Dissection Lab 1(a) - Engineering Materials

(prepared by M. Munro, revised by W. Hallett)

The purpose of these labs is to allow you to learn basic mechanical engineering and design concepts by handling and dismantling common mechanical components and systems, sketching them, and answering questions about them. This lab manual gives you basic information that you will need to do the labs. More detailed information is available in *Marks' Standard Handbook for Mechanical Engineers*, and you will find frequent references to the appropriate sections in it throughout this manual. Details on accessing *Marks'* are given on the table of contents page in this manual.

1 Materials - Introduction

This first lab introduces you to materials science. You will be given a number of different samples of engineering materials which will be used to demonstrate basic concepts in materials properties: strength, hardness, ductility, and failure modes. Your materials courses in second year will explain *why* the materials behave as they do. The pages of this manual contain blanks which you will fill in during the lab.

The four main types of materials are:

1. ____

2. ____

3. ____

4. ____

2 Metals

2.1 Recognizing Common Metals

One of the objectives of this course is to teach you to identify common materials. The materials sample pack that you have received contains a number of common metals, and the following notes summarize their characteristics. Blank spaces have been left for you to fill in typical applications of each of these metals. The identification features that you should look for are:

- colour
- density (weight/unit volume - see table on next page)
- softness (try scratching with a nail), or ease of bending
- magnetism (whether they are attracted by a magnet). The only metals that are attracted to a magnet are iron, cobalt and nickel and their alloys (try a coin). However, some alloys of these elements are *not* magnetic (*e.g.* many stainless steels).

Densities of Common Metals

Note: specific gravity is density relative to that of liquid water. To get density in kg/m^3 multiply by 1000. These are approximate values only - exact values depend on alloy composition.

Metal	**Specific Gravity**	**Metal**	**Specific Gravity**
Magnesium and alloys	1.74 - 1.8	Steel, stainless steel	7.7 - 7.8
Aluminium and alloys	2.6 - 2.8	Brass, bronze	8.2 - 8.8
Titanium and alloys	4.4 - 4.8	Copper	8.8 - 8.95
Zinc alloys	6.0 - 6.6	Lead	11.3
Tin	7.2 - 7.5	Mercury	13.6
Cast Iron	7.0 - 7.6	Tungsten	18.6 - 19.1

Sources: *Machinery's Handbook*, *Marks' Standard Handbook for Mechanical Engineers*

Steel: Ordinary steel is an alloy of iron and carbon; more advanced steels contain other alloying elements as well to give them more strength. Steels vary widely in strength and hardness depending on their composition and the heat treatment they have received. The carbon content varies from 0.1% (a very soft steel) to 1.3% (very hard). Your sample is a soft low-carbon steel. Steel is the most common engineering metal because it combines high strength with low cost. Identification: dull grey in colour, may have rust spots, magnetic, fairly easy to bend.

You will also find steel shafts in many of the objects you dissect: unlike your sample, these may be fairly shiny because they have been machined and/or ground to a smooth surface. Identification: they will be magnetic.

Galvanized steel: Because steel corrodes easily, it is often coated with other metals to prevent corrosion. Galvanized steel has a coating of zinc. Identification: silvery grey colour with a "flaky", somewhat rough pattern in the zinc coating, magnetic. (There is another kind of galvanized steel called "satin coat" which has a dull smooth surface without the "flaky" appearance.)

Stainless Steel: This is a large group of alloys of iron with chromium, and usually nickel as well. They are corrosion resistant, and stronger than many ordinary steels. Identification: silvery colour, lighter in colour than ordinary steel, fairly shiny, fairly hard. There is a very wide range of compositions and properties available. The most commonly used stainless steels are types 304 (18% Cr, 8% Ni) and 316 (17% Cr, 10% Ni, 2% Mo); they are non-magnetic, although they can become slightly magnetic when cold-worked. However, stainless steels with zero or only small amounts of nickel are magnetic (try a stainless steel ruler). Magnetism is therefore not a reliable test for identifying stainless steel. (See Marks' Handbook, p. 6-29 for more details).

Aluminium: The most obvious characteristic of aluminium is that it is much lighter than other metals (density 2.6 g/cm^3, compared with 7.8 for steel and 8.4 for brass). Identification: light silvery colour, sometimes dull but can also be shiny, fairly soft, non-magnetic. It often looks very much like stainless steel, but it is usually softer and of course much lighter.

Copper: Main use is for electrical components - it has the highest electrical conductivity of any metal except silver and gold. Identification: distinctive reddish-brown colour, non-magnetic. When copper oxidizes, it becomes green (*e.g.* roof of the Parliament Buildings, Chateau Laurier).

Brass: An alloy of copper and zinc, stronger and harder than copper, very easily machined. Identification: shiny yellow colour, non-magnetic.

Other metals, not included in your sample kit, which you will encounter in dissection labs or elsewhere, include:

Bronze: an alloy of copper and tin, quite hard and tough, used for wear resistance in gears and bearings. Identification: brownish-yellow in colour, darker than brass, but lighter than copper, non-magnetic. Oxidizes to a dark brown-black.

Cast Iron: an iron-carbon alloy containing 2-4% carbon. The carbon content is much higher than that of steel, which reduces its melting point. It is used only for making castings. (Note that cast iron is *not* pure iron; pure iron is too soft to be a useful engineering metal.) Identification: dull grey, magnetic, usually found only in fairly rough cast parts, surface is rough unless it has been machined, in which case it looks like steel.

Zinc Alloy: widely used for die castings because of its low melting point ($\approx 400\,^\circ$C). Zn with 3-25% Al, small quantity of Mg, up to 2.5% Cu, often called “zamak”. Identification: silvery dull grey, fairly soft, weight similar to steel, non-magnetic, found mainly in precision die-cast parts.

Tinplate: This is steel with a coating of tin to prevent corrosion. Identification: very shiny and bright, magnetic. Often found in tin cans and cookie tins.

Chrome Plating: Many consumer items and automobile parts are plated with a thin layer of chromium or nickel to give them a smooth clean finish. The underlying metal is usually an aluminium, brass or zinc alloy. Identification: very shiny and smooth, brighter than any other metal.

2.2 Hardness and Strength

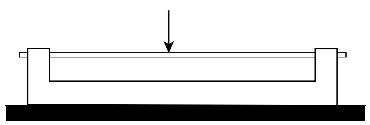
Hardness refers to the ability of a material to resist deformation or scratching. The *strength* of a material refers to the load it can carry without breaking (*cf.* Lab 8). The two concepts are related.

Metals can be either _______________ or _________________ .

A metal which is _______________ is also _______________ and _______________ .

For design, we usually want materials to be strong and stiff: strong, because a strong material allows our parts to be smaller and lighter; and stiff, because we do not want our structures to change shape significantly under load. However, strong materials may be difficult to work, so for ease of manufacturing, we may prefer materials to be softer.

Example 1: deformation of soft steel strip



Elastic deformation means:

- ____
- ____

Plastic deformation means

- ____
- ____

A material deforms plastically when it is loaded beyond the elastic limit (or yield point).

The three methods for making soft metals harder are:

1. ____
2. ____
3. ____
   (which can also be used to make metals softer)

(a) Alloying:

An alloy is a mixture of two or more metals. It is a mechanical mixture, not a chemical compound; the components are usually mixed together in the molten (liquid) state.

Example 2: brass, an alloy of ______________ and ___________________ .

What is the effect of alloying?

- ____

What other metals in the sample bag are alloys?

- ____

- ____

(b) Cold Working

Cold working refers to the hardening of a metal by _____________________________

_________________________ which causes changes in the internal structure.

Example 3: copper rod - soft wire versus hard-drawn rod.

Note the difference in properties. They are both the same material, but the rod is much harder and stiffer. Both have been produced by a process called wire-drawing (*q.v.* Lab 2), which causes extensive plastic deformation and makes the copper rod very hard. However, the soft wire was subsequently softened by annealing (see below)

Example 4: copper strip

(c) Heat Treatment

Heat treatment refers to controlled heating and cooling of a metal.

Hardening: many steels (= iron + carbon) can be hardened by heating to a red heat (material glowing red) followed by sudden cooling. This makes the steel extremely hard but also brittle. It can then be partly annealed and made less brittle by re-heating and slow cooling.

Example 5: soft steel vs hardened steel (knife blade)

- ____

Example 6: hardening of steel rod

Softening (= annealing): most metals, including steel, can be softened by heating them to about 2/3 the melting temperature, then allowing them to cool. For steel, the cooling must be done slowly, or the material will be hardened instead. Most other metals cannot be hardened in this way, and for them the rate of cooling does not matter.

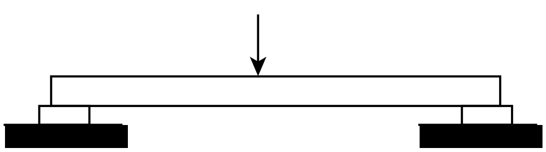
Example 7: softening of hard-drawn copper rod

3 Ceramics

Ceramics are non-metallic, inorganic materials such as glass and porcelain. They are formed by melting or by making the part of wet clay and then firing it at high temperature. Some (*e.g.* silicon carbide, tungsten carbide) are extremely hard and are therefore used in cutting tools for hard metals.

Reference: *Marks' Standard Handbook* 6-139 – 6-140.

Example 8: breaking of tile - compare to bending of metals



Ceramic: exhibits a **brittle fracture**.

- ____

- ____

Metal strip: most metals exhibit **ductile behaviour** - they go through extensive plastic deformation before breaking. The exceptions are very hard metals such as hardened steel, which may undergo brittle fracture as seen in Example 6 above.

- ____

- ____

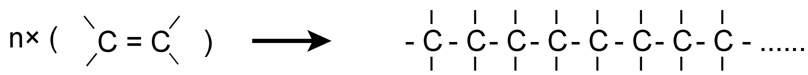
Brittle materials cannot carry loads in tension: tension can cause rapid propagation of a crack, leading to rapid failure. Brittle materials are therefore mostly used in *compression.*

4 Polymers (Plastics, Rubber)

Polymers are long-chain molecules composed of a large number of molecular units joined together. The units are called mers and are usually hydrocarbons or related compounds.

Reference: *Marks' Standard Handbook* 6-189 – 6-205.

A typical polymer: polyethylene



Tough versus Brittle Behaviour: Deformation

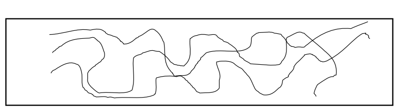
A tough material, before it breaks

- ____

- ____

Example 9: strip of polyethylene bag. Pull the strip slowly, making it stretch a lot, then stop. (Test 1). Then pull it again until it breaks (Test 2).

Test 1: before stretching, the individual polymer chains are randomly oriented. The material can be extensively plastically deformed.



Test 2: after stretching, the plastic deformation has caused the polymer chains to line up. It will finally fail in a manner similar to a brittle fracture.

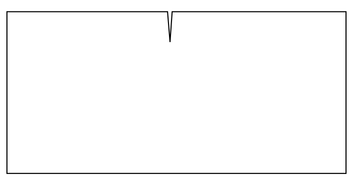
Tough versus Brittle Behaviour: Crack propagation

Brittle materials allow cracks to propagate rapidly. The cracks remain sharp and create a stress concentration at their tip. Ductile (tough) materials deform and make the crack round, reducing the stress concentration and making it harder for the crack to propagate.

Example 10: Styrofoam versus elastic band.

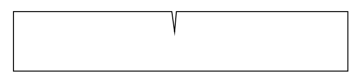
Pull each sample slowly until it breaks. See if you can stop the crack from moving.

Styrofoam slab



Type of behaviour: ____________________

Elastic band



Type of behaviour: ____________________

5 Composite Materials

A composite material combines two or more materials to produce materials which have some of the characteristics of both. An example is fibreglass, which combines the high tensile strength of glass fibres with a resin to bind the fibres together into a structure.

Reference: *Marks' Standard Handbook* 6-206 – 6-208.

6 Summary

The main materials properties concepts covered in this lab have been:

hard versus soft
elastic versus plastic
three methods for hardening metals
one method for softening metals
ductile versus brittle
toughness
crack propagation

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