EDEXCEL NATIONAL CERTIFICATE

UNIT 10: PROPERTIES AND APPLICATIONS OF ENGINEERING MATERIALS

NQF LEVEL 3

OUTCOME 4 - TUTORIAL 1
MATERIAL FAILURE

4 Know about the modes of failure of engineering materials

Principles of ductile and brittle fracture: effects of gradual and impact loading e.g. tensile, compressive, shear; effects of grain size; transition temperature; appearance of fracture surfaces.

Principles of fatigue: cyclic loading; effects of stress concentrations e.g. internal, external; effects of surface finish; appearance of fracture surfaces.

Principles of creep: primary; secondary; tertiary; effects of temperature; strain versus time curve; creep limit; effect of grain size; effect of variations in the applied stress.

Tests: destructive e.g. tensile, hardness, impact, ductility, fatigue, creep; non-destructive e.g. dye penetrant, ultrasonic, radiographic (x-ray, gamma ray), magnetic powder, visual.

Degradation processes: on metals e.g. oxidation, erosion, stress corrosion; on polymers e.g. solvent attack, radiation and ageing; on ceramics e.g. thermal shock, sustained high temperature

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 material to check it meets the specification. Specimens 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 or lack of ductility is indicated by two results from the test as follows.

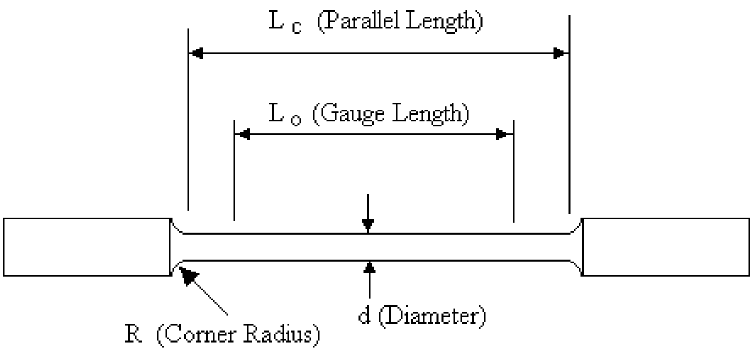
- The % elongation.
- The % area reduction.

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

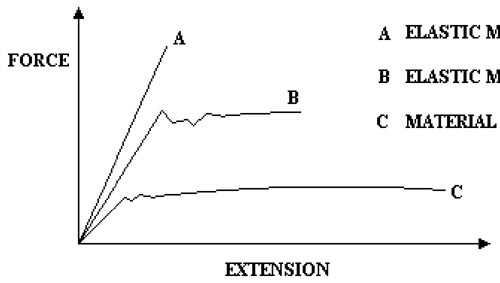
Test specimens may be made from round sections or cut from flat sheets. They should conform to BS18. The standard round section has four principle dimensions as shown.



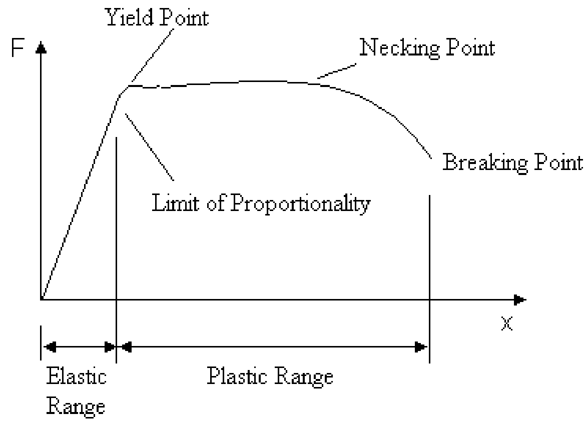
The specimens have standard cross sectional areas and so the diameters are not round numbers. The test should be conducted on approved machines. The specimen is stretched between two chucks and both the tensile force and extension are measured over a wide range until the specimen breaks.

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

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.

$E = \frac{\sigma}{\varepsilon}$ $\qquad \varepsilon = \frac{F}{A}$ $\qquad \varepsilon = \frac{x}{L_o}$

Substitute $\qquad E = \frac{\sigma}{\varepsilon} = \frac{FL_o}{Ax}$

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

WORKED EXAMPLE No. 1

An aluminium tensile test specimen is 5 mm diameter with a gauge length of 50 mm. The force measure at the yield point was 982 N and the maximum force was 1.6 kN. Calculate the yield stress and the ultimate tensile stress.

Cross sectional area $A = \pi d^2/4 = \pi \times 5^2/4 = 19.63\ mm^2$

Yield Stress = 982/19.63 = 50 N/mm^2 or 50 MPa (Note 1 MPa = 1 N/mm^2)

Ultimate Tensile Stress = 1600/19.63 = 81.5 N/mm^2 or 81.5 MPa

At a point on the proportional section the extension was 0.03 mm and the force 800 N. Calculate the modulus of Elasticity (Young's Modulus)

$$E = \frac{FL_o}{Ax} = \frac{800 \times 50}{19.63 \times 0.03} = 67906\ N/mm^2 \text{ or } 67.9\ GPa$$

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)

The same tensile test 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)

2.2 DUCTILE FAILURE

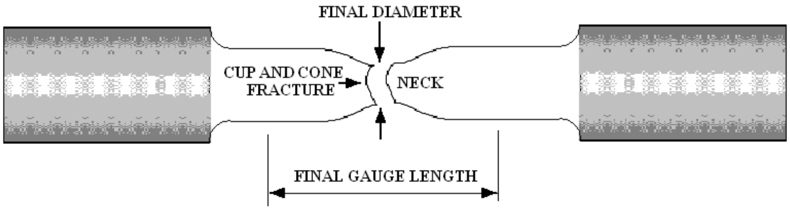
After the specimen has fractured, the two halves are placed back together and the final gauge length and diameter are measured. These values are used to calculate the two indicators of ductility as follows.

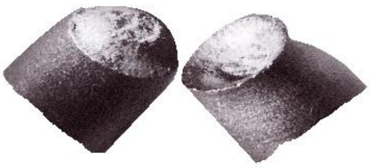
% Elongation = Change in length/Gauge length

% Area Reduction = Reduction in Area/Original Area.

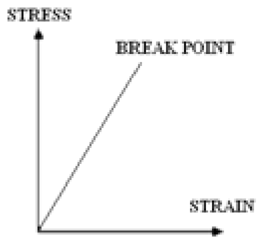
A typical ductile fracture shows a cup and cone as well as a neck.

The larger these values are, the more ductile the material is.



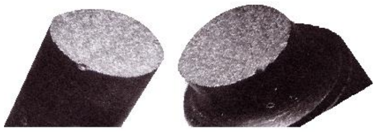


2.3 BRITTLE FAILURE

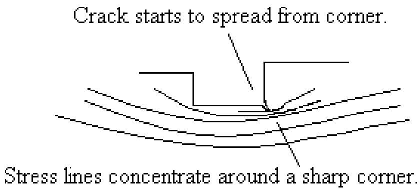


A material such as cast iron can be strong and brittle. The breaking stress may be high but once it starts to fail it does so suddenly with no further resistance. On the other hand some polymers are weak but tough. They will easily yield when stretched but require a lot of energy and stretching to make it break.

Brittle materials exhibit no yield point and a typical stress – strain graph is shown. Failure is quite sudden and no neck appears to warn of impending failure.



A crack must start at some imperfection in the material such as a machining groove on the surface. These raise the local stress level. Sharp corners and undercuts in a machined component will do the same. In a tough ductile material, there will be yielding and resistance to the crack spreading. In a brittle material, the crack, once started, continues to spread very rapidly.



Grinding and polishing a brittle material makes it less prone to cracking. Glass, when polished, exhibits a very high strength but the slightest surface blemish makes it crack easily. This is why glass fibres are so strong but sheet glass so brittle.

Brittle materials are very prone to cracking through sudden impacts that create a crack at a sharp corner. This is why notched specimens are used in impact testing. The Izod and Charpy notched bar test determine how sensitive a material is to crack propagation from a sharp corner.

Most materials become brittle when they are extremely cold but some materials, especially certain types of carbon steels and polymers, may well change from ductile to brittle at temperatures found in nature. There have been some spectacular structural failures in bridges, oil rigs and ships due to the steel becoming brittle at near zero temperatures. This is made worse by the presence of sharp corners (e.g. hatch in ships deck) and by the changes in the steel composition brought about during welding.

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.

WORKED EXAMPLE No.2

A tensile test on a cold worked brass gave the following results.
The diameter of the test piece d =16mm and the gauge length was 80 mm.
After fracture the gauge length was 86.4 mm and the fracture point was 15.2 mm diameter.
The maximum load was 139 kN.
The load and extension at the elastic limit were 69 kN and 0.3 mm respectively.
Calculate the % elongation and % reduction.

SOLUTION

Area = $\pi d^2/4 = \pi \times 16^2/4 = 201 \text{ mm}^2$
Maximum load = 139 000 N
UTS = 139000/201 = 691.2 N/mm^2 or MPa

At the elastic limit F = 69 0000 N and x = 0.3 mm

$$E = \frac{FL}{Ax} = \frac{69000 \times 80}{201 \times 0.3} = 91514 \text{ N/mm}^2 \text{ or } 91.5 \text{ GPa}$$

$$\%\text{Elongation} = \frac{86.4 - 80}{800} \text{x}100 = 8\% \qquad \%\text{ Reduction} = \frac{\left(16^2 - 15.2^2\right)}{16^2} \text{x}100 = 9.75\%$$

SELF ASSESSMENT EXERCISE No. 2

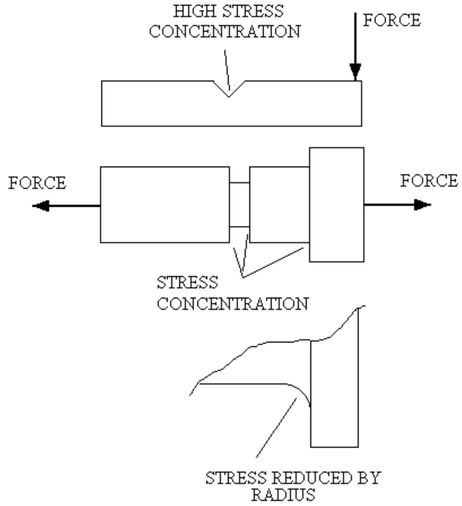
A sample of material is stretched to destruction in a tensile test machine. The original area was 25 mm^2 and the original length was 50 mm. The final area and length was 16 mm^2 and 56.4 mm. The peak load reached was 32 kN. Determine

- 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 F/x =100 kN per mm. Calculate the modulus of elasticity. (200 GPa)

3. NOTCHED BAR IMPACT TESTS

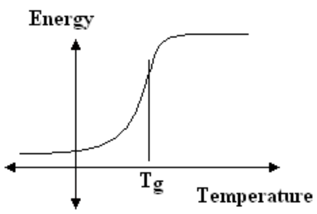
These tests are conducted to determine the ***TOUGHNESS*** or ***BRITTLENESS*** of the material. There are several forms of the tests. The basic principle in all cases is that the specimen is struck with a hammer and the energy absorbed is measured. The greater the energy absorbed, the tougher the material, 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.

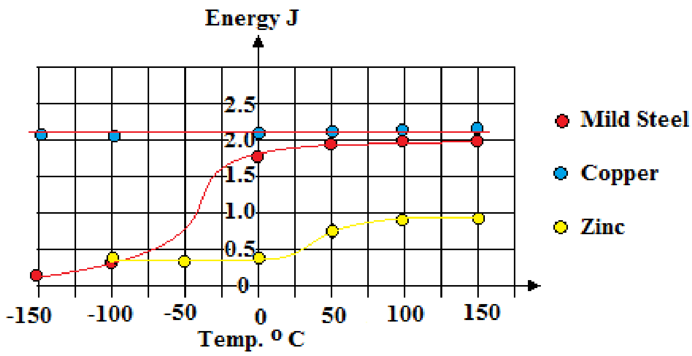
Some materials become brittle when cold and so notch bar tests are conducted to find the temperature at which they become brittle. Some steels of certain compositions have been known to crack at cold temperatures and cause disasters.

TRANSITION TEMPERATURE



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. Notched bar tests are conducted over a range of temperatures to determine where a material becomes brittle and this is one of the properties that should be seriously considered in material selection. A typical graph of absorbed energy against temperature from a notched bar test is shown. The transition temperature is denoted T_g. It is usually taken as the point at which 50% of the fracture is brittle.

The ductile-brittle transition is exhibited in BCC metals, such as low carbon steel, which become brittle at low temperature or at very high strain rates. FCC metals, however, generally remain ductile at low temperatures. (see outcome 1 tutorials for crystal type explanation)

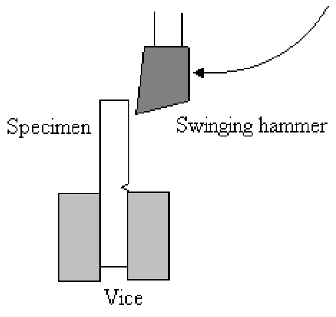


The graph shows typical data for a mild steel, copper and zinc. You can see that copper has no transition temperature. Zinc is more slightly ductile above 20°C. The steel sample has a transition temperature around -50°C.

Non metals also exhibit a brittle transition. Nylon for example undergoes the transition above 50°C so this might be seen as a softening of the material.

IZOD TEST

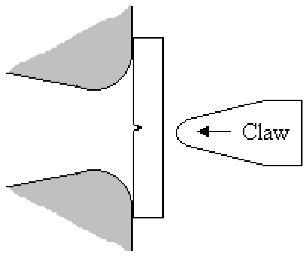
The test specimen is a 10 mm square section with a 45° notch 2 mm deep with a radius of 0.25 mm at the bottom. The specimen is held in a vice and struck by a swinging hammer. The hammer is raised to a height such that it has 162.72 J of energy. When released it achieves a velocity of 3.8 m/s just before 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

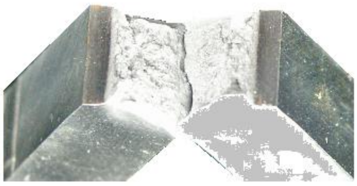
CHARPY TEST

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 from the fracture appearance of the sample. The picture shows a rough surface indicating some ductility.



You can pictures and information on the fracture of samples at this link.

http://pwatlas.mt.umist.ac.uk/internetmicroscope/micrographs/failure/brittle-steel.html

4. **HARDNESS TESTS**

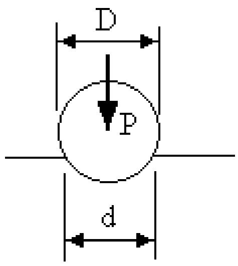
Hardness is the property of a material to resist scratching and indentation. A hard material is needed to resist wear and abrasion and form a good cutting edge. Some materials become brittle when hard, e.g. high carbon steels. In tools such as saw blades, the material needs to be hard and tough and achieving 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.

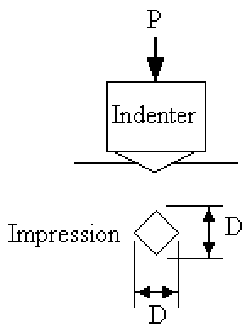
Ferrous materials	K = 30	Copper and alloys	K = 10
Aluminium and alloys	K = 5	Lead, Tin and soft materials	K = 1

SELF ASSESSMENT EXERCISE No. 3

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^o 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. 4

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^o 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.

5. **FATIGUE FAILURE**

Fatigue is a phenomenon that occurs in a material that is subject to a cyclic stress. Although the peak stress in each cycle is less than that needed to make the material fail in a tensile test, the material fails suddenly and catastrophically after a certain number of cycles.

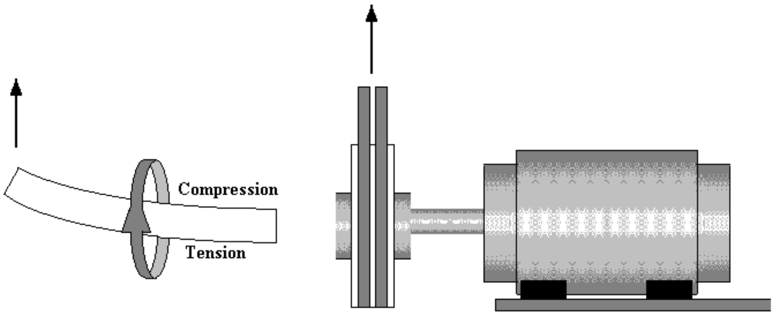
Here are some examples of things that are subject to cyclic stress.

- ***Railway lines that bend every time a wheel passes over it.***
- ***Gear Teeth.***
- ***Springs.***
- ***The suspension cable on a suspension bridge every time a vehicle passes over it.***
- ***The skin and structural members of an aeroplane every time it flies.***
- ***A shaft with a pulley belt drive.***
- ***The connecting rod in a reciprocating engine.***
- ***The stub axle on a vehicle wheel.***

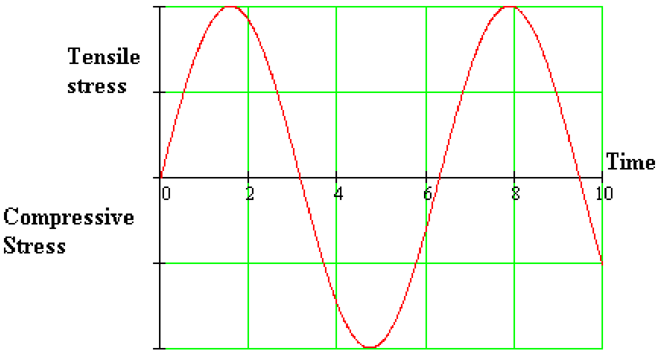
The properties to look for in material selection are ***fatigue strength*** and ***endurance limit*** which are explained in the following.

STRESS FLUCTUATION

Consider the case of an electric motor with a pulley drive on its shaft.

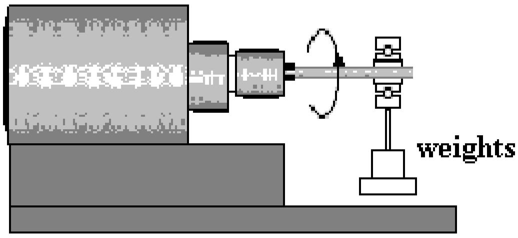


The shaft bends as shown producing tension on one side and compression on the other. As the shaft rotates, any given point on the surface experiences a direct stress that changes from tension to compression once every revolution. The alternating or fluctuating stress causes the failure. A stress - time graph is likely to be sinusoidal in a case like this.



The fatigue life of a component depends on the values of the fluctuation, the mean stress level and the way the stress varies with time. This is not covered here.

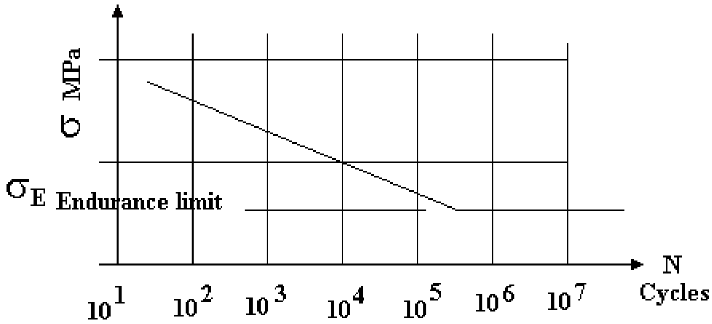
FATIGUE TESTING



A fatigue test should ideally reproduce the same stress levels and fluctuations as in service. The most common form of test is the Wohler Test. In this test, the specimen is held in a chuck with a weight pan suspended from the end as shown. Each revolution bends the specimen so that the surface stress fluctuates between equal tensile and compressive values with a mean level of zero. The maximum stress is easily calculated. The test is repeated with different weights and hence different stress levels. It is rotated until it fails and the number of revolutions is counted. This is the number of stress cycles to failure.

S – N GRAPHS

Test data is presented on a S - N graph. S stands for stress and N for the number of cycles. The symbol used for stress is σ (sigma). The graph is normally plotted with logarithmic scales as shown. This tends to straighten out the graphs. The diagram shows a typical result for steel.



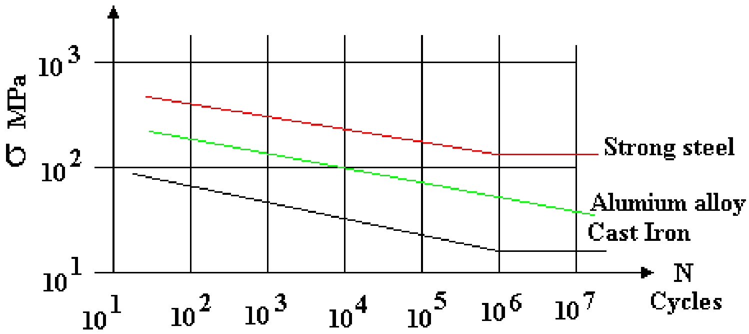
FATIGUE STRENGTH

The fatigue strength is the stress level that produces failure after a specified number of cycles.

ENDURANCE LIMIT

The lower limit σ_E is called the endurance limit. If the stress level is below this limit, it will never fail. Non-ferrous materials have no endurance limit. The diagram shows approximate fatigue characteristics of three materials. Research shows that for ferrous materials the endurance limit is approximately proportional to the tensile strength σ_u.

A conservative relationship is $\sigma_E = 0.3\sigma_u$



For materials with no clear endurance limit, σ_N values are stated instead. This is the number of cycles required to produce failure at the specified stress amplitude.

WORKED EXAMPLE No. 3

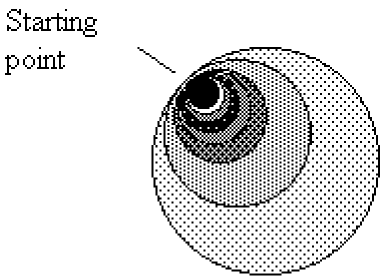
Determine the fatigue strength of a strong steel that gives a life of 10 000 cycles. Use the graph above. What is the endurance limit?

SOLUTION

From the graph, the stress corresponding to 10 000 (10^4) on the red graph is approximately 300MPa. The endurance limit is approximately 200 MPa.

CRACK FORMATION

The crack usually starts at some surface defect or feature that produces a stress concentration. For example, an undercut in a shaft for a circlip or a hole for a pin would cause stress concentration. Any fault in the material such as a slag inclusion will also initiate a crack. Undercuts should have rounded corners to reduce this to a minimum. If the material is ductile, the initial crack will not spread easily and the crack opens up and closes as the stress fluctuates. This wears the surface of the crack smooth. As the crack progresses, new material is exposed which starts to wear smooth.

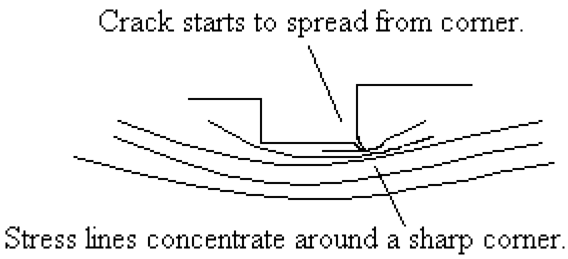


When the crack has spread enough to reduce the cross sectional area of the material to a point where it can no longer carry the load, sudden failure occurs. Often the fracture has an OYSTER SHELL appearance due to the early stages being worn smoother than the later stages.

Cracks spread more easily in brittle material, especially at cold temperatures and failure is sudden.

FATIGUE NOTCH SENSITIVITY

In ductile materials, the crack will start at some point that causes a stress concentration. The diagram shows the stress concentration at the corner of a groove.



The ratio of the raised stress level to the normal stress level is called the stress concentration factor.

$$k_f = \frac{\sigma}{\sigma_o}$$

There are ways of determining values of k_f for specified cases but this is not covered here.

WORKED EXAMPLE No. 4

The fatigue strength of a material in a standard test for a specified number of cycles is 250MPa. The material has a surface notch with a sensitivity factor of 1.4. Calculate the fatigue strength in this case.

SOLUTION

$\sigma = \sigma_o / k_f = 250 / 1.4 = 178.6$ MPa

WORKED EXAMPLE No. 5

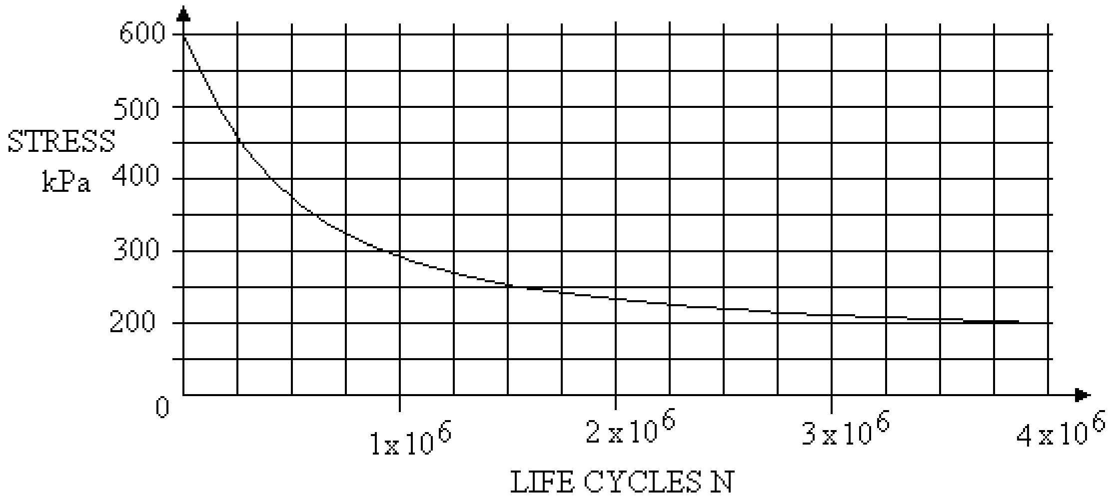
A shaft 50 mm diameter is subject to a bending moment of 3000 Nm. On the surface, there is a notch with a stress concentration factor of 1.6. Calculate the stress produced at this notch.

SOLUTION

$I = \pi D^4/64 = \pi(0.05)^4/64 = 306.8 \times 10^{-9}\ m^4$
$\sigma_o = My/I = 3000 \times 0.025/ 30.68 \times 10^{-6} = 244.5$ MPa
$\sigma = \sigma_o \times k = 244.5 \times 1.6 = 391.1$ MPa

WORKED EXAMPLE No. 6

The S – N graph shown is for a certain material. Determine the stress level that will produce a life cycle of 750 000. State the endurance limit of this material.



SOLUTION

From the graph the stress level corresponding to 750 000 cycles is 325 kPa. The endurance limit is 200 kPa.

OTHER FACTORS AFFECTING THE FATIGUE LIFE

Fatigue failure may be accelerated by any of the following:

- Stress concentrations factor
- The way the stress fluctuates
- Corrosion
- Residual surface stress
- Surface finish
- Temperature
- Bulk mass (size) of the component

Stress concentrations were mentioned earlier and are caused by keyways, holes, grooves, undercuts, corners or any surface mark.

Corrosion takes many forms and weakens the metal. Surface deterioration may set up stress raising factors. Corrosion of some metals spreads along the grain boundary and so weakens the material. It has been known for a component to fail in fatigue because a chemical marker had been used to write part numbers on the surface and the chemicals etched into the surface and weakened the grain boundaries in that region.

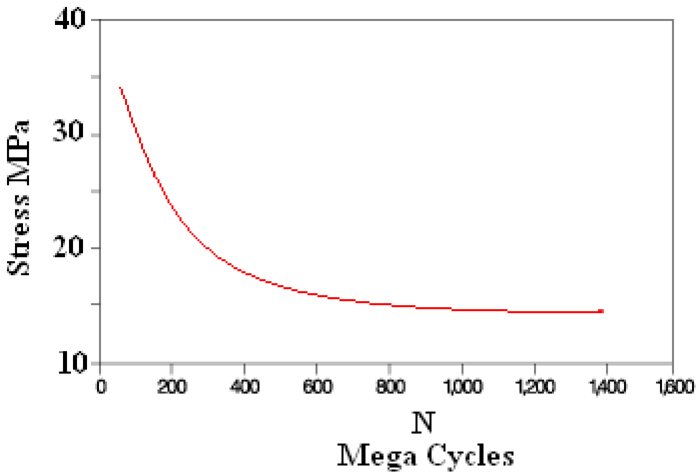
Residual surface stresses can be set up by bending the material thus leaving a permanent stress in it. If the surface has a residual compressive stress, this is beneficial and may be produced by shot blasting or peening.

If a surface is very smooth, there are no points for a crack to start and no stress raisers. Polishing a component improves its fatigue life. For example, the connecting rods on racing car engines are designed to have the minimum mass possible and so are designed with a very small stress safety margin. This would leave them prone to fatigue failure and polishing them makes fatigue failure less likely. On the other hand, rough surface finishes say from turning on a lathe, reduce the fatigue life. Components have been known to fail in fatigue simply because a part number was engraved on the polished surface.

Hot temperatures cause surface oxidation and degradation and so reduce the fatigue life. Thermal expansion and contraction is itself a cause of fatigue stress For example, the leading edges of aeroplanes get hot in flight and cool at other time causing expansion and contraction. Aeroplane body panels are often shaped by shot blasting so inducing a compressive stress on the surface to counteract fatigue.

SELF ASSESSMENT EXERCISE No. 5

1. A shaft 80 mm diameter is subject to a cyclic bending moment of ±800 Nm. On the surface, there is a notch with a stress concentration factor of 1.3. Calculate the stress fluctuation produced at this notch. S – N graph for the material is shown. What is the expected life of the shaft. (±20.7 MPa and about 300 Mega Cycles)



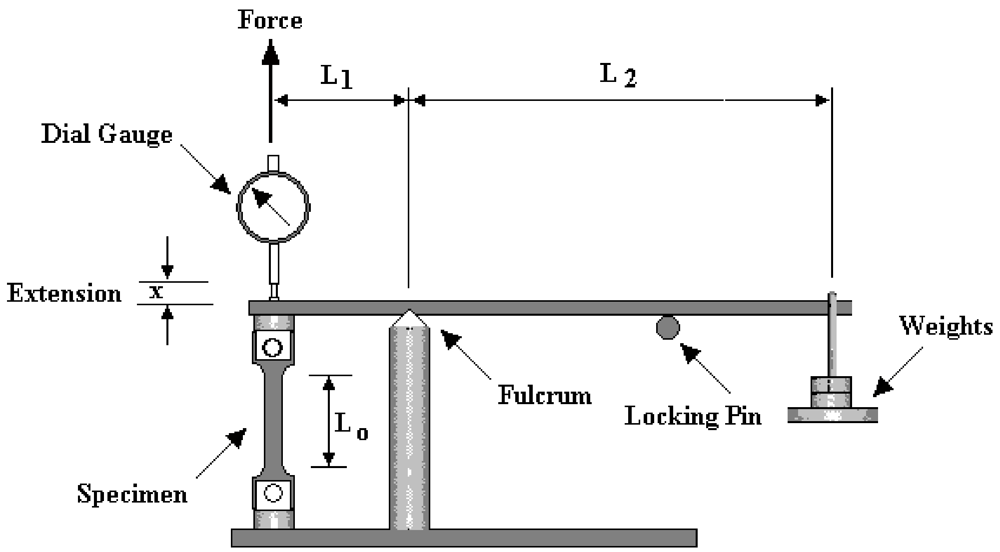
6. **CREEP**

Creep is a phenomenon where some materials grow longer over a period of time, when a constant tensile stress is applied to it. The material may well fail although the tensile stress is well below the ultimate value.

TEST MACHINE

A simple laboratory test machine is illustrated below. The specimen (usually lead or polymer) is fitted into the clamps with a pin at each end. The weights (W) create the tensile force (F) through a simple lever such that $F = W\,L_2/L_1$. A dial gauge may be used to measure the extension of the specimen although an electronic instrument may also be used for recording directly into a computer.

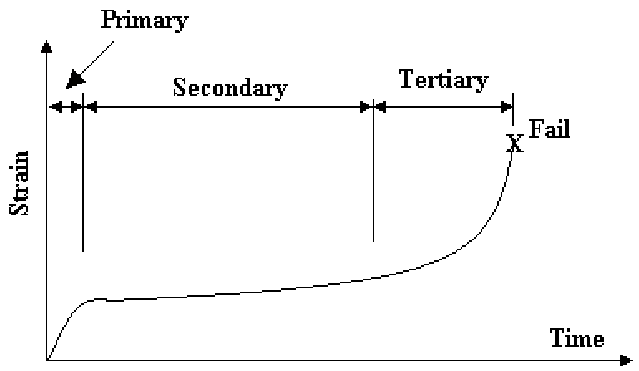
The specimens are normally rectangular in section as they are cut from thin plate.
The tensile stress is $\sigma = F/A$. A is the cross sectional area.
The strain is $\varepsilon = x/L_o$ where x is the extension and Lo the gauge length of the specimen.



The lever is locked in place by a locking pin. A weight is added and the dial gauge is adjusted to zero. The locking pin is removed and a stop watch started at the same moment. Recordings are taken of extension and time. These are plotted to produce an extension time graph. A better machine would use electronic instruments and plot the graph automatically.

TYPICAL RESULTS

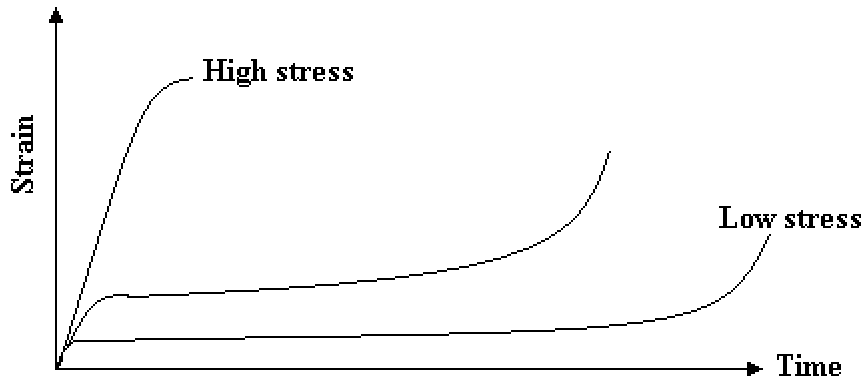
A typical result for a lead specimen is shown below.



CREEP CHARACTERISTICS

Creep usually occurs in three stages called ***primary***, ***secondary*** and ***tertiary***. In the primary stage extension is fast but this stage is not always present. In the second stage the extension is at a constant rate and relatively slows. In the tertiary stage the extension quickens again and leads to failure.

The creep rate is affected by the stress level. Higher stress levels increase the creep rate.



FACTORS AFFECTING CREEP

Most materials will not creep at all until a certain stress level is applied. This level is called the ***LIMITING CREEP STRESS***.

Metals like lead creep very easily at room temperatures and so do polymers. This is made much worse when the polymer is warmed.

PROLONGED HIGH TEMPERATURE

The limiting creep stress of metals is reduced at high temperatures. This is a very important factor in the design of turbine blades. In gas turbines, the blades are subject to high temperatures and prolonged periods of centrifugal force that causes them to creep. If the tip of the blades touches the casing, a catastrophic failure will occur. Much research has been conducted into finding creep free materials for turbines.

Test machines for high temperature creep use a heated oven to surround the specimen.

Ceramic materials are much less likely to exhibit creep tendencies and there is research into composite ceramics for high temperature components. Even so, a sheet of glass in a window for a very long time will measurably thicken at the bottom due to its own weight.

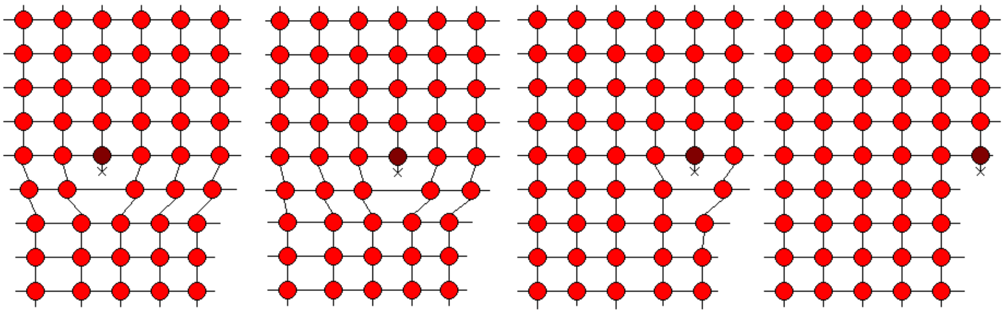
Another way of indicating creep properties are to state the stress values that produces a certain % extension within a stated time. For example: not more than 0.5 % within the first 24 hours.

CREEP MECHANISM

To understand the mechanism of creep you need to have a good knowledge of metallurgy. Here is a very basic description. There are three basic mechanisms.

DISLOCATION, SLIP AND CLIMB.

In crystalline materials, dislocations slip through the stressed crystal lattice. A molecule with a free bond forms the dislocation as shown. When the material is stressed the bonds can jump as shown until the molecule with the free bond is at the edge. Dislocations can move in either direction or climb when they meet obstacles such as impurities. Generally, they accumulate at the crystal boundary.



GRAIN BOUNDARY SLIDING.

As dislocations gather at the grain boundary, voids are created and these change into ruptures as the material starts to fail. In the tertiary stage of creep the grain slip at their boundaries.

DIFFUSION FLOW.

At low stress and high temperatures, atoms diffuse from the sides of the grains to the top and bottom thus making them longer

7. 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

7.1 DYE PENETRANT

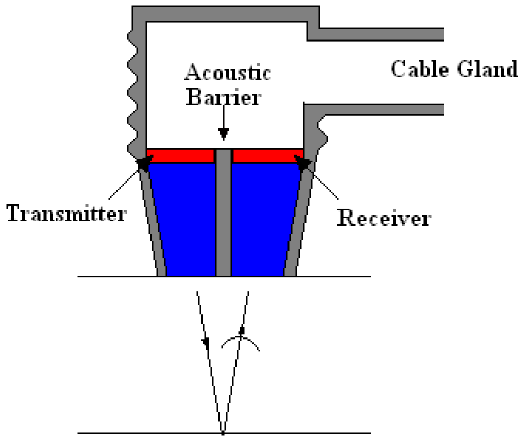
This is a test to find cracks in the surface of component for example checking for fatigue cracks in aircraft parts before they spread and cause failure. The component is sprayed with a solvent cleaner to remove grease. Next it is sprayed with a coloured dye (normally red) that penetrates into the cracks. 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

7.2 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

7.3 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.

7.4 RADIOGRAPHY

This involves the use of penetrating gamma or X RAY 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.

8. DEGRADATION

Many aspects of material failure through degradation have been covered in the preceding work. Here is a summary of the main points.

CORROSION

Corrosion through oxidation and electrolytic attack only applies to metals and failure can result when the corrosion makes the component/structure/product no longer fit for purpose or because it has so weakened the structure that the material breaks. Corrosion is generally accelerated by prolonged high temperature.

STRESS CORROSION

This is a form of failure due to the presence of corrosion and tensile stress in the material. The tensile stress opens up the crack and allows the corrosion to penetrate deeper. The cracks are usually on the microscopic level and follow the grain boundaries in the material. Failure occurs at stress levels between normal tensile failure and the fatigue threshold. The tensile stress may be the result of residual stresses produced by welding or some other reason.
You can read much more about this and see some good pictures and case examples at
http://corrosion-doctors.org/Forms-SCC/scc.htm

SOLVENT

A solvent is a liquid that dissolves another substance. Solvents as a material are useful for cleaning, forming a base for paint, varnishes, lacquers, industrial cleaners, printing inks and so on. Organic solvents are often toxic, contribute to air pollution and are inflammable. Their use has declined.

Polymers are prone to solvents attack that weaken it and destroys it so great care must be exercised in material selection concerning the substances the polymer will come into contact with. For example, the rubber or plastic seals used on engineering pipe systems must not fail because of attack from the liquid in the pipes. The compatibility of a range of materials with chemicals is easily found on web sites such as http://www.upchurch.com/TechInfo/polymerInfo.asp

A search engine for compatible materials is http://www.upchurch.com/TechInfo/chemComp.asp

Clearly ceramics do not dissolve and are often used to contain solvents.

RADIATION

Many materials change over time on exposure to light. Polymers like PVC in particular will yellow with age due to exposure to the radiation present in daylight. To prevent this chemicals are added to the mix to stabilize it so that UVPC used in construction stay white for many years.

Polymers used for medical equipment and elsewhere, will degrade as a result of exposure to radiation such as Gamma and X rays and electron-beam.

It has long been known that radiation exposure can lead to significant alterations in the materials. Radiation affects the polymer molecules causing dissociation and other things that lead to failure. This may take days, weeks, or months after irradiation to have an affect. Resulting changes can be embrittlement, discoloration, odour generation, stiffening, softening, enhancement or reduction of chemical resistance, and an increase or decrease in melt temperature.

Because the effects of ionizing radiation depend greatly on polymer chemical structure, the dose necessary to produce similar significant effects in two different materials can vary.

A common undesirable effect resulting from the irradiation of some polymers is discoloration (usually yellowing). Discolouration also occurs with prolonged exposure to ultra violet light and plastics used for outdoor applications (such as motor car parts and double glazing) will discolour or fade with time so additives are used in manufacture to prevent this. You will find further "in depth reading" at http://www.devicelink.com/mddi/archive/00/02/006.html

THERMAL SHOCK

Brittle materials, especially ceramics, are prone to fracture by sudden changes in temperature. A sudden change can cause rapid and unequal expansion or contraction that set up tensile stresses in the material causing it to break. For example, putting a drinking glass or glass bottle in boiling water will often result in it breaking.

SELF ASSESSMENT EXERCISE No. 6

1. The King Street Bridge over the Yarra River in Melbourne was completed on 12 April 1961. Soon after completion, on 10 July 1962, one span collapsed under the weight of a 47 ton semi trailer, though the weight was within the bridge limits. The collapse occurred following an unusually cold night. What would be the chief suspect for the cause of the failure and why?

2. A jet engine failed after a period of service due to the tips of the turbine blades touching the surroundings cover. A lack of which material property do you think caused the blades to do this?

4. Railway tracks are laid down on sleepers and welded together to form long seamless length. The tracks are slightly bent every time a wheel passes over it and flexes back again after it has passed. The track must perform without failing through many summers and winters.

- What are the mechanical properties required of the steel and which form of destructive testing would you perform on samples?
- What non destructive tests would be suitable to inspect the tracks during maintenance at points where it is most stressed?

5. Precision grinding is conducted on steel pins used in the manufacture of aircraft undercarriage mounts. These pins are subjected to fatigue stress when in operation. What ND Tests would be carried out after grinding and why?

6. Why should care be taken when using a solvent to clean plastic structures?

7. In the aircraft industry the use of engraving and etching of part numbers on machined components was banned. Why do you think this was?

8. Describe the following forms of non destructive testing and give examples of their uses.

- Dye Penetrant
- Magnetic Powder
- Ultrasonic
- Radiography

9. When a power station using steam generators is brought on line for the first time or after a shut down period, the system is gradually warmed by leaking the steam through it. Why do you think this is?

10. Find a suitable plastic for making a container for petrol. What is the main concern when selecting the material?