INVESTIGATION OF THE MECHANICAL PROPERTIES OF METALS
Practical : MAT 1

1. Introduction
Aims

(i) To investigate the mechanical properties of metals, how they can be varied, and to achieve some understanding why these properties vary.

(ii) An introduction to the metallurgy of steels, including how their properties depend on
- processing (as drawn and annealed)
- composition (carbon content)

(iii) To gain practical experience of the following techniques, and an understanding of what information can be obtained from these techniques.
- tensile testing
- hardness testing
- metallography - how specimens are prepared, use of an optical microscope

Background

Generally metals have higher stiffness, strength, and toughness than polymers; whereas polymers tend to be lighter, more flexible, and have higher resistance to environmental degradation. It is important for an engineer to have an understanding of the properties of both classes of materials to make intelligent use of them in design. In general it is not the best approach to simply replace a metal component with plastic a one without rethinking the design.

The properties of metals are linked to the chemical composition, processing path, and resulting microstructure of the material. For metals and alloys of a particular composition most properties depend on microstructure. Processing is a means to develop and control microstructure, for example hot rolling, cold drawing, and heat treatment.

In order to select a material for a particular component the engineer must have an intimate knowledge of what properties are required. Consideration must be given to the environment (e.g. corrosive, high temperature, high stress) and how the component will be fabricated (e.g. welded, bolted). Some of the mechanical properties to be considered are :

- Strength - tensile, yield, compressive, shear
- Elastic moduli
- Hardness
- Toughness
- Ductility
- Fatigue
- Creep
- Friction

In the selection process what is required for one application may be totally inappropriate for another. For example, steel beams for a railway bridge require a totally different set of properties than the steel rails that are attached to the wooden ties on the bridge deck. In designing the bridge the steel must have sufficient strength to withstand substantial applied loads. In addition this application requires a steel with high toughness, good weldability, and good corrosion resistance. The steel rails however must have high strength coupled with excellent wear resistance.

Steel is iron with ≤ 2 weight % carbon. Iron with > 2 wt % C is known as cast iron, also many steels that are used in practice have other alloying additions such as Cr, Mn, N, Nb, Ni, Si, Ti, and V. In steels the microstructural constituents (i.e. the parts that make up the alloy) have the names ferrite, pearlite, bainite, martensite, cementite, and austenite. An introduction to the metallurgy of steels is given in ***Appendix I***. In the example considered above the two steels have different microstructures. The structural steel has a ferrite plus pearlite microstructure and the rail steel has a fully pearlitic microstructure. In both cases the microstructure plays the primary role in providing the desired properties, hence it can be seen how material properties can be tailored by microstructural manipulation or alteration. Knowledge about microstructure is thus paramount in component design and alloy development.

A tensile test enables the strength of a material to be obtained. In this test a material is subjected to uniaxial loading which tends to stretch the material. A longitudinal specimen is gripped at both ends and stretched at a slow controlled rate until rupture occurs. A stress strain curve can be plotted during a tensile test (Fig 1), which enables the following material characteristics to be determined : elongation, yield strength, proof stress, ultimate tensile strength, and Young's modulus.

A hardness test measures the resistance of a material to indentation, by using an indentor of known ~~geometry (e.g. pyramid shaped diamond for the Vickers hardness test), loading~~ it with a known mass and measuring the size (or depth) of the indent on the surface of the metal. This test can be classed as a non destructive testing (NDT) technique (whereas tensile testing is clearly destructive). Hardness testing is often used in quality control applications, and for investigation of failures.

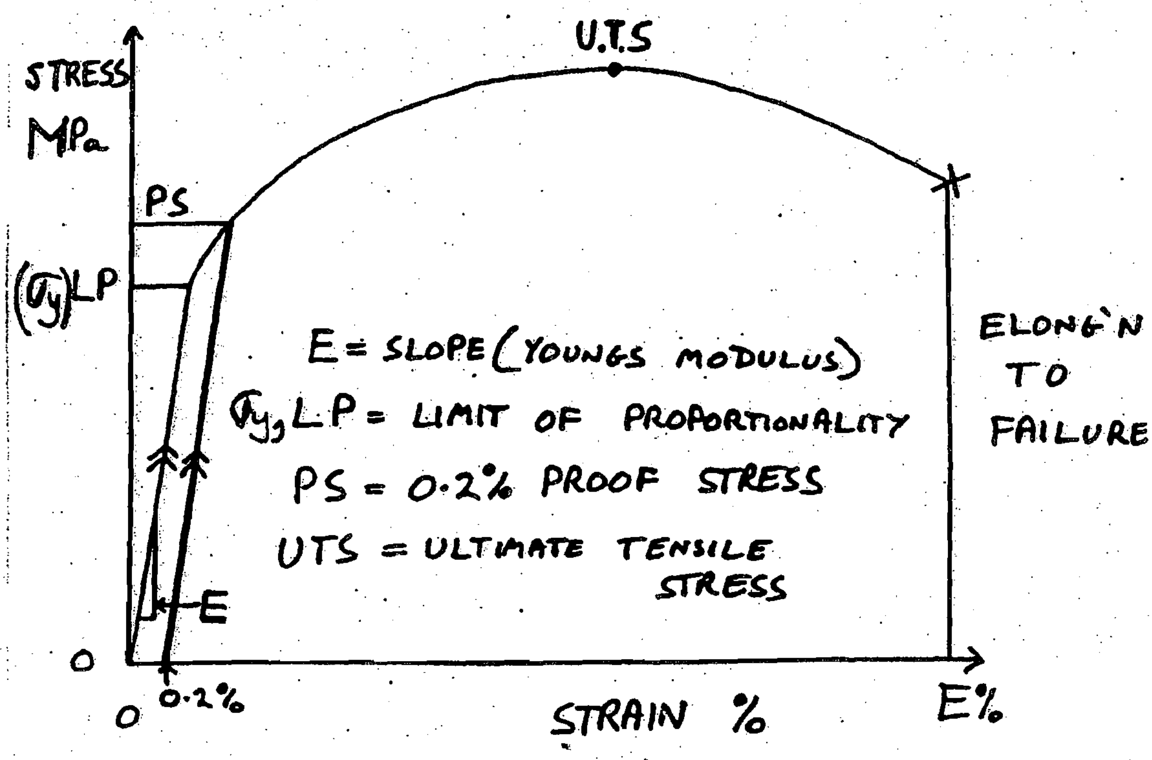


Fig 1. Stress-strain curve obtained from tensile testing.

Metallography leads to information about the microstructure of metals and alloys, generally by using polished and chemically etched samples and viewing these samples under an optical microscope. Using information obtained from metallography and relating it to results from mechanical property testing (i.e. tensile and hardness testing) can lead to an understanding of why a material behaves as it does.

NB This practical introduces a number of important concepts from materials science and engineering, it will probably be useful to refer back to the information contained here to obtain an idea of how all the concepts interrelate. Many of these concepts should become clearer following, or by comparison with, the lectures and tutorials.

2. Experimental procedure

This practical involves tensile testing, hardness testing and metallography of steels.

2.1 Tensile testing

The following samples are provided for tensile testing:

material	composition wt % carbon	condition	code
steel	0.1	as drawn	A
steel	0.1	annealed	AN
steel	0.4	annealed	D
steel	0.8	annealed	N

Details of how to use the tensile tester, and which parameters should be used for each material are given in the laboratory.

Before tensile testing measure the original width and thickness of the specimens. To obtain elongation at fracture(%) measure the gauge length before and after testing.

From the tensile testing you should obtain the following values :

Young's modulus
Ultimate tensile strength
Yield strength
Elongation at fracture(%)
Reduction in area at fracture(%)

2.2 Hardness testing

The steel samples should be hardness tested using the Vickers hardness tester (with an indentor load of 30 kg). A minimum of 3 indents should be made on each sample.

2.3 Metallography

Metallographic samples of steel are available for examination. Sketches of the microstructures should be made, and the different features clearly labelled. The microscope magnification that was used when making the sketches should also be noted (what is the diameter of the field of view observed down the microscope ?).

3. Write up

The report from this practical is to be written up individually, and to be handed in a week from the date of the lab. It is not necessary to re-write the introductory information or the experimental procedure given in this script, however it would be useful to attach a copy of this script to your report.

The report should include the following :

- A load-extension curve for each material.
- Table of results including : specimen details, elongation (%), reduction in area (%), yield strength, ultimate tensile strength, Vickers hardness. You may find it helpful to include data from specimen dimensions etc. that needs to be used in determining the results.

    The units for each of the values should also be given.

- Plot graphs of elongation (%), yield strength, ultimate tensile strength against % C in the steel.
- Plot yield strength, and ultimate tensile strength against hardness.
- Images of the microstructures.

Additionally in the report you should answer these questions and consider the following points:

Consider where the most significant sources of error and inaccuracy are in this practical.

Is there a relationship between: hardness and yield strength; hardness and ultimate tensile strength ? Can you find a mathematical relationship to describe this ?

What is the influence of increasing the carbon content of the steel on elongation (%), yield strength, ultimate tensile strength, and hardness ?

What is the influence of increasing the carbon content of the steel on the microstructure, and how does this relate to the mechanical properties ?

What is the influence of cold work (the process of *drawing*, which leads to *work hardening*) on the mechanical properties of steel, and on the structure of the steel ?

Finally conclude your report with information you have discovered and learned as a result of this practical that will be of use to you as mechanical engineers.

References

Materials Science and Engineering, W.D. Callister, 4th Edn., 1997.
Specific references about steel are given at the end of Appendix I
An informative web site about materials can be found at : http://www.matter.org.uk/

Jane Blackford 3.04.
jane.blackford@ed.ac.uk

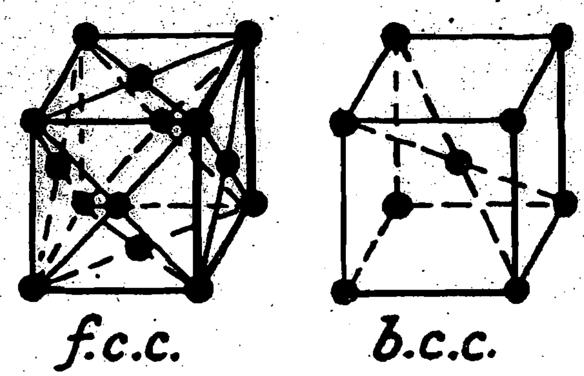
APPENDIX I

The metallurgy of carbon steel - a simple view

(NB the information given below is applicable for steels with ≤ 0.8 weight % carbon)

Iron shows allotropy, i.e. it has more than one crystal structure.

In particular, at room temperature iron is Body Centred Cubic (BCC) and above about 900°C it is Face Centred Cubic (FCC). The BCC structure is called "ferrite", the FCC "**austenite**".



Steel is an alloy of **iron** and (amongst other things) **carbon**.

At high temperature, carbon has relatively high solubility in austenite (max 2.1%) but very low solubility in ferrite at room temperature (max 0.02%).

Let's say you have a sample of steel containing 0.4% carbon. At a temperature of 1000°C all the carbon will be dissolved in the iron. This is because at this temperature the structure is FCC austenite, which has a solubility limit for carbon of 2.1%.

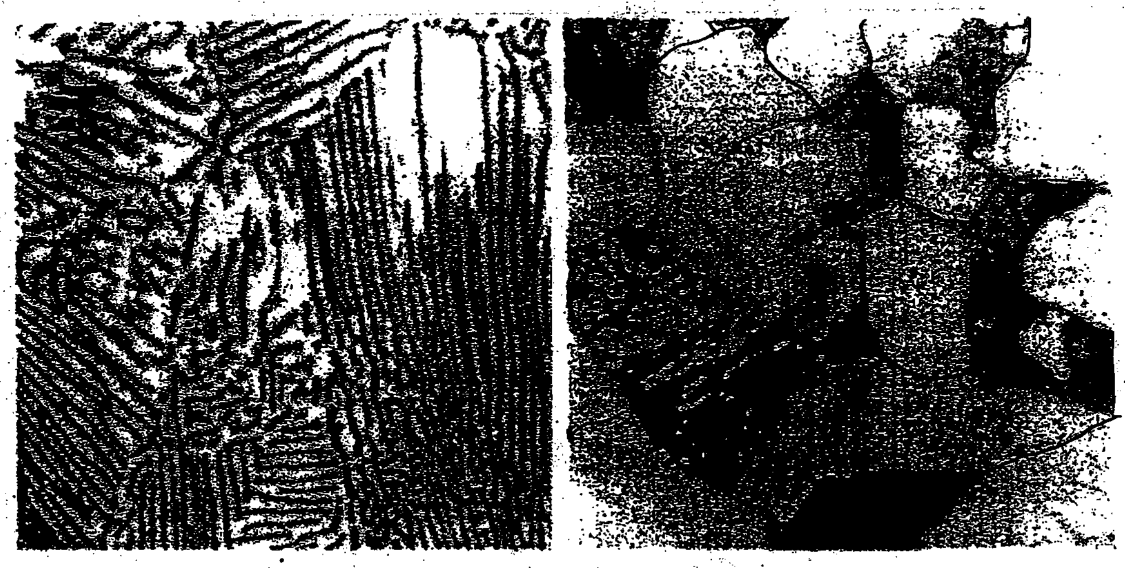
If you cool the alloy to a temperature below 900°C, the steel wants to change its structure to BCC ferrite. But the solubility limit for carbon in ferrite is only 0.02%, i.e. almost zero.

What's going to happen to the carbon?

The carbon cannot remain dissolved in the steel, so it comes out of solution. In fact, it chemically combines with some of the iron to form an iron carbide, usually Fe_3C. This is called "**cementite**".

The austenite (FCC) changes into two different structures, ferrite (BCC) and cementite (Fe_3C). These form as alternate layers in the steel.

The layers are often very thin, and the combination of these layers often appears as a dark mass under the optical microscope. At high magnification it may be possible to distinguish, or resolve, the individual layers. The combined structure is called "pearlite", because it is said to resemble mother of pearl. It may also appear to resemble a finger print pattern.

(a)  (b)

a) 0.8% Carbon steel b) 0.4% Carbon steel

The amount of pearlite in the steel at room temperature depends on the carbon content. As a rough approximation, for steels, the fraction pearlite (X) will be given by the following equation:

$$X = \frac{C}{0.8}$$

where C is the carbon content (%).

So, in our example we had a steel with 0.4% carbon. We would expect the structure seen under the microscope to be about 50% pearlite.

Further reading

Materials Science and Engineering, W.D. Callister, Chapter 9
Metallurgy for Engineers, E.C. Rollason, Chapter 9
Steels, R.W.K. Honeycombe, Chapter 3

A.J. McLaren

Glossary

The information given below is intended to aid your understanding of the subject and this practical in particular. You may find it useful to cross reference information here with information you are given in lectures, read in text books or find on the web.

Alloy

A metal-like substance produced by mixing two or more metals or non-metals. Ceramics can also be mixed to form alloys.

A binary alloy contains two components.

A ternary alloy contains three.

Metallography
The study of the structure of metals and alloys by various methods, especially by optical and electron microscopy.

Solid solution

An arrangement of different atom or molecule types within the same crystal lattice. Solid solutions tend to form when the interaction between the component atoms is small, i.e. they neither attract nor repel each other.

junk
How strong is this material ?
How much load will this component take ?
How far can this material deform without breaking ?
What laboratory tests can we do to measure strength ?
How are these tests interpreted ?