTING TEMPERATURE

This is the temperature at which the material melts or solidifies. Pure elements usually have a clear temperature at which they melt or freeze although it depends on the pressure. Many materials (e.g. wood) do not melt.

### FLUIDITY

This important property in materials used for CASTING. it governs how easily the molten material flows. For example cast iron has good fluidity and casts well.

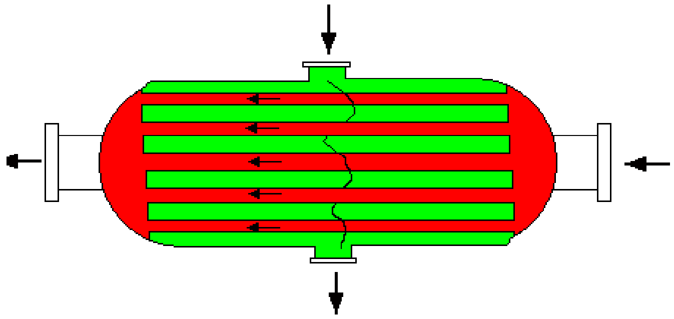
### THERMAL CONDUCTIVITY

This is a property that governs how well a material conducts heat. The formula for the heat flow rate conducted through a wall of area A is given by the following formula.

$$\Phi = \lambda A \Delta\theta/t$$

$\Phi$ is the heat flow rate in Watts.
$\lambda$ is the thermal conductivity in W/m K
t is the thickness of the wall.
$\Delta\theta$ is the temperature difference between the two sides of the wall.

As with electrical conductivity, sometimes we need materials that are good conductors and sometimes we need good insulators. Good conductors are needed for heat exchangers and good insulators are needed for lagging and insulating buildings.



Typical Heat Exchanger Design

Roofing Insulation

## THERMAL PROPERTIES OF COMMON MATERIALS

You will find a full table on the web site www.freestudy.co.uk under resources.

| **Name** | Melting Point $T_m$ K | Specific Heat c J/kg | Coeff. Of Linear expansion $\alpha$ 1/K | Thermal Conductivity $\lambda$ W/mK |
|---|---|---|---|---|
| Aluminium | 932 | 913 | $23 \times 10^{-6}$ | 201 |
| Copper | 1356 | 385 | $17 \times 10^{-6}$ | 385 |
| Iron, pure | 1810 | 106 | $12 \times 10^{-6}$ | 80 |
| Steel, mild | 1700 | 420 | $15 \times 10^{-6}$ | 63 |
| Alumina, ceramic | 2300 | 800 | $9 \times 10^{-6}$ | 29 |
| Brick, building | | | $9 \times 10^{-6}$ | 0.6 |
| Carbon, graphite | 3800 | 710 | $7.9 \times 10^{-6}$ | 5.0 |
| Concrete | | 3350 | $12 \times 10^{-6}$ | 0.1 |
| Glass wool | 1400 | 670 | | 0.04 |
| Kapok | | | | 0.03 |
| Melamine formaldehyde | | 1700 | $40 \times 10^{-6}$ | 0.3 |
| Nylon | 470 | 1700 | $100 \times 10^{-6}$ | 0.25 |
| Polystyrene | 510 | 1300 | $70 \times 10^{-6}$ | 0.08 |
| Wood, oak (with grain) | | | | 0.15 |

## WORKED EXAMPLE No. 1

Calculate the heat transfer through a flat copper plate 200 mm tall by 300 mm wide and 25 mm thick when the surface temperatures are 150°C and 55°C.

### SOLUTION

$$\Phi = \frac{\lambda A(\theta_h - \theta_c)}{t} = \frac{385 \times (0.2 \times 0.3)(150 - 55)}{0.025} = 87\,780 \text{ W}$$

## SELF ASSESSMENT EXERCISE No. 3

1. Which one of the materials listed in the table is the best conductor and which the best insulator?

2. A heat exchanger is used to heat water on the outside of the tubes with hot gas on the inside of the tubes. Think of 4 properties that the tube material must have in order to do this successfully for a long period of time. Suggest a suitable material.

3. Calculate the heat loss through a flat sheet of glass 2 m x 1 m and 5 mm thick when the surface temperatures are 20°C and 5 °C. (Answer 6 kW)

4. Find and name a suitable material for insulating the loft of a house. What other important property would it need besides insulation?

5. Insulated freight containers for transporting refrigerated goods usually have walls made from Glass Fibre skins separated by a layer of insulation. Find out what a suitable material would be for this.

## THERMAL EXPANSION

When solids and liquids are heated, the molecules vibrate more and take up more space so the material expands. Consider first the expansion in one direction.

If a bar of material of length $L_o$ has its temperature increased by $\Delta\theta$ degrees, the increase of length is $\Delta L$.
This is directly proportional to the original length L and to the temperature change $\Delta\theta$. It follows that :-

$$\Delta L = \text{constant x } L_o \, \Delta\theta$$

The constant of proportionality is called the coefficient of linear expansion ($\alpha$).

$$\Delta L = \alpha \, L_o \, \Delta\theta$$

**WORKED EXAMPLE No. 2**

A thin steel band 850 mm diameter must be expanded to fit around a disc 851 mm diameter. Calculate the temperature change needed. The coefficient of linear expansion is $15 \times 10^{-6}$ per $^oC$

**SOLUTION**

Initial circumference of ring = $\pi D = \pi \times 850 = 2670.35$ mm
Required circumference = $\pi \times 851 = 2673.50$ mm
$\Delta L = 2673.50 - 2670.35 = 3.15$ mm
$\Delta L = \alpha \, L \, \Delta\theta$
$3.15 = 15 \times 10^{-6} \times 2670.35 \times \Delta\theta$
$\Delta\theta = 3.15/(15 \times 10^{-6} \times 2670.35) = 78.6$ Kelvin

## SUPERFICIAL EXPANSION

This is about the change in area of a flat shape. Consider a flat plate of metal with area $A_o$. The change in area is $\Delta A$ and this is directly proportional to the temperature change so:-

$$\Delta A = \text{constant x } A_o \, \Delta\theta$$

The constant is the coefficient of superficial expansion $\beta$

$$\Delta A = \beta \, A_o \, \Delta\theta \qquad \text{Note } \beta = 2\alpha$$

**WORKED EXAMPLE No. 3**

A steel sheet has an area of 500 $cm^2$ at $20^oC$. Calculate the area when it is heated to 300 $^oC$. The coefficient of superficial expansion is $30 \times 10^{-6}$ per $^oC$

**SOLUTION**

$\Delta A = \beta \, L \, \Delta\theta = 30 \times 10^{-6} \times 500 \times (300 - 20) = 4.2 \text{ cm}^3$
The new area is 504.2 $cm^2$

## CUBICAL EXPANSION

Since a material expands in all direction the volume changes. The change in volume is $\Delta V$.

This is directly proportional to the original volume $V_o$ and to the temperature change $\Delta\theta$. It follows that :-

$$\Delta V = \text{constant x } V_o \Delta\theta$$

The constant of proportionality is called the coefficient of cubical expansion expansion ($\gamma$).

$$\Delta V = \gamma V_o \Delta\theta$$

Note that $\gamma = 3\alpha$

### WORKED EXAMPLE No. 4

Calculate the change in volume of 1 $m^3$ of water when it is heated from 10 $^oC$ to 80 $^oC$. The coefficient of cubical expansion is 210 x $10^{-6}$ per $^oC$

### SOLUTION

$\Delta V = 210 \times 10^{-6} \times 1 \times (80 - 10) = 14.7 \times 10^{-3}\ m^3$ or 14.7 $dm^3$ or 14.7 litre

### SELF ASSESSMENT EXERCISE No. 4

1. When heated so that the temperature change is the same for both, which expands the most, copper or aluminium?

2. A brass bar is 600 mm long and 100 mm diameter. It is heated from 20 $^oC$ to 95$^oC$. Calculate the change in length. $\alpha$ is 18 x $10^{-6}$ per $^oC$. (Answer 0.81 mm)

3. A steel ring is 50 mm diameter and 2 mm thick. It must be fitted onto a shaft 50.1 mm diameter. Calculate the temperature to which it must be heated in order to fit on the shaft. The initial temperature is 20 $^oC$ and the coefficient of linear expansion is 15 x $10^{-6}$ per $^oC$.
(Answer 133.3 K)

4. A stub shaft 85.2 mm diameter must be shrunk to 85 mm diameter in order to insert it into a housing. By how much must the temperature be reduced? Take the coefficient of linear expansion is 12 x $10^{-6}$ per $^oC$. (Answer -195.6 K)

5. A tank contains 40 $m^3$ of oil at 10$^oC$. Calculate the volume at 40$^oC$ given $\gamma$ = 700 x $10^{-6}$ per $^oC$
(0.84 $m^3$)

6. Copper sheet covers a wall and has an area of 20 $m^2$ at 15$^oC$. What is the change in area when it is heated to 80$^oC$? $\beta$ = 34 x $10^{-6}$ per $^oC$. (44.2 x $10^{-3}$ $m^2$)

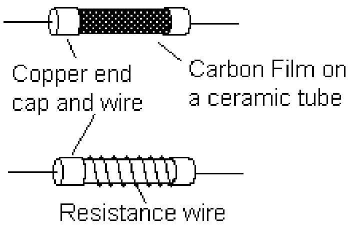
4. **<u>ELECTRICAL PROPERTIES</u>**

## ELECTRICAL CONDUCTIVITY

In electric theory the current flowing through a resistor is governed by Ohms Law **$V = IR$** where V is the voltage difference between the terminals, I the current flowing between the terminals and R the resistance measure in Ohms.

Resistance creates and dissipates heat and the power lost as heat is **$P = I R$** Watts.

Electronic resistors are manufactured to have a specific resistance with a given degree of accuracy. They are manufactured to withstand various degrees of heat and temperature as well as environmental conditions. Here are some examples of resistors used in electronics.




There are instances where the heat generation is desirable such as in electric heaters. In other instances resistance is undesirable such as in electric wire transmission lines.

Often we need a material that does not conduct electricity so that electric conductors are ***insulated*** from the surroundings for safety. This might be the insulation on a conductor wire or the materials of electric tools and equipment. Fixed insulators for high voltage work like those shown below will be made from ceramics while others working at low voltages are often made of plastic. Here are some examples of electric insulators.

***Resistivity*** (also called volume resistivity) is a property that allows us to calculate the resistance of a uniform length of material. The best conductor of electricity is silver but this is too expensive for use as wiring in homes and factories so copper is the best compromise followed by aluminium.

| **Name** | **electrical resistivity** $\rho$ **Ω m** |
|---|---|
| CONDUCTORS | |
| Aluminium | $26.5 \times 10^{-9}$ |
| Brass (70Cu/30Zn) | $\approx 80 \times 10^{-9}$ |
| Bronze (90Cu/10Sn) | $300 \times 10^{-9}$ |
| Carbon | $\approx 8 \times 10^{-4}$ |
| Cobalt | $60 \times 10^{-9}$ |
| Copper | $17 \times 10^{-9}$ |
| Gold | $24 \times 10^{-9}$ |
| Iron, pure | $100 \times 10^{-9}$ |
| Lead | $210 \times 10^{-9}$ |
| Nickel | $590 \times 10^{-9}$ |
| Platinum | $110 \times 10^{-9}$ |
| Silver | $16 \times 10^{-9}$ |
| Sodium | $45 \times 10^{-9}$ |
| Steel, mild | $150 \times 10^{-9}$ |
| Tin | $110 \times 10^{-9}$ |
| Titanium | $530 \times 10^{-9}$ |
| Zinc | $59 \times 10^{-9}$ |
| RESISTANCE WIRE | |
| Constantan (45 Ni/55 CU) | $470 \times 10^{-9}$ |
| Nichrome (80Ni/ 2 Cr) | $1.1 \times 10^{-6}$ |
| INSULATORS | |
| Glass | $1 \times 10^{12}$ |
| Mica | $9 \times 10^{13}$ |
| Quartz (fused) | $10.5 \times 10^{17}$ |
| Rubber | $1 \times 10^{13}$ |
| PET | $1 \times 10^{20}$ |
| Teflon | $1 \times 10^{24}$ |
| Polycarbonate | $1 \times 10^{13}$ |

The formula for calculating the resistance of a wire is as follows.

**$R = \rho L/A$** $\rho$ is the resistivity, L the length and A is the cross sectional area.

You will also come across the formula **$R = L/A\sigma$** where $\sigma$ is the conductivity **$\sigma = 1/\rho$**

The table is for your reference and shows the approximate resistivity values of materials.

**It should be remembered that materials chosen for their electrical resistivity are also chosen for their other properties such as cost, ease of manufacture, melting point and ability to survive environmental and operating conditions.** For example oxide films on the surface of materials like copper and aluminium can produce a high resistance to electric current.

Most materials will break down and conduct when the voltage exceeds a certain value (the ***breakdown voltage***). Air for example will ionise and conduct and this is seen as arcing. Transformers contain oil for cooling purposes and the oil must insulate the windings but will breakdown at a certain level.

## SELF ASSESSMENT EXERCISE No. 5

1. Calculate the resistance of a copper wire 5 m long and 0.3 mm diameter. The resistivity is $1.7 \times 10^{-8}$ Ohm metre. (Answer 1.202 Ω)

2. Calculate the resistance of a nichrome wire 2 m long and 0.2 mm diameter given $\rho = 108 \times 10^{-8}$ (Answer 68.75 Ω)

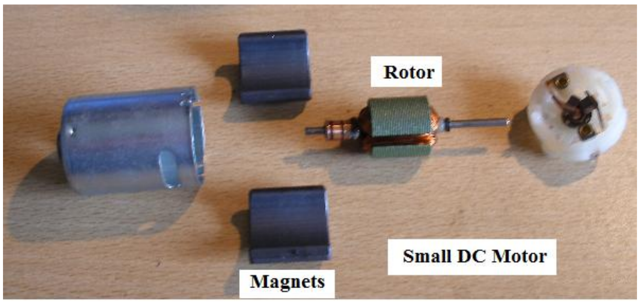
3. The heating element of a 1 kW electric heater is a bar made from SILICA that encapsulates a spiral resistance wire that generates the heat. What would be a suitable material for the wire? What are the properties required from the wire and the silica?

4. What would be the ideal properties of a material for the body of an electric hand drill? Suggest a suitable material.

5. In electrical equipment that requires high reliability, the pins and sockets of plugs and connectors are gold plated. Why is this?

## MAGNETS

Magnetic devices are widely used as either permanent magnets or electro-magnets in a diverse range of items including ***electric transformers***, ***motors, generators, electro-magnets, loud speakers, computer drives***, ***audio devices*** and ***fridge magnets***.

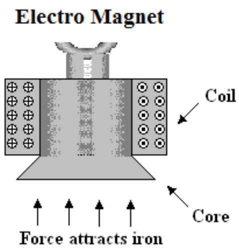


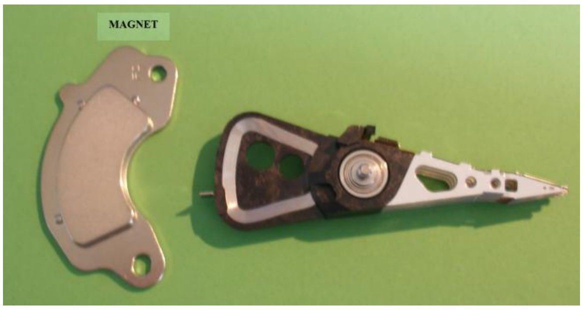

Small ferrite ring for electronic use

415 V - 240 V

240 V - 110 V

Small transformers for electronic equipment




MAGNET USED IN THE POSITIONING OF A HARD DRIVE HEAD

Stronger magnets mean smaller devices. The magnetism depends on a material property called ***PERMEABILITY***. Usually this is expressed as a ratio to the permeability of free space (symbol $\mu_o$) and is called the ***RELATIVE PERMEABILITY*** with symbol $\mu_r$.

**Table of approximate values for magnetic materials**

| **Material** | **Relative Permeability** |
|---|---|
| Mu-metal (Nickel Iron Alloy) | Up to 50,000 |
| Permalloy (Nickel Iron Alloy) | 8,000 |
| Electrical steel | 4,000 |
| Ferrite (nickel zinc) | 16–640 |
| Ferrite (manganese zinc) | >640 |
| Steel | 100 |
| Nickel | 100 – 600 |
| Neodymium magnet | 1.05 |

This property is difficult to list as a table because it is not usually very constant in value and changes with the magnetic flux density. You need to understand magnetisation in depth in order to perform calculations with this property.

The main equation used in calculations is **$B/H = \mu_o\mu_r$**

B is the magnetic flux density in Tesla, H is the magnetising force and $\mu_o$ is the absolute permeability with a value of $12.566 \times 10^{-7}$

The main magnetic material is ***Iron*** used to make steel and ferrite. The permeability depends very much on the structure and composition of the alloy. When choosing a magnetic material you need to consider the **cost**, the way it will be ***formed*** and the ***environmental conditions*** it will be used in. There are a range of magnetic materials that go under various names. ***Rare earth metals*** are used to make small powerful magnetic devices and gets its name from the section of the periodic tables called rare earth elements. The following is a summary of some of the materials.

- **Alnico Magnets -** A magnetic alloy largely made from Aluminium, Iron, Cobalt and Nickel. This is a relatively low cost material. It can be used at high operating temperatures and has very good corrosion resistance.

- **Rare Earth Magnets** – made from Samarium, Cobalt, Neodymium, Iron and Boron. Both Samarium Cobalt and Neodymium magnet alloys are powdered metals which are compacted in the presence of a strong magnetic field and are then sintered.

- **Neodymium Magnets (Rare Earth) -** or Neo, is made up of Neodymium, Iron and Boron and is moderate in price but has poor corrosion resistance so they usually have a protective coat. They are only used at 80°C to 200°C. Premium grade versions are quite expensive. This magnetic material is extremely powerful and its use in Hard Disc Drives and motors has resulted in much miniaturisation. Neodymium permanent magnets usually offer the best value when comparing price and performance.

- **Samarium Cobalt Magnets (Rare Earth) -** made up largely of Cobalt and Samarium. Because it is difficult to process it is the most expensive of the rare earth magnets. This permanent magnetic material offers high resistance to corrosion and it can withstand high operating temperatures, up to 350°C. Samarium Cobalt magnetic materials are used extensively in the aerospace market or in areas of industry where performance is the priority concern and cost is secondary. Samarium Cobalt magnets is the second most powerful magnetic material and it exhibits excellent resistance to demagnetization**.**

- **Ceramic Magnets (Ferrite)** – made from Strontium and Ferrite. Ferrite is one of the most cost effective magnetic materials manufactured in industry. The low cost is due to the cheap, abundant raw materials used to make large quantities of products.

- **Bonded Magnets -** made from Ceramic, Neodymium, Iron, Boron or Samarium and Cobalt powders which are bonded in a plastic matrix. They can be formed by injection or compression moulding into accurate complex shapes. Bonded magnet materials have a moderate resistance to corrosion and a low tolerance to heat because of the binder material. Bonded magnet materials are commonly used in automotive parts because they lend themselves to large production quantities and complex shape can be produced at a low cost.

- **Flexible Magnets (Rubber) -** manufactured by mixing Ferrite or Neodymium magnet powders with synthetic or natural rubber and rolling or extruding them. They are versatile and low cost. Applications are micro-motors, gaskets, novelties, signs, and displays. Ferrite flexible magnet material is very low energy and it does not usually replace fully dense magnet materials. Flexible Neodymium material is higher in strength, but is made in limited quantities and the cost is high.

**SELF ASSESSMENT EXERCISE No. 6**

1. Calculate the permeability of a ferrite material with a relative permeability of 250. ($314.15 \times 10^{-6}$)

   Conduct some research in order to answer the following questions.

2. What kind of material is used to make the cores of large electric transformers for mains electricity at 50 or 60 Hz?

3. Which magnetic material would be used to form the core of an electronic inductor for use at radio type frequencies?

4. Which magnetic material would be used to form a flat flexible fridge magnet?

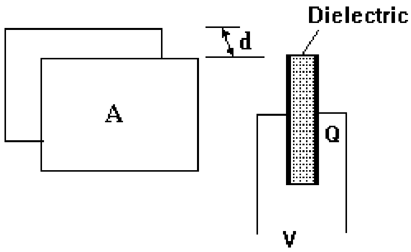
5. Which magnetic material is commonly used to make electric guitar pickups?

6. Which magnetic material is commonly used in computer hard disc drives?

## PERMITTIVITY

This is a property that governs how much static electricity (electro-static charge) can be stored on an ***electric capacitor***. It is usually expressed as the ratio to the value for free space (symbol $\boldsymbol{\varepsilon_o}$). The main equation used in calculations with this property is $\mathbf{C = \varepsilon_o \varepsilon_r A/d}$

C is the capacitance in Farads and A the area of the capacitor plates and d the distance between them. $\varepsilon_o$ is the absolute permittivity with a value of $\varepsilon_o = 8.85 \times 10^{-12}$




Capacitors are used in many electronic devices. The pictures show a few examples. In basic form it is two parallel conducting plates separated by a material called a ***dielectric***. It is the permittivity of the dielectric that governs the charge stored. Increasing the permittivity increases the charge that can be stored so high values mean smaller devices.

Here is a table of some common materials.

| MATERIAL | $\varepsilon_r$ |
|---|---|
| Free Space | 1.000 |
| Air | 1.006 |
| Paper | 2 approx. |
| Glass | 7 approx. |
| Mica | 4 approx. |
| Ceramic | 6 approx. |
| Plastics | various |


An ideal dielectric will have a very high resistance so the resistivity and breakdown voltage is also very important.

### SELF ASSESSMENT EXERCISE No. 7

1. Calculate the permittivity of a mica with a relative permittivity of 6.
   ($53.1 \times 10^{-12}$)

   Conduct some research in order to answer the following questions.

2. What kind of dielectric material has high breakdown voltages?

3. If a simple capacitor has two metal plates separated by air. A mica sheet is inserted between the plates. What will be the affect on the capacitance value?

## 5. DURABILITY/DEGRADATION

### CORROSION RESISTANCE

You will find much information and pictures at http://www.corrosion-doctors.org

### OXIDISATION

Corrosion takes many forms and it would require a very large section to explain it. The following is a brief summary of the forms of corrosion that occur with materials.

Oxygen from the environment combines with the material to form a new substance, usually an oxide film on the surface. If the oxide film is easily removed to expose new material, the process will continue until all the material is oxidised. In the case of most ferrous materials the oxide film is rust and this lets water through and crumbles away. In the case of copper and aluminium, the oxide film is durable and forms a protective coat on the surface. Materials like Gold and Silver do not oxidise easily but important engineering materials that resist oxidation are zinc, chromium, cadmium and others.

### GALVONIC CORROSION

This is caused by electrolytic action between dissimilar metals. It requires the presence of water, especially if it contains salt to create an electrolytic cell and so care must be taken when different metals are used in an assembly. The compatibility of metals is listed as the Electrode Potential (in volts) and the further apart two metals are in the table, the worse the electrolytic action. The more positive metal is called anodic and the more negative cathodic. The ions move from the anodic to the cathodic.

**TABLE OF ELECTRODE POTENTIAL IN VOLTS**

| | | | |
|---|---|---|---|
| Lithium | -3.02 | Nickel | -0.23 |
| Potassium | -2.92 | Tin | -0.14 |
| Sodium | -2.71 | Lead | -0.12 |
| Magnesium | -2.34 | Hydrogen | 0.00 |
| Aluminium | -1.66 | Copper | +0.34 |
| Zinc | -0.76 | Mercury | +0.8 |
| Iron | -0.44 | Silver | +0.8 |
| Cobalt | -0.29 | Gold | +1.68 |

Components and structures are often treated or coated to reduce corrosion. If the coating is to be affective, it must be compatible in the above list. Here is a list of some of the preparatory treatments and coatings used for metals.

**TREATMENT**

- ***Pickling***
- ***Degreasing.***
- ***Wire brushing***
- ***Shot and vapour blasting***
- ***Flame descaling***
- ***Abrasive finishing***
- ***Polishing***
- ***Barrelling***

**PROTECTIVE COATINGS**

- ***Galvanising***
- ***Sherardising***
- ***Calorising***
- ***Chromising***
- ***Chromating***
- ***Phosphating***
- ***Metal Spraying***
- ***Cladding***
- ***Anodising***
- ***Electroplating***
- ***Plastic Coating***
- ***Paint Coating***

## OTHER PROPERTIES

The following list of properties is given without detailed explanation.

**SUITABILITY FOR MANUFACTURE**

Manufacturers of many materials have an index to show the suitability of the material to forms of manufacture such as the following.

Machineability
Weldability
Arc Resistance
Ability to be hot and cold rolled
Ability to be drawn
Ability to be forging
Ability to be extruded
Ability to be cast
Mould Shrinkage
Surface finish and appearance
Melt flow rate (MFR) for polymers

**CHEMICAL ATTACK**

Metals may be degraded by a variety of chemicals such as acids and alkali and these must always be considered. The material should always be checked for

Resistance to oxidation
Resistance to Suphidation (e.g. sulphur in the atmosphere)
Compatibility with solvents

Polymers do not corrode but may be prone to attack from other chemicals such as SOLVENTS which dissolves them away.

Ceramics are in the main resistant to most forms of chemicals and this is why they have been used for containers down the centuries.

**POROSITY**

We should mention here the importance of porosity. If a material allows liquid or gas to seep through it then this may cause problems such as contamination of food stuffs. On the other hand, porosity is necessary for a material used as a filter.

**DIMENSIONAL STABILITY**

We should also mention dimensional stability here. A material subjected to prolonged heat, cold, pressure and stress may change its dimensions and shape (e.g. creep covered in a later tutorial). Plastic bottles containing pressurised fizzy drinks should not change their shape over its intended shelf life.

**OPTICAL**

Emissivity
Reflection Coefficient
Refractive Index

**SELF ASSESSMENT EXERCISE No. 8**

1. Go to the website http://www.engineersedge.com/galvanic_capatability.htm or some other suitable source and explain the following in respect of ***galvanic corrosion***?

   i. What is considered a harsh environment for metallic structures?
   ii. What is the maximum acceptable difference in electrode potential for a harsh environment?
   iii. Would brass screws be suitable to use on steel structures in a harsh environment.

2. Using a web site such as Matweb, find a cast iron that has good machinability.

3. Which kind of degradation will affect the dimensions of a turbine blade in a jet engine?

4. Which kind of degradation could make a bottle of fizzy drink lose its fizzyness?

5. Sometimes the moulds used to cast metal components are made larger than the dimensions of the finished product. List two reasons for this.