EDEXCEL NATIONAL CERTIFICATE
UNIT 12 – ENGINEERING MATERIALS
OUTCOME 2

TUTORIAL 3 – NON MECHANICAL PROPERTIES

2. PROPERTIES AND EFFECTS OF PROCESSING

***Mechanical properties*:** density, tensile strength, shear and compressive strength, hardness, toughness, ductility, malleability, elasticity, brittleness: effects of forming processes and heat treatment

Thermal properties: expansivity, thermal conductivity

***Electrical and magnetic properties*:** resistivity, permeability, permittivity

***Durability*:** corrosion resistance, solvent resistance, protection processes

***Tests*:** destructive testing e.g. tensile, hardness, impact, ductility; non-destructive testing e.g. dye penetrant, ultrasonic, magnetic powder, visual and tactile inspection

This is a continuation of tutorial 2

Calculations involving material properties may not be part of the required outcome but examples are included in this tutorial for those that want them.

The main self assessment for this tutorial are contained in separate assignments

CONTENTS

1. INTRODUCTION

In order to determine the properties of materials many standard tests have been devised. This tutorial covers the main tests for determining mechanical properties.

Testing can be divided up into Destructive and Non Destructive and as the names imply, one destroys the sample and the other does not. Non destructive tests may be carried out on the actual component or structure to see if it has any defects (e.g. checking aircraft skins for cracks). Destructive tests may use a specimen from a batch of new bulk material to check the batch or the specimen may be made from a structure that has been in use (e.g. checking material that failed unexpectedly).

2. DESTRUCTIVE TESTS

2.1 TENSILE TESTING

The tensile test is conducted in order to find the following properties of a material.

- The yield stress.
- The ultimate tensile stress.
- The elastic range.
- The ductile range.
- The modulus of elasticity.

Ductility is indicated by two results from the test as follows.

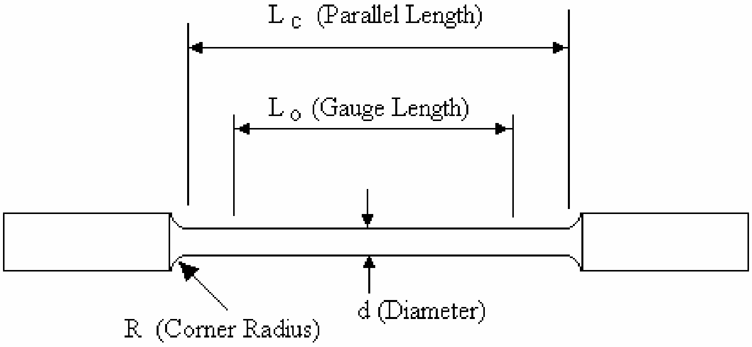
- The % elongation.
- The % area reduction.

Pictures courtesy of Lloyd Instruments
www.lloyd-**instruments**.co.uk/

There are other properties that can be discovered for materials with more complex behaviour.

TEST SPECIMENS

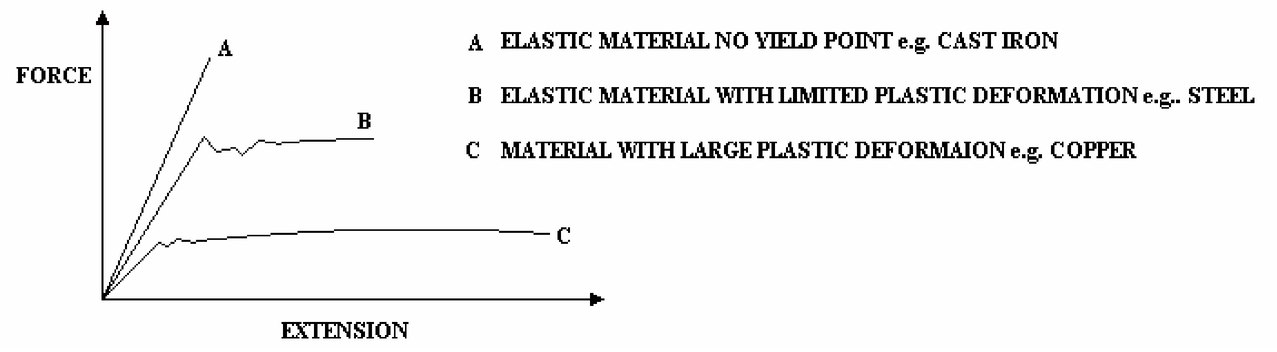
Test specimens may be made from round sections or cut from flat sheets. They should conform to BS18. The standard round section has four principle dimensions as shown.



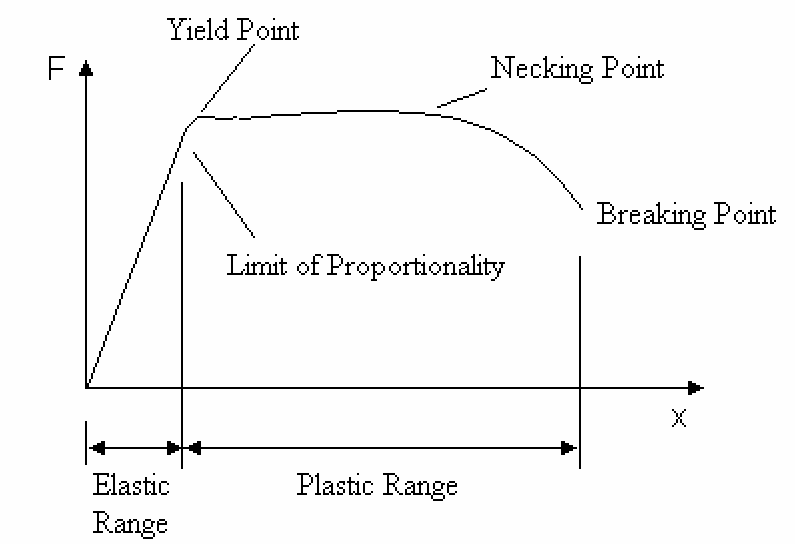
The specimens have standard cross sectional areas and so the diameters are not round numbers. The test should be conducted on approved machines. The specimen is stretched between two chucks and both the tensile force and extension are measured over a wide range until the specimen breaks.

The gauge length is the length over which the extension is measured with an EXTENSOMETER.

The tensile force is measured with a load cell. On modern machines the force and extension are plotted by the machine. The diagram shows typical Force – extension graphs for some materials.



TYPICAL FORCE – EXTENSION GRAPH FOR A DUCTILE MATERIAL



In the elastic range the material will spring back when the force is removed. In the plastic range the material is permanently damaged and remains stretched when the force is removed. The permanent damage starts at the yield point. Usually this is the same point as the limit of proportionality. At the necking point the material starts to narrow at the point where it is going to break and a pronounced neck forms. Because the cross sectional area is reduced, the force needed to stretch it further becomes smaller but the stress in the material remains the same. Eventually at some point the specimen will break and this point gives us the ultimate tensile stress.

STRESS AND STRAIN

Stress	σ = Force/Area
Strain	ε = Extension/Gauge length
Yield stress	σ_y = Yield Load/Original Area.
Ultimate Tensile Stress	σ_u = Maximum Load/Original Area

SELF ASSESSMENT EXERCISE No.1

A tensile test specimen has a cross sectional area of 100 mm^2. The force measure at the yield point was 41 kN and the maximum force was 42 kN. Calculate the following.

- The yield stress (410 MPa)
- The tensile strength. (420 MPa)

MODULUS of ELASTICITY

As long as the material is within the elastic range and the graph is a straight line as shown, the ratio of F/x and hence σ/ε is constant. The ratio σ/ε is called the modulus of Elasticity and has a symbol E. This property determines how elastic the material is.

$E = \sigma/\varepsilon$ $\sigma = F/a$ $\varepsilon = x/L_o$

Substitute **$E = \sigma / \varepsilon = FL/A\,x$**

The units of E are the same as the units of stress.

SELF ASSESSMENT EXERCISE No.2

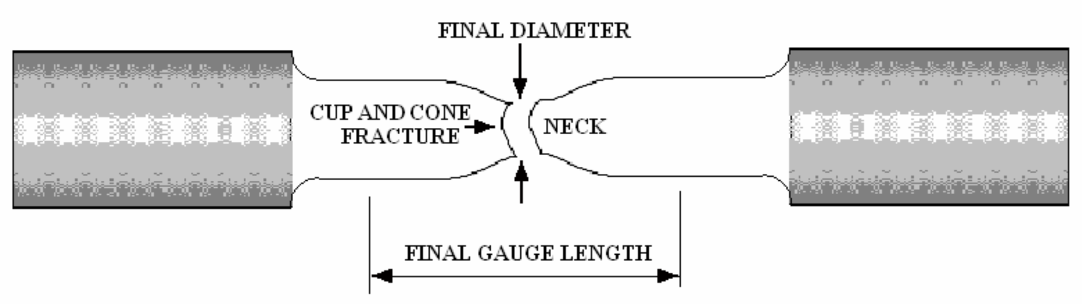
The same tensile test as described in the last problem showed that the force at the limit of proportionality was 40 KN and the extension was 0.095 mm over a gauge length of 50 mm.

Calculate the modulus of elasticity. (210 GPa)

DUCTILITY

After the specimen has fractured, the two halves are placed back together and the final gauge length and diameter are measured. These values are used to calculate the two indicators of ductility as follows.

% Elongation = Change in length/Gauge length
% Area Reduction = Reduction in Area/Original Area.
A typical ductile fracture shows a cup and cone as well as a neck.
The larger these values are, the more ductile the material is.



SELF ASSESSMENT EXERCISE No.3

A sample of material is stretched to destruction in a tensile test machine. The original area was 25 mm^2 and the original length was 50 mm. The final area and length was 16 mm^2 and 56.4 mm. The peak load reached was 32 kN. Determine

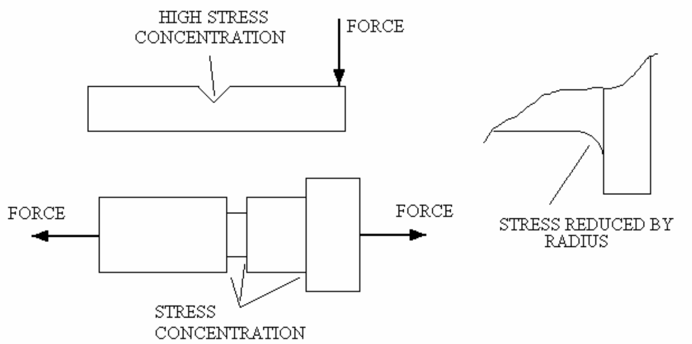
- The percentage reduction. (6.25%)
- The percentage elongation. (12.8%)
- The tensile strength. (1280 MPa)

During the tensile test described, the results of force against extension in the elastic region gave a stiffness of 100 kN per mm. Calculate the modulus of elasticity. (200 GPa)

2.2. **NOTCHED BAR IMPACT TESTS**

These tests are conducted to determine the TOUGHNESS or BRITTLENESS of the material. There are several forms of the tests. The basic principle in all cases is that the specimen is struck with a hammer and the energy absorbed is measured. The greater the energy absorbed, the tougher the material, the smaller the energy absorbed, the more brittle the material. The picture shows the universal pendulum impact tester MAT21 from TQ http://www.tq.com

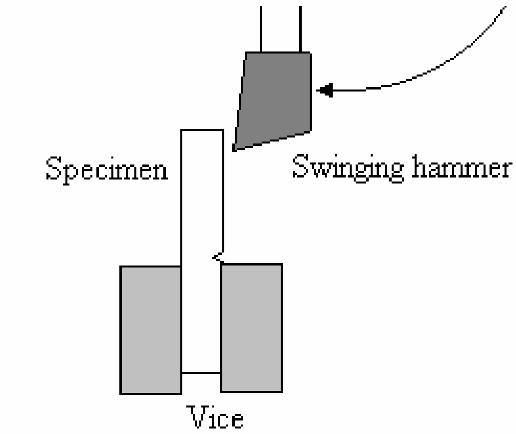
Brittleness is indicated by the easy way that a crack spreads through the material. Cracks always start at some scratch or blemish on the surface. In tension these open out. A tough material is difficult to pull apart but a brittle material spreads the crack easily. In these tests, the specimen has a notch cut in it to make the crack start at that point. The stress level in a material is greatly increased at a notch or any sharp corner and this point is important in the design of components. Where sharp corners occur a radius should be used to reduce the effect.



Some materials become brittle when cold and so notch bar tests are conducted to find the temperature at which they become brittle. Some steels of certain compositions have been known to crack at cold temperatures and cause disasters.

IZOD TEST

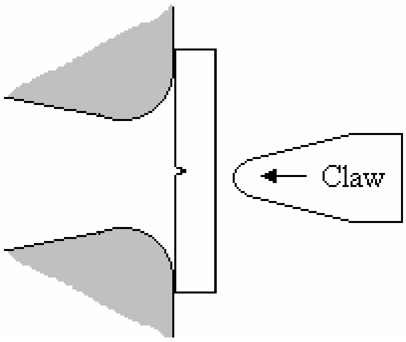
The test specimen is a 10 mm square section with a 45^o notch 2 mm deep with a radius of 0.25 mm at the bottom. The specimen is held in a vice and struck by a swinging hammer. The hammer is raised to a height such that it has 162.72 J of energy. When released it achieves a velocity of 3.8 m/s just before it strikes the specimen. If the specimen fractures, the hammer swings beyond the point and the height it reaches indicates how much energy was absorbed in the blow.



The picture shows an Izod tester for plastic specimens (The MAT20 from TQ)
http://www.tq.com

CHARPY TEST

In the Charpy test the specimen is similar but laid horizontally against stops and the swinging claw hits it in the middle with a velocity of 5 m/s and energy of 298.3 J. The height of the swing again registers the energy absorbed.



FRACTURE APPEARANCE

Much can be told by examining the fracture surface.
Brittle metals break with little sign of ductility such as tearing. The surfaces are granular.
Ductile metals may not break completely and shows a fibrous surface with evidence of tearing.
Brittle polymers produce smooth glassy surfaces.
Ductile polymers show a large reduction of area with tearing in evidence.

2.3. **HARDNESS TESTS**

Hardness is the property of a material to resist scratching and indentation. A hard material is needed to resist wear and abrasion. A hard material is needed to form a good cutting edge. Some materials become brittle when hard, e.g. high carbon steels. In tools such as saw blades, the material needs to be hard and tough and achieving this is difficult. Carbon steels can be hardened on the surface and left tough inside. A hard metal may be used with a tough metal to form a composite structure as in some hacksaw blades. Materials that are both tough and hard (such as Titanium) are expensive.

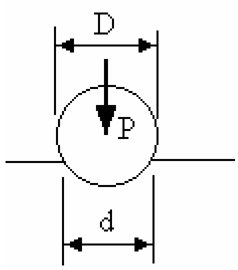
There are many forms of tests to measure hardness. Each gives rise to its own units of hardness. These can be converted from one to the other and conversion charts are probably best.

You can find useful material such as conversion charts, formulae and help to calculate hardness at
http://www.gordonengland.co.uk/hardness/vickers.htm
and at http://www.npl.co.uk/force/guidance/hardness/
Although individual machines may be used for each test, a universal test machine can do most of them. Illustrated is the MAT24 from TQ http://www.tq.com

BRINELL TEST

A hard steel ball is pressed into the surface with a known force and the diameter of the impression is measured. The hardness is defined as follows.

$$H_B = \frac{\text{Load}}{\text{Surface Area of the indentation}} = \frac{2P}{\pi D\left[D - \sqrt{\left(D^2 - d^2\right)}\right]}$$



H_B is the Brinell Hardness number, D is the diameter of the ball and d is the diameter of the indentation.
P is the applied load in kg.
To ensure the indentation is a sensible size, an appropriate combination of ball diameter and load is needed. This is calculated as follows. $P/D^2 = K$
K is a constant that is selected from the table below and D is the ball diameter in mm. P is the load in kg.

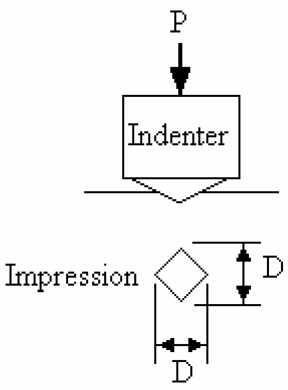
Ferrous materials	K = 30
Copper and alloys	K = 10
Aluminium and alloys	K = 5
Lead,Tin and soft materials	K = 1

SELF ASSESSMENT EXERCISE No. 4

Find the load required for ball 10 mm diameter when used on Copper Alloy.

If the resultant diameter of the impression produced by this load is 1 mm, what is the Brinell hardness? (1000 kg)

VICKERS TEST



This is similar in principle to the Brinell test and the same machine is often used to conduct it. It is most useful on hard tool steels. The indenter is a diamond in the form of a square pyramid with an angle of 136° between faces.

The mean length of the diagonal is measured (D) and the Vickers hardness number calculated as follows. $H_D = 1.844\frac{P}{D^2}$

Standard loads are used of 5, 10, 20, 30, 50 and 100 kg. It is necessary to state the test load when quoting the hardness number do for example $H_D(30) = 150$ means that the load of 30 kg produced a hardness number of 150.

SELF ASSESSMENT EXERCISE No.5

The mean length of the diagonal in a Vickers test was 1.2 mm under a load of 50 kg. Calculate the hardness number. (64)

ROCKWELL TEST

The Rockwell test is based on measuring the depth of penetration of the indenter and so direct indication is possible on the machine by use of a sensitive dial gauge. A range of indenters and standard loads are used. A preload is applied to the indenter in order to account for any springiness in the system. When the dial has settled it is zeroed and then the full load is applied. The hardness is read directly. There are several scales depending on the load used.

The main indenters are a 1.6 mm hard steel ball and a 120° diamond cone for harder materials. The initial load is 10 kg. The table shows the scales used.

Scale	Indenter	Full Load
A	Diamond	60 kg
B	Ball	100 kg
C	Diamond	150 kg
D	Diamond	100 kg

For soft materials a range of scales up to V using a ball of 12.7 mm diameter is also available.
Other forms of hardness tests that do not damage the surface are available such as the Shore Scleroscope that drops a plunger onto the surface and records the height of the bounce.

3. NON DESTRUCTIVE TESTING

You will find a lot of pictures and video clips on the following at
http://www.ndt-ed.org/index_flash.htm

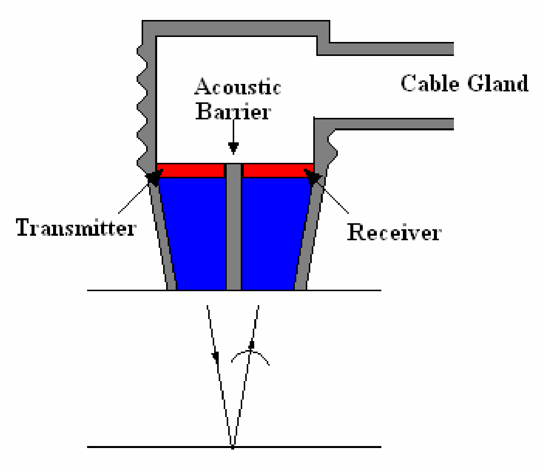
3.1 DYE PENETRANT

This is a test to find cracks in the surface of component for example checking for fatigue cracks in aircraft parts before they spread and cause failure. The component is sprayed with a solvent cleaner to remove grease. Next it is sprayed with a coloured dye (normally red) that penetrates into the cracks. It is then dried and sprayed with a developer, usually a white talc powder. The dye in the cracks is drawn into the developer and shows up brightly. The dye may be fluorescent and an ultra violet lamp is needed to see them.
The diagram shows a gear with cracks revealed at the root of the teeth.
Visit http://www.twi.co.uk/j32k/protected/band_3/ksijm001.html to see more details

3.2 MAGNETIC POWDER

This is used for parts made from ferrous material. A strong magnetic field is passed through the component. Around any crack, the magnetic field will be concentrated and magnetic iron dust is attracted to it. Magnetic powder may be dusted on in dry form or the test may be carried out in a tank full of liquid with dust suspended in it.
For some good pictures, and fuller details visit
http://www.ndt-ed.org/EducationResources/CommunityCollege/MagParticle/Indications/DryExamples.htm

3.3 ULTRASONIC SOUND



Ultrasonic sound was used to locate cracks and defects in materials long before it was used in hospitals for producing images of unborn babies.

In ultrasonic testing, high-frequency sound waves are transmitted into a material to detect imperfections or to locate changes in material properties. The most commonly used ultrasonic testing technique is pulse echo, whereby sound is introduced into a test object and reflections (echoes) from internal imperfections or the part's geometrical surfaces are returned to a receiver.
A dual element transducer consists of two crystal elements housed in the same case, separated by an acoustic barrier. One element transmits, and the other element receives.

3.4 RADIOGRAPHY

This involves the use of penetrating gamma- or X-radiation to examine materials and product's defects and internal features. An X-ray machine or radioactive isotope is used as a source of radiation. Radiation is directed through a part and onto film or other media. The resulting shadowgraph shows the internal features and soundness of the part. Material thickness and density changes are indicated as lighter or darker areas on the film. The darker areas in the radiograph represent internal voids in the component. This method is widely used for checking welds in pipes.